REVIEW OF NEURAXIAL TECHNIQUES IN ANAESTHESIA: RISKS, CAUSES, AND RECOMMENDATIONS FOR SPINAL CORD INJURIES

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Neuraxial procedures, including spinal and epidural anesthesia, may carry potential complications. Although rare, spinal cord injuries resulting from anesthetic practices (referred to as Anaes-SCI remain a significant concern for surgical patients. This systematic review aims to identify high-risk patient profiles, summarize the causes and consequences of SCI associated with neuraxial techniques in anesthesia, and provide management recommendations. A comprehensive literature search was conducted in accordance with Cochrane guidelines, and specific inclusion criteria were employed to identify relevant studies. Of the initial 384 studies screened, 31 underwent critical appraisal, and their data were extracted and analyzed. The findings of this review indicate that the primary risk factors for Anaes-SCI were extreme age, obesity, and diabetes. Anaes-SCI resulted from various causes, including hematoma, trauma, abscess, ischemia, and infarction, among others. The consequences predominantly included motor deficits, sensory loss, and pain. Delayed treatment for Anaes-SCI was frequently reported. Despite the potential complications, neuraxial techniques continue to be among the preferred choices for opioid-sparing pain management, contributing to reduced patient morbidity, improved outcomes, shorter hospital stays, and prevention of pain becoming chronic, with associated economic benefits. This review underscores the importance of meticulous patient management and close monitoring during neuraxial anesthesia procedures to minimize the risk of spinal cord injury and associated complications.

Keywords: spinal cord injury, spinal anesthesia, epidural anesthesia, anesthesia, analgesia, paraplegia, hematoma, acute back pain, sensory deficit, motor deficit, neuraxial technique.

ОБЗОР НЕЙРОАКСИАЛЬНЫХ ТЕХНИК В АНЕСТЕЗИИ: РИСКИ, ПРИЧИНЫ И РЕКОМЕНДАЦИИ ПО СПИНАЛЬНЫМ ПОВРЕЖДЕНИЯМ

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Нейроаксиальные процедуры, включая спинальную и эпидуральную анестезию, могут сопровождаться потенциальными осложнениями. Хотя редки, спинальные повреждения, возникающие вследствие анестезиологических практик (называемые Анест-СПП), остаются значительной проблемой для хирургических пациентов. Настоящий систематический обзор нацелен на

выявление группы пациентов с высоким риском, суммирование причин и последствий СПП, связанных с нейроаксиальными техниками в анестезии, а также предоставление рекомендаций по управлению. Проведен всесторонний поиск литературы в соответствии с рекомендациями Кокрейна, и для выявления соответствующих исследований использовались конкретные критерии включения. Из первоначально отобранных 384 исследований 31 подверглись критической оценке, и их данные были извлечены и проанализированы. Результаты этого обзора указывают на то, что основными факторами риска для Анест-СПП были экстремальный возраст, ожирение и диабет. Анест-СПП возникали из-за различных причин, включая гематому, травму, абсцесс, ишемию и инфаркт, среди прочего. Основные последствия включали в себя нарушения двигательных функций, утрату чувствительности и боли. Часто сообщалось о задержке в лечении Анест-СПП. Несмотря на потенциальные осложнения, нейроаксиальные техники продолжают оставаться одними из предпочтительных методов для предупреждения боли с минимальным применением опиоидов, что способствует снижению заболеваемости пациентов, улучшению результатов, сокращению продолжительности пребывания в больнице и предотвращению хронификации боли, сопряженной с экономическими выгодами. В данном обзоре подчеркивается важность тщательного управления пациентами и близкого мониторинга во время процедур нейроаксиальной анестезии для минимизации риска повреждения спинного мозга и связанных осложнений.

Ключевые слова: повреждение спинного мозга, спинальная анестезия, эпидуральная анестезия, анестезия, анальгезия, параплегия, гематома, острая боль в спине, нарушение чувствительности, нарушение двигательных функций, нейроаксиальная техника.

