Pain Ther (2025) 14:817–839
https://doi.org/10.1007/s40122-025-00726-6

REVIEW

Neurological Deficits Following Regional Anesthesia and Pain Interventions: Reviewing Current Standards of Care

Salah N. El-Tallawy · Rania S. Ahmed · Gehan I. Salem · Tariq A. Alzahrani · Mamdouh M. Haddara · Radwa H. Ahmed · Mohamed S. Nagiub · Abdullah T. Alsubaie · Mohamed M. Ali · Mahmoud M. Elbasha · Ahmed A. Ahmed

Received: December 19, 2024 / Accepted: March 10, 2025 / Published online: March 27, 2025

ABSTRACT

Regional anesthesia (RA) has become an integral part of modern anesthesia practice and acute pain management strategies. It provides effective pain relief, reduces opioid consumption, and facilitates enhanced recovery after surgery. However, like any medical intervention, RA is not without risks. RA is associated with potential complications, including neurological deficits which can range from mild and transient to severe and permanent. These neurological deficits may result from non-adherence to established standards of care and deviations from the clinical practice guidelines. An online database search was conducted across multiple websites to identify the relevant articles. The inclusion criteria were articles in English, published between January 2010 and July 2024. The search included various study types, such as case series,

S. N. El-Tallawy (✉) · T. A. Alzahrani
College of Medicine, King Khalid University Hospital, King Saud University, Riyadh, Saudi Arabia
e-mail: salaheltallawy@yahoo.com

T. A. Alzahrani
e-mail: talzahrani@ksu.edu.sa

S. N. El-Tallawy
Anesthesia Department, Faculty of Medicine, Minia University & NCI, Cairo University, Cairo, Egypt

R. S. Ahmed
College of Medicine, Alfaisal University, Riyadh, Saudi Arabia
e-mail: raniasalah246890@gmail.com

G. I. Salem
Rheumatology, Rehabilitation and Physical Medicine Department, Faculty of Medicine, Assiut University, Assiut, Egypt
e-mail: gehan_us@yahoo.com

M. M. Haddara
King Faisal Specialist Hospital and Research Center, Riyadh, Saudi Arabia
e-mail: hadmaa@icloud.com

R. H. Ahmed
Clinical Pathology Department, Faculty of Medicine, Assiut University, Assiut, Egypt
e-mail: missarnob@yahoo.com

M. S. Nagiub
College of Medicine, Badr University, Cairo, Egypt
e-mail: hamadasalah13579@gmail.com

A. T. Alsubaie
Anesthesia Department, King Saud University Medical City, King Abdulaziz University Hospital, King Saud University, Riyadh, Saudi Arabia
e-mail: al-suba3e@hotmail.com

M. M. Ali · M. M. Elbasha · A. A. Ahmed
Anesthesia Department, King Saud University Medical City, Riyadh, Saudi Arabia
e-mail: mohm10027@gmail.com

M. M. Elbasha
e-mail: dr.mahmoud9987@gmail.com

A. A. Ahmed
e-mail: ahmedkader333@gmail.com

observational studies, cross-sectional analyses, cohort studies, longitudinal studies, systematic reviews, and practice guidelines. A total of 38 articles met the inclusion criteria and were included in this comprehensive review which examines the neurological complications associated with regional anesthesia and pain interventions, with a particular focus on how deviations from the standards of care contribute to adverse neurological outcomes. Furthermore, it highlights preventive strategies aimed at minimizing the risks of these complications and improving patient safety.

Keywords: Regional anesthesia; Ultrasound-guided regional anesthesia; Acute pain management; Pain interventions; Epidural steroid injection; Neurological complications; Nerve injury; And standards of care

Key Summary Points

Why carry out this study?

The review was conducted to address the following key objectives:

To highlight the importance of adhering to standard guidelines to ensuring patient safety.

To identify neurological complications which may arise from regional anesthesia and pain interventions.

To examine how deviations from best practices contribute to these complications.

To analyze the contributing factors and the mechanisms leading to neurological injuries.

To discuss preventive strategies and provide recommendations for reducing the incidence of neurological complications and improving patient outcomes.

What was learned from the study?

Key insights gained regarding neurological deficits associated with regional anesthesia and pain interventions:

Adherence to established clinical guidelines is essential for preventing complications. Deviations from these standards can lead to significant neurological deficits.

Several mechanisms contribute to neurological injuries, including mechanical trauma, chemical neurotoxicity, and vascular compromise.

Preoperative assessment, continuous monitoring, and the use of imaging tools improve precision and reduce the risk of complications.

Early recognition of complications and timely intervention are critical for preventing progression and improving patient outcomes.

Preventive strategies, along with effective multidisciplinary management of complications, play a pivotal role in mitigating risks and ensuring patient safety.

INTRODUCTION

Adherence to established guidelines during regional anesthesia and pain interventions is essential to ensuring patient safety and minimizing the risk of complications. Regional anesthetic techniques effectively provide superior pain control, enhance patient outcomes, and promote faster functional recovery [1, 2]. These techniques are widely utilized in various surgical procedures and pain management, offering effective pain management and facilitating faster recovery than general anesthesia.

Despite their benefits, regional anesthesia techniques are not without risks. They carry inherent complications, such as nerve injury, infection, hematoma, or local anesthetic (LA) systemic and neurotoxicity. However, strict adherence to best practices significantly reduces these risks [3, 4]. Neurological deficits are among the most serious complications, potentially resulting in significant morbidity. Improper techniques or deviations from clinical practice guidelines may result in various neurological complications, including nerve injury, prolonged sensory loss, or even paralysis [5]. Although these complications are rare, their impact on patients can be devastating.

Understanding the mechanisms underlying these deficits is essential for enhancing patient safety and improving outcomes [6, 7]. This review explores the neurological complications following regional anesthesia and pain interventions, emphasizing how deviations from the standards of care can contribute to adverse neurological outcomes. It also examines the possible mechanisms of neuronal injury and outlines preventive measures to minimize the associated risks.

METHODS

A comprehensive search strategy was employed across databases, including PubMed, Medline, Google Scholar, and Web of Science. The search process used a list of keywords such as regional anesthesia, ultrasound (US)-guided regional anesthesia, acute postoperative pain, pain interventions, epidural steroid injection, neurological complications, standards of care, and nerve injury. The search strategy focused on the articles published during the last 15 years, from 2010 to 2024. The search included various study types, such as case series, observational, cross-sectional, cohort, longitudinal studies, systematic reviews, and practice guidelines. Articles that met the inclusion criteria, such as articles published in English that specifically addressed neurological deficits following regional anesthesia. Studies involving patients who developed neurological complications as a result of regional anesthesia or pain interventions were included, while articles focusing on complications unrelated to neurological outcomes were excluded. Additionally, non-English articles, editorials, conference papers, and expert comments were excluded from the search. The selected articles underwent screening by two independent reviewers who applied the same evaluation criteria. The final reviewing strategy of the literature search resulted in a total of 38 articles included in this review (Fig. 1). This review is based on previously published studies and provides an overview and analysis of the existing literature related to neurological complications of regional anesthesia and does not contain any new studies with human participants or animals conducted by the authors.

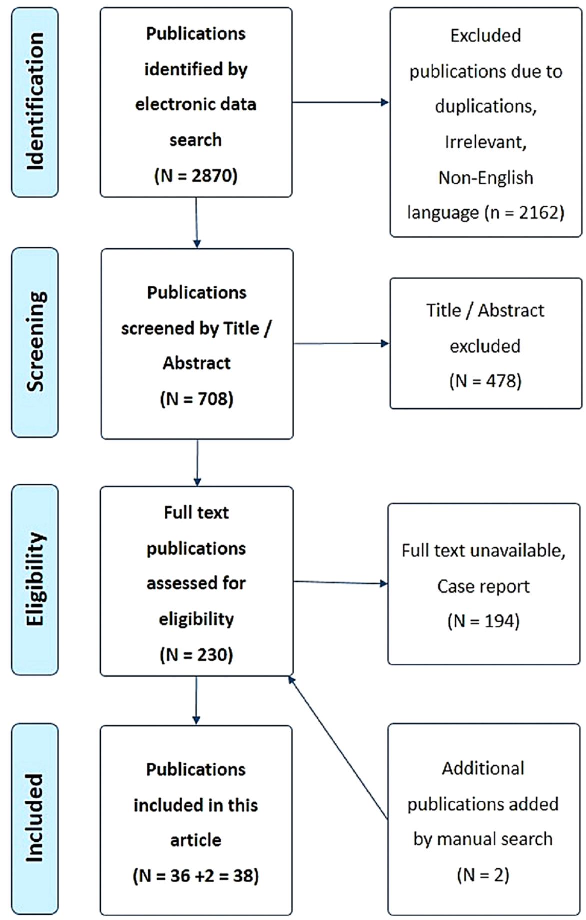

Fig. 1 Flowchart describing the selection process of included studies

NEUROLOGICAL DEFICITS FOLLOWING REGIONAL ANESTHESIA AND PAIN INTERVENTIONS

Incidence of Neurological Deficits

The incidence of neurological complications following regional anesthesia varies significantly based on the type of nerve block, patient characters, and the use of imaging tools. Determining the exact incidence of perioperative nerve injury presents significant challenges. Generally, the incidence of nerve injury following neuraxial blockade is extremely low, though these injuries can often be permanent. In contrast, injuries resulting from peripheral nerve blockades are more common but rarely lead to long-term or permanent damage [5, 9].

Despite advancements in technology, such as US and fluoroscopy guidance, computed tomography (CT) and magnetic resonance imaging (MRI) guidance, the rates of peripheral nerve injuries have remained consistent over the years. Overall, the data indicate that the incidence of neurological complications is low, typically reported at less than 1%, while permanent neurological deficits occur in approximately 0.01–0.03% of cases. Long-term injuries following peripheral nerve blocks are rare, with an incidence of 2–4 per 10,000 blocks [5, 9]. Neurological complications after neuraxial anesthesia are also very rare, with transient neurological symptoms occurring in 0.1–0.4% of cases, and long-lasting neurological deficits ranging from 0.3 to 10 per 10,000 procedures. However, these rates have been observed to rise, particularly among high-risk patients [5, 10].

For neuraxial techniques, the incidence of specific neurological complications includes epidural hematoma, which occurs in 2 per 100,000 to 1 per 140,000–220,000 neuraxial procedures, and spinal epidural abscess, with an incidence of 1 in 40,000 to 1 in 100,000 neuraxial anesthetics. Although these are very rare, they can have devastating neurological consequences if unrecognized [11]. A Swedish study reported vastly different incidences of spinal hematoma, ranging from a risk of 1:200,000 in young women undergoing obstetric epidural blockade to a risk of 1:22,000 in elderly women undergoing hip fracture repair, and as high as 1 in 3600 for those undergoing knee arthroplasty [12].

The incidence after pain interventions revealed that transforaminal epidural procedures for pain management can be associated with catastrophic neurological injuries. Several case reports have described infarctions of the spinal cord, brain stem, cerebrum, or cerebellum following both lumbar [13, 14] and cervical [15] transforaminal injections. Recent evidence has highlighted the role of particulate steroids in these injuries, suggesting that the effectiveness of non-particulate steroidal preparations, such as dexamethasone, may be comparable to that of particulate preparations [14, 16]. It is recommended not to use particulate steroids for cervical transforaminal epidural injections. To avoid direct injection into critical structures, the final position of an immobile needle during transforaminal injection should be confirmed by injecting a contrast medium under real-time fluoroscopy [5].