Introduction

Spinal cord injuries (SCI) resulting from anesthesia procedures, known as Anaesthesia-associated SCI (Anaes-SCI), are rare but carry significant concerns for surgical patients. These injuries often lead to severe outcomes with presumed mortality risks and long-lasting impacts on the affected individuals' quality of life. Morbidities associated with Anaes-SCI include transient or permanent neurological symptoms, epidural hematoma or abscess (which, if not promptly diagnosed and treated, can lead to irreversible neurological changes like muscle weakness), direct traumatic spinal injury, and adhesive arachnoiditis. These conditions may manifest with symptoms such as back pain, tingling, reduced sensation, or even permanent loss of feeling and/or muscle function.

Anesthetic procedures commonly involve neuraxial techniques, which encompass epidural and spinal methods. Epidurals are frequently employed to effectively manage pain during and after surgery, as well as for pain control in trauma and critically ill

patients. In contrast, spinal techniques are often preferred for their relative ease, speed, and reliability, and they tend to have fewer complications compared to epidurals or combined approaches. This is likely because the subarachnoid technique is typically used as a single-shot procedure for anesthesia, while the epidural technique involves the continuous placement of a catheter, mainly for intra- and post-operative pain relief.

To prevent complications, a thorough preoperative assessment and physical examination of patients are typically conducted to identify clinical conditions that increase the risk associated with neuraxial techniques. This can be particularly challenging in the case of traumatic SCI patients in the emergency room, as they may already have tissue damage, including damage to the meninges and nerve tissue.

Although epidural techniques are generally considered safe, patients with spinal canal malformations, extremes of age, compromised immune systems, or critical illness are at a higher risk of Anaes-SCI. The same applies to polytraumatized patients with pre-existing neurological conditions, pregnant patients with spinal issues, individuals undergoing antiplatelet or anticoagulant therapies, and those with abnormal blood supply or neurological deficits. Neuraxial techniques are generally not recommended for patients with traumatic spinal cord injuries due to the risk of blood pressure fluctuations or other signs of autonomic hyperreflexia.

Given the potential severity of Anaes-SCI, despite its low reported frequency, it is crucial to systematically gather and analyze data about this type of SCI. This systematic review aims to identify high-risk patient profiles, summarize the causes and consequences of SCI due to neuraxial techniques, and provide management recommendations.

Materials and Methods

Our research adhered to the guidelines set forth by Cochrane for systematic reviews and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) principles [29,30]. The review protocol was preregistered in the International Prospective Register of Systematic Reviews (PROSPERO) under No. 378214. Our electronic database search included PubMed, Scopus, and Web of Science. The search was conducted by two independent researchers, commencing on October 12 and concluding on November 18, 2022. Additionally, the other two authors of this manuscript meticulously reviewed all the selected articles, and a consensus was achieved.

For this review, we implemented the patient, intervention, comparison, and outcome (PICO) strategy, focusing on the question: "What are the causes, consequences, and management/recommendations of spinal cord injury resulting from neuraxial anesthesia techniques in human patients?" In our PubMed search, we used the following Mesh terms: "Spinal Cord Injuries" [Mesh] AND "Anaesthesia and Analgesia" [Mesh]. For Web of Science, our keywords were: "Spinal Cord Injuries due to Anaesthesia." In the case of Scopus, we used the search terms "Spinal Cord Injuries"

and "Anaesthesia." We also conducted an additional search in PubMed using the following combinations: "Spinal Cord Injuries" [Mesh] AND "Anaesthesia and Analgesia" [Mesh] AND Paralysis; "Spinal Cord Injuries" [Mesh] AND "Anaesthesia and Analgesia" [Mesh] AND toxicity; "Spinal Cord Injuries" [Mesh] AND "Anaesthesia and Analgesia" [Mesh] AND dysesthesia; "Spinal Cord Injuries" [Mesh] AND "Anaesthesia and Analgesia" [Mesh] AND hematoma; "Spinal Cord Injuries" [Mesh] AND "Anaesthesia and Analgesia" [Mesh] AND Awakening; "Spinal Cord Injuries" [Mesh] AND "Anaesthesia" [Mesh] AND neuropathy. To ensure maximum coverage, we also conducted a manual search of articles.

The screening of articles was carried out by all authors to identify eligible studies based on the following inclusion criteria: publications within the last 40 years, encompassing case reports or case series, and epidemiological/clinical studies written in English. Exclusion criteria included comments and editorials, studies involving only general anesthesia, complications related to spinal cord injuries not stemming from the anesthetic procedure, injuries caused by other forms of needling such as acupuncture or chronic pain treatment, and spinal cord metastasis due to cancer discovered during anesthesia procedures. The selection process was consistent with the PRISMA guidelines [1].

The data extraction process from the articles involved capturing information regarding the study type, the anesthesia method used, the causes of spinal cord injury, associated complications, treatment approaches, and any recommendations provided. Notably, the assessment of bias risk was omitted, as all the studies under review were case reports focusing solely on the cause-and-effect relationships of spinal cord injuries. The selection of manuscripts was a collaborative effort, with unanimous agreement among all authors.

Results

The search for publications yielded a total of 384 manuscripts, with 131 from PubMed, 184 from Web of Science, 59 from Scopus, and 10 additional sources. After reviewing titles and abstracts, we initially selected 54 manuscripts. Subsequently, we excluded duplicates, resulting in 50 articles for full-text evaluation. Of these, 19 studies were further excluded for various reasons: two were related to patients with pre-existing spinal cord injuries unrelated to anesthesia, three dealt with complications of general anesthesia, six were published in languages other than English, one was a literature review without case reports, five articles discussed SCI caused by tumors, and one had been published more than 40 years ago. As a result, 31 manuscripts were included in this systematic review for comparison.

The initial analysis included 20 single case reports and seven case series, totaling 20 patients with Anaes-SCI. Epidural anesthesia was the most frequently used technique (29 patients), followed by spinal anesthesia (9 patients), and one case involving a combination of epidural and spinal anesthesia. In one case report, the

specific anesthesia procedure was not reported. These neuraxial procedures were often administered alongside general anesthesia in 19 cases. Notably, the lumbar region was punctured in 23 patients, the thoracic region in 12, the cervical region in four, and the thoracic-lumbar region in three, while in two cases, the placement level was either unknown or not reported.

The primary risk factors identified were extremes of age, encompassing one child, six late elderly individuals, and six early elderly individuals, along with the presence of obesity and/or diabetes (two obese and two diabetic patients). The possible causes or etiology of Anaes-SCI included hematoma (14 cases), unspecified catheter/needle trauma (7 cases), abscess (5 cases), ischemia (4 cases), infarction (3 cases), adhesive arachnoiditis (2 cases), haematomyelia (1 case), unspecified inflammation (1 case), and cases where the cause was not reported or remained unknown (5 cases).

Consequently, several patients experienced motor deficits, with 27 patients developing paraplegia and seven experiencing dyskinesia or motor weakness. The most commonly reported symptoms included sensory loss (20 patients) and pain (9 patients). Urinary sphincter tone absence and/or urinary incontinence were reported by five patients. Additionally, four deaths were reported, resulting from a hypotensive crisis, massive pulmonary embolus, septic shock, and ischemic cerebellar stroke, either during or after hematoma or injury management.

Many authors noted delayed treatments for resolving Anaes-SCI, including 17 surgeries for hematoma decompression or laminectomy, catheter removal in 5 cases, and rehabilitation for 10 patients. Corticosteroids were commonly used to reduce inflammation, and antibiotics were administered in cases of abscess.