Mechanism of Neural Injury

Neural injury following regional anesthesia or pain interventions can manifest as transient neurological symptoms (TNS), including burning pain, hypoesthesia, tingling or paresthesia, and motor weakness. These symptoms may develop following regional techniques or pain interventions. TNS is generally a self-limiting condition that resolves spontaneously within a few hours to a few days post-surgery. However, persistent nerve damage can occur due to direct trauma, prolonged ischemia, predisposing neuropathy or neurotoxicity, potentially leading to long-term sensory or motor deficits [11, 17]. Predisposing diseases may decrease the threshold of nerve injury, increasing the risk of postoperative nerve injury. This concept aligns with the "double crush" hypothesis, which suggests that neural function is compromised when axons compressed at one site, become more vulnerable to damage at another site. Additionally, proximal neural injuries may heighten the likelihood of distal nerve impairment [9]. Although the underlying mechanisms of neurological deficit following regional anesthesia are not fully understood, several contributing factors have been identified.

Mechanical or Traumatic Injury

Nerve damage following LA injection may result from direct trauma, hematoma formation, or secondary to local inflammation. Injury can occur from different types of trauma to the spinal cord or peripheral nerves during the procedure due to needle or catheter trauma, intraoperatively from surgical trauma and manipulations, or postoperatively due to nerve compression caused by post-operative positioning, tight dressings, hematomas, inflammation, and infection [9, 11]. The main source of direct peripheral nerve injury is likely attributed to the injection of LA into a fascicle, causing myelin and axonal degeneration [11]. To reduce the risk of nerve injury, regional techniques should ideally be performed under imaging guidance, such as US or fluoroscopic, to improve needle placement accuracy and enhance needle visibility [5].

Chemical Neurotoxicity

Local anesthetics can cause neurotoxicity, particularly when the nerves are exposed to high concentrations or prolonged infusions of the LAs [11]. Establishing maximum allowable doses for LAs is essential to prevent neurotoxicity. Nerve injury can also result from the injection of toxic substances, such as alcohol, phenol, or high concentrations of LAs [5, 11].

All commonly used LAs in clinically used concentrations produce neuroapoptosis and neurotoxicity in a concentration-dependent manner. The toxicity correlates with the lipophilicity and therefore with the potency of the LA, but is independent of the chemical class (ester/amide). Ester- or amide-type LAs are equally neurotoxic.

The effect of LAs on neurons includes calcium homeostasis, reducing mitochondrial metabolism thereby increasing oxidative stress, and directly increasing the rate of cell death [18, 19]. The net result of these processes results in a dose-dependent neuronal death, with low doses of anesthetic inducing apoptosis and a high dose inducing necrosis [9, 19].

Studies on the toxicity of LAs have shown that the degree of neurotoxicity depends primarily on the concentration of the LA. Over time, the concentrations of the LAs used have decreased. The high concentration of lidocaine 2% is more toxic than equipotent doses of bupivacaine 0.5% [18, 20]. A comparison of LD_{50} values for different LAs indicated the following order of neuroapoptotic potency, listed from highest to lowest toxicity: tetracaine > bupivacaine > prilocaine = mepivacaine = ropivacaine > lidocaine > procaine = articaine [21].

Cases of cauda equina syndrome (CES) were initially reported after the introduction of the microcatheter technique for continuous spinal anesthesia using hyperbaric 5% lidocaine. Subsequently, transient neurologic symptoms characterized by radicular pain without motor deficit were observed after a single dose of spinal lidocaine injection. The development of CES strongly implicated neurotoxic effects of lidocaine, which were exacerbated by the accumulation of hyperbaric lidocaine in the caudal dural sac when repeated dosing through spinal catheters [18].

Vascular Cause

Nerve ischemia can result from hypoperfusion, prolonged use of a tourniquet, vascular compromise during nerve blocks, or vascular abnormalities. To reduce the risk of complications, it is important to avoid prolonged tourniquet times or excessive pressure [6, 11]. Vascular injuries are among the most catastrophic potential complications following regional anesthesia. Ischemic vascular injuries may arise from embolic phenomenon, direct trauma, or vasoconstriction of the artery of Adamkiewicz, leading to anterior spinal artery syndrome or watershed ischemia due to hypotension or vasoconstriction [11].

Inflammation and Infection

Infection, often accompanied by inflammation, can lead to nerve damage. Strict adherence to aseptic technique is crucial, particularly in emergencies or immune-compromised patients. Nonspecific inflammation of the peripheral nerves is increasingly recognized as a significant mechanism contributing to neurological deficits following peripheral nerve blocks [11, 22].

Pre-Existing Pathology

Patients with underlying nerve pathology are more susceptible to peripheral nerve complications, although the exact mechanisms remain unclear. Risk factors include prolonged duration of nerve block and increased sensitivity to LA neurotoxicity. Pre-existing conditions, such as diabetic neuropathy or post-chemotherapy-induced neuropathy, increase the risk of already compromised nerves [2, 22, 23].

Other Causes

Direct neurogenic injury to the spinal cord or peripheral nerve caused by needle or catheter trauma, LA toxicity, or surgical trauma varies in severity and prognosis [11]. Some nerve injuries may occur independently of the anesthetic or surgical intervention. For example, a patient who underwent total knee replacement under neuraxial anesthesia with a continuous epidural catheter may develop foot drop due to a peroneal compressive neuropathy at the fibular head, unrelated to the epidural catheter. Such injuries can often be treated and may lead to complete recovery [2, 5].

Specific Injuries Following Neuraxial Procedures (Spinal or Epidural)

Epidural Hematoma

This serious complication typically arises from unrecognized coagulation disorders or anticoagulation therapy. Early symptoms may include vague sensory changes below the site of the hematoma, followed by flaccid paralysis of the lower extremities. Late complications can involve neurogenic bowel and bladder dysfunction [24]. If not promptly diagnosed and treated, an epidural hematoma can compress the spinal cord, potentially resulting in irreversible neurological damage.

Epidural Abscess

This is the second most severe complication following neuraxial procedures, primarily resulting due to failure to ensure an aseptic technique, particularly in emergency situations or among immune-compromised patients. Symptoms include pain, fever, and elevated inflammatory markers, along with specific signs such as sensory deficits, paraparesis, and, later, neurogenic bowel and bladder dysfunction [25]. An epidural abscess can lead to spinal cord compression and irreversible neurological damage.