The second analysis encompassed two prospective and two retrospective studies, involving a total of 41,251 patients who received neuraxial blocks. One manuscript also evaluated peripheral nerve blocks [13]. Among these patients, the most frequent complication was localized pain in 9.05% of cases, followed by 3.1% experiencing sanguineous punctures. Adverse neurological outcomes affected 1.12% of patients, and 0.08% had anesthesia toxicity or permanent peripheral nerve injury after neuraxial block. The frequency of epidural hematoma ranged from 0.03% to 0.02%, and 0.03% of cases reported epidural abscesses. One study delved into nine cases of epidural abscesses with significant negative consequences, including lower-limb paraplegia, urinary or fecal incontinence, and radiating pain.

The analyzed manuscripts provided recommendations for improving anesthetic procedures, the necessity of identifying high-risk patients, and underscored the importance of early diagnosis coupled with appropriate treatment. They also emphasized the value of involving acute pain units when managing Anaes-SCI.

Discussion

Our comprehensive search has illuminated the rarity of Anaes-SCI as a complication but has underscored the devastating and often untreatable consequences it can entail, including paraplegia and, in some unfortunate cases, even death. While many minor cases may resolve within the first six months, it is paramount to approach them with caution, given the profound impact they have on patients, their families or caregivers, and anesthesiologists. Safety concerns often lead to the preference for neuraxial anesthesia over general anesthesia in critically ill patients, unless there are absolute contraindications. It's important to note that, while some deaths may be directly or indirectly linked to the anesthesia procedure, it is widely acknowledged that the underlying critical or advanced illness is the primary cause of death in most instances.

The occurrence of spinal-epidural hematoma, ischemia, abscess, or meningitis leading to SCIs due to neuroaxis anesthesia is reported in less than 0.03% of patients. Major complications can affect up to 1.5% of patients, while minor complications, such as localized pain at the epidural insertion site, are reported by 9% of patients. This localized pain is primarily associated with multiple block attempts and suboptimal patient-controlled epidural analgesia [4]. It's worth noting that the risk of sanguineous punctures tends to increase with patient age and is related to the level of puncture, with a higher risk in more caudal segments [3]. Advanced age also heightens the risk of dural perforation, while patient size correlates with the risk of catheter misplacement, particularly in shorter individuals [2]. A retrospective study revealed that 11% of patients who underwent neuraxial blocks experienced side effects or complications, encompassing sensory or motor deficits, nausea, vomiting, and pruritus [4]. Permanent peripheral nerve injury, subcutaneous tissue hematoma, epidural abscesses, and arachnoiditis have also been reported but affect fewer than 0.1% of cases [5].

The scarcity of Anaes-SCI cases, coupled with underreporting and potential bias in insurance-based data, makes it challenging to obtain reliable and consistent information regarding these injuries. Clinical studies often underestimate the true incidence, and regional anesthesia is sometimes unjustly blamed [5,6]. In this systematic review, we found only a few case reports in the literature, indicating the need for increased reporting of Anaes-SCI by anesthesiologists. This is vital to drive technical improvements that can help prevent such injuries and their consequences.

There is a growing call to include discussions of the risk of permanent neuropathy resulting from neuraxial block techniques in informed consent conversations with patients, particularly for high-risk individuals. Such high-risk patients include those with pre-existing neurological disorders, immunocompromised status, diabetes mellitus, obesity, high body mass index, a lower spinal approach, patients on antiplatelet or anticoagulation therapies, extremes of age, and those in critical care. It's important to recognize that, in addition to human error, other risk factors may come

into play, and even healthy patients under competent care can experience severe injuries. These risk factors are not always known to the anesthesiologist, rendering a significant proportion of Anaes-SCIs unpredictable or unpreventable [6,7]. Often, there is no clinical or radiographic evidence of direct trauma, leaving the etiology of Anest-SCI unclear. In such cases, the diagnosis of Anaes-SCI is only made after the development of neurological disturbances [8], including paraplegia, which can result from spinal cord compression, infarction, or direct trauma. The causes of Anaes-SCI are diverse and can sometimes involve a combination of mechanical, ischemic, and neurotoxic insults, vertebral canal abscesses, hematoma, meningitis, nerve injury, and adhesive arachnoiditis [10]. These insults can lead to symptoms such as numbness, weakness, total spinal anesthesia, pain, paraparesis, reversible paraplegia, incomplete or permanent paraplegia, and even direct or indirect death [9]. While death is an uncommon consequence, it can result from spinal cord compression, causing neurological, respiratory, and cardiovascular impairments directly, or from complications like pulmonary embolism that complicate a good neurological recovery following abscess or hematoma decompression indirectly [2].