Spinal Cord Injury

Although rare, spinal cord injuries can be severe complications from needle misplacement, accidental intramedullary injections, spinal deformities, or unknown anatomical variations, as well as secondary to compressive lesions like hematoma or abscess. Utilizing imaging tools such as fluoroscopy or US is highly recommended, particularly for patients with complex anatomical challenges (e.g., scoliosis, previous spine surgeries) [2, 22]. Diagnosis of a compressive lesion, such as epidural hematoma or abscess, demands emergent neurosurgical consultation for consideration of decompression.

Post-Dural Puncture Headache (PDPH)

PDPH is an uncommon complication associated with intrathecal blocks, particularly when small pencil-point spinal needles are used. It occurs more frequently following an unintentional dural puncture with a large-bore epidural needle. PDPH remains a serious complication of labor epidural analgesia after accidental dural puncture. A persistent cerebrospinal fluid (CSF) leak resulting from a dural puncture can lead to a severe headache that worsens in the sitting or upright position [26]. However, the exact underlying mechanisms of PDPH are still incompletely understood, and long-standing beliefs of dysregulation of CSF homeostasis due to CSF fluid loss are currently being challenged. Other mechanisms of PDPH are suggested, related to the autonomic nervous system or the release of calcitonin gene-related peptide associated with activation of the meningeal and cerebral arteries. If not properly managed, PDPH can result in additional complications, such as subdural hematoma and cranial nerve palsies [27].

Factors Associated with Deviation from Standard of Care

Deviations from the standards of care have been identified as significant risk factors for the development of neurological complications following regional anesthesia.

Inadequate Patient Assessments

A key contribution to these deviations is inadequate patient assessments, in particular the failure to conduct a comprehensive preoperative evaluation. For instance, failing to perform a thorough preoperative evaluation may overlook anatomical abnormalities, previous neurological deficits, or musculoskeletal deformities. The primary goal of such evaluation for patients with neuromuscular disorders is to predict and minimize potential neurologic complications while improving surgical outcomes [28]. Patients with preexisting neurological conditions, such as inflammatory neuropathies, spinal canal stenosis, and vertebral pathologies, are at a higher risk of neurological complications following regional anesthesia [29].

Not reviewing the patient's anticoagulation profile further exacerbates these risks, especially during neuraxial procedures. Similarly, inadequate history taking, such as neglecting to inquire about significant systemic diseases, ongoing neurological disorders, or past adverse effects related to regional anesthesia, can increase the likelihood of complications.

There is increasing evidence of the connection between preoperative psychological factors and psychological interventions to improvements in postoperative pain outcomes [30]. Poor communication with patients during and after the procedure may also contribute to a higher risk of neurological complications. Effective communication is critical to ensure patient understanding and to mitigate risks associated with regional anesthesia [31–33].

Technical Factors

Technical errors are another crucial aspect of deviations from the standard of care. Issues such as incorrect needle positioning, using excessive force, or improper angles during needle placement can result in direct nerve damage or technical failure [34]. Similarly, incorrect needle selection, such as using a cutting or large-gauge spinal needle, may increase the likelihood of adverse outcomes like PDPH [27]. Anatomical variations in nerve and vascular structures may further complicate procedures, particularly in patients with unique or atypical anatomy [33].

Limited Access to Imaging Tools

Failure to use proper imaging guidance, such as ultrasound or fluoroscopy, can result in incorrect insertion sites or needle misplacement, significantly increasing the risk of unintentional nerve damage. Ultrasound guidance during peripheral nerve blocks has been shown to improve success rates and to reduce the risks of complications [2, 22]. Similarly, the use of nerve stimulation during these procedures enhances needle placement accuracy, further minimizing the likelihood of complications [23–25]. A Cochrane review of 33 trials involving 2293 pediatric patients suggests that ultrasound guidance likely reduces the risk of failed regional blocks and moderately decreases postoperative pain 1 h after surgery, with a reduction of 1.3 points on the pain scale. It also significantly increases the block duration by approximately 42 min. There may be little or no difference in the risk of transient neurological injury [35].

Injection of the Correct Drug

Dosing errors involving LAs can pose significant risks. Improper use of the recommended doses may result in systemic or neurotoxicity. Higher concentrations, excessive volumes, or prolonged infusions of LAs administered via continuous catheter techniques can increase the risk of neurotoxicity. Certain LAs like lidocaine in high concentrations have been specifically associated with neurotoxicity. Furthermore, unintentional intravascular injection or the administration of large volumes of LAs can lead to systemic toxicity [22, 34].

Suboptimal Surgical Positioning

Improper patient positioning during surgery can significantly increase the risk of nerve injury.

Additionally, the positioning required for surgical procedures may contribute to neurologic complications. Several mechanisms are implicated in the nerve injury during surgery, including traction, transection, compression, contusion, ischemia, and stretching [2, 36]. These complications can range from transient peripheral neuropathies to more severe conditions such as compartment syndrome and rhabdomyolysis. Data from the American Society of Anesthesiologists Closed Claims highlights that peripheral nerve injury, a subset of positioning-related injuries, accounts for 15% of claims across surgical disciplines. Placing patients in non-standard positions during surgery, including excessive flexion, abduction, or tight fixations during general anesthesia, along with prolonged surgery, can lead to nerve compression, and highlighted risk of nerve injury, especially in predisposed patients [30, 33, 37]. Furthermore, the physical forces exerted during surgery, such as placement of prostheses, can be excessive, and may strain anatomical structures distal from the surgical site, including the vertebral column [5, 36]. Additionally, certain surgical procedures necessitate patient positioning that would be intolerable without anesthesia. Awareness of suboptimal surgical positioning should encourage a careful evaluation of the risk–benefit ratio when considering regional anesthetic techniques [2, 36].

Musculoskeletal Disorders

Musculoskeletal deformities can impact patient positioning during surgery, hinder access to regional anesthesia, and obscure anatomical landmarks. Poor positioning of the patient on the operating table may leave certain areas of the body inadequately supported, necessitating additional care during anesthetic management [2, 36]. Patients with longstanding rheumatoid arthritis which is characterized by the destruction of synovial joints, primarily affecting the small joints, as well as the temporomandibular joint and spine joints, pose unique challenges for anesthesiologists [2, 34, 37].

Orthopedic Surgery and Regional Anesthesia

Patients with musculoskeletal deformities may pose challenges for regional anesthesia due to difficulties with surgical positioning and limited access to regional techniques. Orthopedic surgeries are among the most common procedures performed in patients with rheumatoid arthritis or other musculoskeletal disorders, and most regional anesthetic methods may be utilized. The most common contraindications for regional anesthesia include patient refusal, anticoagulant therapy, infection at the puncture site, and hemodynamic instability [2, 35]. Additionally, patients with musculoskeletal deformities are more prone to undergo major orthopedic surgeries in suboptimal positions and for prolonged durations. All these risk factors are likely to contribute to increased adverse outcomes following neuraxial analgesia [35].

Regional Techniques in Anesthetized or Deeply Sedated Patients

The practice of initiating regional blocks in adults under general anesthesia remains controversial due to concerns about the inability of the anesthetized patients to report pain or paresthesia, and potentially increasing the risk of neurologic complications [36]. Paresthesia and pain during nerve block placement or LA injection have been identified as significant risk factors for serious neurologic deficits associated with regional techniques. Consequently, many experts highlight the importance of maintaining close communication with the patient during neuraxial procedures as a key element of safe practice. Current evidence supports performing epidural insertion in awake or minimally sedated patients to ensure safety [36, 37]. However, needle and catheter placement in anesthetized adults may be an acceptable alternative in carefully selected cases. Studies on lumbar epidural insertion during general anesthesia have shown a low incidence of neurologic complications [35–37].

The performance of regional blockade on anesthetized patients theoretically increases the risk of postoperative neurologic complications, because these patients are unable to respond to painful stimuli [8]. Additionally, as benzodiazepines increase the threshold for seizure, benzodiazepine premedication may result in direct cardiovascular collapse, and skipping signs of central nervous system (CNS) toxicity [38].

The American Society of Regional Anesthesia guidelines recommend that neuraxial regional anesthesia or interventional pain procedures should not be performed in adult patients under general anesthesia or deep sedation. Adults with specific conditions such as developmental delay, or multiple bone trauma, and pediatric patients may be appropriate exceptions to this recommendation. The overall risk of neuraxial anesthesia should be weighed against its expected benefit [5].

Type of Needle

Needle-tip characteristics (long versus short bevel needles), needle design (cut versus blunt tip needles), and needle diameter (large pore versus small pore diameter needles) can influence the likelihood and severity of nerve injury. The location of the needle tip during the injection of the LA has an important role in determining the severity of nerve injury [35, 39]. Needle tip localization during injection should be monitored by peripheral nerve stimulation, injection pressure monitoring, and/or ultrasound guidance. There are no human data to support the superiority of one technique over another with regard to reducing the possibility of nerve injury [5].

Intraneural Injections

Numerous studies have shown that both nerve stimulation (NS) and paraesthesia methods exhibit low sensitivity for nerve localization, with 38.2% sensitivity for paresthesias and 74.5% for motor response to peripheral nerve stimulation (PNS) [28]. Recently, a stimulation current of 0.2 mA or less has been identified as reliable for the detecting intraneural placement of the needle, while currents ranging from 0.2 to 0.5 mA cannot exclude intraneural positioning [29]. Consequently, the absence of a motor response to NS does not rule out the possibility of an intraneural needle position, and attempting to confirm needle position with NS when US indicates that intraneural location could lead to unnecessary attempts at localization. Although the use of US guidance has not been proven to lower the rate of neural complications secondary to peripheral nerve blocks, it has significantly enhanced our understanding of the anatomical findings that facilitate successful nerve blocks to be performed successfully with minimal complications [21].

Continuous Catheter Techniques

Continuous Epidural Catheter Complications of epidural catheter include catheter migration, difficult insertion or removal, a sheared catheter with retained part, and infection. A wide range of complications including abscess, spinal hematoma, radiculopathy, breakage, migration, kinking, and knotting can occur as the catheter is inserted into the epidural space. Breakage of epidural catheters is a rare but worrying complication. Visualization of the retained catheters is difficult, and active surgical intervention might be necessary for the removal of catheter fragments [40]. Various techniques were attempted to remove the trapped epidural catheter, including slow and gentle traction in the lateral position, changing the patient's position, saline flushing, allowing time delay for potential loosening, and radiological evaluation. Finally, the catheter can be successfully removed by introducing prolene suture material into the epidural catheter for reinforcement, then applying gentle traction. While a trapped epidural catheter is uncommon, but it is documented in the literation [41].

Continuous Spinal Catheter The use of continuous spinal anesthesia carries a failure of the technique, difficulty in threading the catheter, especially with the microcatheters (25–32 G), catheter kinking, and a higher risk of PDPH. Additionally, the use of spinal microcatheters has been associated with case reports of cauda equina syndrome and transient neurological deficits [42]. To avoid maldistribution of LA spread towards the sacral segments, this should be ruled out before continuous subarachnoid blocks [5].

Continuous Peripheral Nerve Catheter Apart from difficult catheter insertion, infection, unintentional removal, or failure, traumatic injury during catheter placement and removal has been reported. Improper placement can lead to catheter misplacement or dislodgement, and this may render the catheter ineffective for pain relief. Kinking or knotting may result in difficult removal of the catheter [43].

Continuous Surgical Wound Catheter Accidental catheter removal or migration can lead to insufficient pain relief. Leakage at the insertion site, and from surgical wounds can reduce efficacy, increase tissue irritation, and necrosis, and predispose to localized infection. Prolonged catheterization may predispose to wound dehiscence and reopening of the wound [44].

Continuous Intra-Articular Catheter Intra-articular and subacromial pain pump catheters have been associated with glenohumeral joint chondrolysis, giving peripheral nerve catheters an even more important role in pain management after orthopedic surgery. Like other catheter techniques, it may associated with catheter dislodgement, kinking, obstruction, and leakage. Sepsis with local infection and abscess formation or systemic infection may result after prolonged use [45].