Many of the identified causes and consequences are associative rather than causative. Neuraxial injuries are predominantly associated with mechanical damage, drug-related neurotoxicity, or a combination of both. The response to such injuries is often inconsistent due to anatomical and physiological variations. In cases of tissue damage, neurotoxicity is exacerbated by the absence of protective connective tissue barriers. The use of vasoconstrictors can further complicate local anesthetic clearance [6]. Consequently, spinal cord ischemia or vertebral canal hematoma presents a particularly poor prognosis due to reduced blood flow, whereas conditions like meningitis and most nerve injuries and abscesses can often result in full recovery [4]. However, if there is a delay in diagnosis, the prognosis becomes considerably worse [10]. The risk period for complications and related symptoms can extend for hours, days, or even weeks [3]. In the case of adhesive arachnoiditis, the symptoms, including pain, may manifest more insidiously and may take years to become evident [4]. Localized pain following epidural analgesia, usually in the lumbar region due to needling, has also been reported but should be carefully distinguished from lower back pain [5].

Preventing Anaes-SCI necessitates a highly personalized approach to anesthesia. A comprehensive medical history, coupled with a meticulous patient examination, is crucial for tailoring the anesthetic protocol and minimizing the risk of Anaes-SCI. Magnetic resonance imaging (MRI) is the preferred diagnostic modality for assessing the presence of spinal pathologies and determining spinal canal and epidural space dimensions, even in adults, where depths can be as small as 1.5 cm. If MRI is unavailable, preoperative computerized tomography can be considered, although it comes with drawbacks like radiation exposure, lower diagnostic accuracy, and limited

cost-effectiveness, applicable to specific patients only. Nevertheless, it can offer valuable insights, particularly for high-risk patients or when MRI is contraindicated. The use of ultrasound, while not the primary choice, can assist in determining the best approach for neuraxial blocks, especially in patients with prior spinal issues and anesthesia interventions [2,5,6].

Throughout the perioperative period, it is vital to remain vigilant for potential signs of spinal cord trauma, which may manifest as weakness, numbness, radicular back pain, or bowel and bladder dysfunction [4]. Blood pressure should also be closely monitored, as unexplained hypotension can result from intrathecal injection of local anesthetic during epidural analgesia in conjunction with general anesthesia, necessitating double-checking catheter placement [8]. The choice of puncture site for neuraxial techniques should align with the specific region of the body requiring anesthesia or analgesia for each patient. The lumbar epidural approach generally carries fewer serious complications, particularly among higher-risk patients such as the elderly. The mid-thoracic spinal region is particularly prone to infarction due to its anatomically narrow canal, limited vascularization, and the presence of the Adamkiewicz spinal artery. Additionally, the cervico-thoracic region is the most vulnerable and carries the highest risk of spontaneous epidural hematoma [6]. In the past, the thoracic approach was often avoided due to concerns about more severe complications arising from hematoma or abscess compared to the lumbar region. In terms of the subarachnoid technique, the puncture location is consistently lumbar, always below the L2 level. In this review, most of the complications were reported in the lumbar region, likely due to the higher frequency of neuroaxial techniques in this area.