Delayed Recognition of Complications

Early recognition of the injury is very crucial for immediate and timely interventions and to prevent the progression of the injury. Multiple barriers to the early recognition of perioperative nerve injury, including deficits being masked by sedation or analgesics, continuous catheter technique, or the lack of patient ambulation until after hospital discharge [29]. Failure of perioperative monitoring and insufficient postoperative follow-up can lead to late recognition of complications with a higher risk of neuronal injury and long-term damage [46, 47].

Level of Education and Training

An experienced anesthesiologist will carry out a proper preoperative assessment, check the equipment, and perform the procedure, hence improving the success rate [33], while, inexperienced anesthesiologists' lack of training can lead to increased failure rate and risk of complications. Not following protocols and practical guidelines for performing the technique, proper dosages, monitoring and postoperative follow-up, particularly neurological checks may delay diagnosis and treatment of complications [48].

Lack of Communication with the Patient

Good communication with the patient during the procedure is almost important. It is important to maintain verbal communication with the patient throughout the procedure as this is helpful for detecting any signs of systemic or local toxicities at an early stage [38]. To diagnose neurological deficits early, it is crucial to communicate with the patient about the importance of self-observation, as many patients presume postoperative symptoms are normal and do not report them to medical staff [21]. It is important to engage with the patient both before and during the procedure, highlighting the significance of proper positioning and cooperation. Prior to the injection, educate the patient about local infiltration to help alleviate the anxiety regarding pain throughout the procedure [39]. Advise patients to communicate with the physician if they feel uncomfortable or encounter any side effects. Make sure that patients understand the effects of LAs and emphasize that they should tell the physician if any symptoms develop [2, 39].

Specific Risk Factors (Table 1)

The anatomy of peripheral nerves is variable in location and structure, and this increases the susceptibility to nerve injury [11]. Risk factors such as patient's associated comorbidities, preexisting neurologic disorders, inflammatory neuropathies, diabetes, smoking, high body mass index (BMI), long procedures, prolonged tourniquet time, older age, and type of

Table 1 Incidence and risk factors of some neurological deficits following regional anesthesia and pain interventions

Neurological deficit	Incidence	Risk factor
Overall incidence of deficits [5, 9, 22, 28, 48] Permanent neurological deficits	< 1% 0.01–0.03%	Anatomical variations LA neurotoxicity Direct trauma Vascular injury Lack of training Associated comorbidities Preexisting risk factors
Peripheral nerve injuries [5, 9, 22, 28]	2–4/10,000 blocks	Anatomical variations LA neurotoxicity Direct trauma Vascular injury Nerve ischemia Limited access to imaging tools RA in deeply sedated or anesthetized patients Prolonged tourniquet time Intraneural injection Preexisting pathology
Neuraxial neurological deficits: [5, 10, 22, 29] Transient complications Long-lasting Serious neuraxial injuries	0.1–0.4% 0.3–10/10,000 blocks 0–4/10,000	Direct trauma Anatomical variations Musculoskeletal disorders Hematomas Abscess Neurotoxicity Suboptimal surgical positions
Specific neurological deficits: Epidural hematoma [10, 12, 24, 69] Epidural hematoma in obstetrics [10, 12] Epidural hematoma in elderly women [10, 12] Epidural hematoma after epidurals [13, 70] Epidural hematoma after spinals [12, 70]	2/100,000 to 1/140,000–220,000 1:200,000 1:22,000 1 out of 18,000 1 out of 158,000	Unrecognized coagulation disorders Anticoagulation therapy Direct trauma Vascular injury
Epidural abscess [5, 9, 25, 69]	1/40,000 to 1/100,000	Failure to ensure an aseptic technique Immuno-compromised patients

Table 1 continued

Neurological deficit	Incidence	Risk factor
Post-dural puncture headache (PDPH) [10, 26, 27, 71, 72]	0.3– < 3%	Obstetric patients
General	0.8–5%	Young women
Spinal anesthesia in obstetric	4.2%	Needle size
Atraumatic (pencil point) spinal needle	Up to 11%	Needle design
Cut tip (traumatic) spinal needle	50–80%	Multiple trials
Accidental dural puncture by epidural needle		Lack of training
		Prior headache
		Accidental dural puncture
Local anesthetic toxicity: [10, 11, 22, 70, 73]	0.03%, or 0.27 per 1,000 peripheral nerve blocks	Unintentional intravenous injection
Local anesthetic systemic toxicity (LAST)	0.76 cases/10 000 procedures	Accidental vascular puncture
In children		Accidental overdose
In adults		High volume facial plan block
		Continuous catheter techniques
		Intravenous local anesthesia (e.g., iv injection of lidocaine)
Local anesthetic neurotoxicity (LANT) [11, 74]	0.02–0.5%	Higher concentration of LA
		LA infusion for prolonged duration
		LA injected directly into the nerve (e.g., intra-fascicular injection)
		Additives
		Vaso-constrictive
		Toxic solution (e.g. phenol or alcohol)

ADP accidental dural puncture; *LA* local anesthetic; *RA* regional anesthesia

surgery, (e.g., orthopedic surgeries in particular) are all linked to increased risk of neurological injury [5, 28] (Table 1).

Assessments of Neurological Complications After Regional Anesthesia and Pain Interventions:

While the immediate recognition of a neurologic complication in the postoperatively period would strongly implicate a perioperative issue such as surgical, anesthetic, or positioning-related, several barriers can hinder early detection. Postoperative sedation or analgesia may mask the presence of such complications [11, 49, 50].

Barriers to Early Recognition of Neurological Complications Following Regional Anesthesia

Patient and Caregiver Level of Education Patients and caregivers may be unaware and mistakenly attribute postoperative symptoms to the effect of the regional block, delaying further evaluation [10].