To reduce the incidence of Anaes-SCI, continuous theoretical education and hands-on training are of paramount importance. This ensures the provision of optimal techniques, along with a deeper understanding of pharmacological aspects. It's critical to adhere to recommended patient positioning, utilize a meticulous aseptic technique, and ensure the removal of excess disinfectants that could irritate the spinal cord. Additionally, care should be taken to avoid the introduction of significant volumes of air when performing the air resistance technique, and needle withdrawal should be considered whenever a patient reports pain. To mitigate anesthetic neurotoxicity, it's crucial to thoroughly review and adhere to recommended concentrations and dosages. Special precautions should be taken when using transforaminal and paramedian approaches to prevent vascular trauma [6]. Regarding the epidural technique, it's important to avoid attempting the epidural at the same spinal level if an accidental dural puncture occurs, as it carries the risk of total spinal anesthesia [6].

During the performance of the technique, it is crucial to remain alert to any occasional symptoms, such as pain or paresthesia. Vigilance should not equate to automatic cessation but rather prompt reevaluation and, if necessary, recommencement

of the procedure using an alternative approach. In cases of continuous epidural analgesia, if sensory or motor loss is observed, pharmacologic administration should be halted immediately, and frequent assessments should continue until signs of recovery appear. When recovery fails to manifest within an hour, a multidisciplinary team, comprising an anesthesiologist, neuroradiologist, neurosurgeon, and neurologist, should intervene to prevent the worsening of neurological symptoms. The initial step involves obtaining an emergency MRI to ensure the correct diagnosis. If decompression is required, it should be performed promptly, as the progression of tissue damage is time-dependent. Ideally, it should be carried out within 8 hours of the technique's onset or the emergence of symptoms, as recovery and outcomes are time-sensitive. The pathophysiology and cellular changes occurring within the first 8 hours post-injury are complex and appear to involve neurotoxic events due to the anesthetic agent, along with damage resulting from the disruption of the blood-brain barrier. It should be noted, however, that pre-clinical studies have rarely focused on Anaes-SCI, which hampers a complete understanding of its pathophysiological mechanisms [5,6]. In this context, Acute Pain Units are equipped to offer individualized postoperative care, encompassing postoperative surveillance, pain management, diagnostic procedures, trauma assessment, medical conditions, and complications related to the reported anesthetic techniques [1].

The treatment of Anaes-SCI is primarily driven by the nature of the injuries and the patients' symptoms. Patients with no neural deficit and mild symptoms or those who encountered difficult punctures should undergo follow-up, which includes monitoring vital signs, neurologic function, and assessment of post-dural puncture headache. If symptoms persist, patients should be evaluated by a neurologist or neurosurgeon, and immediate neurophysiologic testing or imaging should be performed. In cases of incomplete or unresolved lesions, follow-up should continue for up to 5 months [6]. The reported cases included in this review indicate that antibiotics are commonly used in the treatment of Anaes-SCI, particularly to address abscesses. Corticosteroids are also administered to aid in cord decompression, and analgesics are provided for pain management [8,10].

Conclusions

This systematic review focused on case reports, case series, and epidemiological/clinical studies, given the impracticality of conducting randomized placebo-controlled clinical trials to investigate Anaes-SCI. While this approach has limitations, such as the challenge of precisely determining the frequency and complications associated with Anaes-SCI due to the rarity of reported cases, it provides valuable insights. The scarcity of cases hampers a comprehensive understanding and the identification of underlying mechanisms and risk factors, making it difficult to propose definitive recommendations [5,8]. Nonetheless, despite the rarity of complications, neuraxial techniques remain crucial for effective pain prevention and

management. They significantly reduce patient morbidity, enhance outcomes, shorten hospital stays (supporting enhanced recovery programs), and mitigate the risk of pain chronification, ultimately yielding economic benefits. Another limitation of this study is the exclusion of non-English language manuscripts. This decision aimed to minimize potential misinterpretations of published material and did not hinder the search and review of the studies incorporated into this comprehensive review.

In summary, neuraxial techniques remain among the most effective options for opioid-sparing pain management. While Anaes-SCI is a rare occurrence, it can result from multifactorial factors, including healthcare decisions, equipment, medications, patient characteristics, and human knowledge. This manuscript represents a pioneering effort in the field, laying the groundwork for more extensive studies and the refinement of anesthetic protocols.

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