Professional and Trained Nurses at PACU To ensure the safe and effective recovery of surgical patients, nurses must be competent in postoperative care. Early detection of complications and adverse effects is possible with proper nurse surveillance. The neurological assessment should initially focus on the level of consciousness, orientation, sensory and motor functions, pupillary size, equivalence, and responsiveness. If the patient has received regional anesthesia (e.g., spinal, epidural), sensory and motor blockade may still occur, and dermatome levels and residual block should be evaluated [49].

Anesthetic Causes Postoperative drowsiness, sedation, or analgesia can obscure or mask the symptoms of neurological complications. Additionally, sedation may interfere with clinical evaluation by suppressing early signs of deficits [21].

Surgical Causes Postoperative factors such as dressings, drains, castings, and activity restrictions can limit patient mobility and mask neurological deficits. These complications may only become evident when normal activity levels are resumed [31, 50].

Multidisciplinary Team Communications Effective neurological consultations often require detailed knowledge of the surgical procedure, regional anesthetic technique, and other intraoperative events, which can hinder accurate diagnosis. Open and direct communication between anesthesia, surgical, and neurology teams is essential for facilitating meaningful evaluation and interventions [11, 49].

Access to Imaging Tools In the setting of neuraxial anesthesia, any concern of spinal cord dysfunction requires emergent neuroimaging [5]. Diagnostic access to advanced diagnostic tools like MRI may be delayed when needed, but computed tomography (CT) can be done instead for rapid, but less detailed, assessment [31, 51]. MRI is the preferred imaging modality. However, imaging should not be delayed to arrange an MRI or to get a neurologic consultation. Computerized tomography or CT myelography is acceptable as initial imaging to exclude a compressive lesion [5].

Electro Physiologic Testing It has the same limitations in being able to adequately access muscles and nerves that may be discriminatory for localization [11, 52]. Both electromyography (EMG) and nerve conduction studies (NCS) may help confirm neuropraxia with conduction block or define preexisting disease when performed acutely. The extent of a perioperative neurogenic injury will be better clarified by electro-diagnostic studies performed 3 weeks after injury [5].

Imaging Tools In most cases of neuraxial injury, MRI is preferable to CT, given its ability to localize the epidural catheter, differentiate soft tissue structures, define neurogenic impingement of adjacent structures (cord or nerve roots), and identify preexisting comorbidities (such as spinal stenosis) [28, 53]. CT of the spine is sufficient to identify space-occupying lesions such as epidural hematoma or abscess which require urgent neurosurgical intervention, but lacks the soft tissue discriminatory sensitivity of MRI. CT or CT myelography is acceptable as initial imaging to exclude a compressive lesion [50, 51].

Monitoring Tools for the Assessment of Neurological Complications

Monitoring tools enhance the patient safety and the overall outcomes of regional anesthesia and pain interventions by reducing the risk of nerve injury and improving the success rates [2, 5].

Peripheral Nerve Stimulation (PNS) versus Ultrasound (US) in Regional Anesthesia (RS) PNS is associated with higher risks of vascular complications such as vascular punctures and LA systemic toxicity and is time-consuming compared to the US. In contrast, the US offers comprehensive visualization of the nerve plexuses and vascular structure, decreasing complications, decreasing block setup, and enhancing patient comfort. Modern portable US technology further improves RA by providing superior image resolution, precise needle guidance, and greater accessibility for practitioners [54].

Recent studies comparing US-guided techniques with nerve stimulation techniques with and without stimulating catheters, indicate that US-guided peripheral nerve catheters are associated with faster placement, reduced patient discomfort, and lower failure rates than those placed with NS [55, 56].

Neurophysiological Studies (EMG and NCS) NCSs are electrophysiological tests whereby a peripheral motor, sensory, or mixed sensorimotor nerve is stimulated, and a recording is made of the motor or sensory response. EMG can help localize the site of a nerve injury as well as assess the severity of the injury and whether recovery is occurring [52]. The Needle is placed into muscles innervated by different spinal roots, pathways through the plexus, and peripheral nerves to identify characteristic electrical changes of neurogenic, myopathic, or neuromuscular transmission disorders. EMG and NCS are complementary to one another and are almost always performed together, and in common practice are referred to collectively simply as EMG [51, 52]. Electrophysiology testing yields its best results 14–21 days after an injury. However, it should be considered immediately if there is a question of pre-existing injury [50, 57] (Table 2).

Prevention of Neurological Complications Following RA and Pain Interventions

Comprehensive preoperative assessment and patient preparations are crucial before any regional anesthetic technique. Physicians must be informed of the potential risks and the mechanisms behind these complications. This can help in their early recognition and prevention of such complications. Appropriate management of complications can ensure patient safety and improve outcomes [5, 11].

Additionally, to understanding the mechanisms of LA-induced neurological damage to prevent chronic toxicity of LA on nerve fibers, physicians should apply LA carefully, especially when it is injected near nerve fibers. The main points are: cautious use at a low concentration (lidocaine should not be used at high concentration, especially adjacent to nerve fibers), and intrathecal continuous infusion should be carefully utilized [38, 58, 59].

Recommendations to minimize the neurological complications following regional anesthesia and pain interventions are shown in Table 3.

Management Strategies of Neurological Complications Following Regional Anesthesia and Pain Interventions

Management of neurological deficits following regional anesthesia requires multidisciplinary and multimodal approaches to ensure optimal outcomes [10, 11]. Once a neurological deficit has been identified, immediate actions should include discontinuing LA infusions, performing an initial clinical examination, obtaining an early neurological consultation for an unbiased diagnosis, ordering diagnostic imaging and neurophysiological studies, and initiating a physical therapy and rehabilitation program [2, 11, 60]. Early recognition is critical and clinicians must remain vigilant and able to identify postoperative symptoms, such as pain, paresthesia, sensory loss, or motor weakness. A thorough assessment is vital and includes detailed history taking, physical examinations, and diagnostic imaging to assess the extent of neurological injury [29, 61, 62].

Once the initial diagnosis has been confirmed, early intervention is the key to ensuring improved outcomes. Administer analgesics and consider corticosteroids if inflammation is suspected.

Initial medical treatment management includes rest, analgesics for pain, and adjuvants such as anxiolytics, muscle relaxants, and corticosteroids when indicated. Neuropathic pain is managed pharmacologically by antidepressants and anticonvulsants guided by the practice guidelines [5, 62]. Corticosteroids are beneficial if significant inflammation is suspected or spinal cord injury resulting from direct trauma or interventional pain procedure. However, corticosteroids carry the risk of hyperglycemia, which can exacerbate ischemic brain injury. Collaborations with neurologists, neurosurgery, physical therapists, and rehabilitation specialists are essential to develop effective multidisciplinary team management [29].

In severe cases, neurosurgical interventions may be necessary for surgical decompression (e.g., epidural hematomas or abscesses) or when there is evidence of nerve injury.

Table 2 Comparison of different monitoring modalities during regional anesthesia and pain intervention

Device	Effectiveness in early detection	Advantages	Limitations	Uses
Ultrasound (US) guidance [2, 22, 54, 56]	Highly effective	Real-time and direct visualization of nerves, vessels, and needle placement; reduces risk of direct trauma and vascular injection US remains the most effective intraoperative tool	Operator-dependent; requires training	Peripheral nerve blocks, neuraxial anesthesia
Nerve stimulation (NS) [23–25, 55, 56]	Moderately effective	Helps confirm needle proximity to nerves; useful when US is unavailable	Less precise than US; does not prevent intraneural injection	Peripheral nerve blocks (as an adjunct to US)
X-ray (fluoroscopy) guidance [5, 11, 28, 51, 53]	Moderately effective	Provides real-time imaging of bony landmarks and contrast injection verification Fluoroscopy is useful for neuraxial and pain interventions	Lacks soft tissue and nerve visualization making it inferior to US for nerve visualization; risk of radiation exposure	Epidural steroid injections, facet joint injections
Injection pressure monitoring (IPM) [9, 11, 52]	Effective for preventing nerve injury	Alerts to excessive resistance, reducing risk of intrafascicular injection. It serves as valuable adjuncts	Does not provide anatomical visualization	Peripheral nerve blocks (adjunct to US/NS)
Electromyography (EMG) [11, 28, 51, 52, 57]	Effective for early postoperative detection	Detects early signs of nerve injury; useful for tracking recovery	Not useful intraoperatively; requires specialized expertise	Postoperative neurological assessment
Nerve conduction studies (NCS) [11, 28, 52, 53, 57]	Useful for confirming deficits	Identifies conduction block vs. axonal damage; helps differentiate causes of deficits	Delayed detection (best after 2–3 weeks); limited immediate utility. It does not assist during the procedure itself	Postoperative evaluation of nerve function

Table 3 Recommendations to minimize the neurological complications following regional anesthesia and pain interventions

General [10, 67, 75, 64, 65]	Adopt evidence-based practices and updated guidelines Obtain adequate history and careful patient selection Pre-procedure assessment and physical examination Obtaining informed written consent before any procedure Document the type and the dose of the LA used Proper documentation of the procedure, medication, and technique Pre-procedure safety checklist Have emergency drugs available to manage adverse effects Improving documentation including any potential side effects or complications
Local anesthetics [5, 9, 38, 67, 75]	Fractionated injections Start by the smallest volume and lowest effective dose Avoid injection of a bolus without an aspiration test Start by injecting a test dosing Make injections slowly to avoid inadvertent IV Choose your local anesthetic solution wisely Add epinephrine at a ratio of 1:200,000 to slow vascular uptake, unless it is contraindicated Consider neurologic signs or symptoms as a manifestation of anesthetic toxicity
Needles [11, 38, 64]	Use short bevel insulated needles Needles of appropriate length and diameter for each block technique Slowly needle advancement Avoid needle or catheter placement without imaging devices
Technique [5, 9, 38, 67]	Accurate localization of the nerve by using tools such as nerve stimulators and US Strict aseptic technique Avoidance of forceful, and fast injections Avoidance of injection against abnormal resistance Be careful when injecting around vessel-rich regions Abort injection if the patient reported pain Avoid performing blocks in anesthetized or deeply sedated patients Repeat the technique blocks after a failed block Maintain verbal communication with the patient
Monitoring [9, 38, 53, 67, 75]	Emphasize the routine use of imaging techniques like US and fluoroscopy Monitoring of the injection pressure Blood pressure monitoring during neuraxial techniques Maintain verbal communication with the patient Describe the early symptoms of local anesthetic toxicity to patients Instruct patients to inform the physician if they experience any uneasiness Postoperative monitoring and continuous follow-up

Table 3 continued

Education and Training [5, 38]	Education, and simulation training for anesthesiologists Hand-on workshops on cadavers and live scenarios Full orientation by landmarks and surface anatomy Regular auditing and feedback

Outcomes for compressive lesions (epidural hematoma or spinal epidural abscess) are dependent on the severity of neurologic impairment and the duration of symptoms at the time of neurosurgical decompression. Most experts agree that neurologic recovery is improved with early decompression (< 8–12 h from symptom onset in epidural hematoma and < 36 h from symptoms onset for spinal epidural abscess) [5, 61]. Patients with persistent deficits may require physical and rehabilitation programs, including physical and occupational therapy, to enhance outcomes and improve the quality of life. Collaborations with neurologists, neurosurgery, physical therapists, and rehabilitation specialists are essential to develop effective multidisciplinary team management [5, 63]. Additionally, proper documentation of the incident thoroughly is vital to help for future management and enhance the quality of care and patient safety [5, 61].

DISCUSSION

Regional anesthesia plays a crucial role in effective pain relief, reducing opioid consumption, and significantly contributing to enhanced recovery after surgery [2, 5]. Despite advancements in imaging technology and improved anesthetic techniques, neurological deficits following RA and pain interventions remain a significant concern. This comprehensive review emphasizes the importance of strict adherence to clinical practice guidelines and a proactive approach in RA and pain interventions to ensure patient safety and optimal outcomes. Notably, the majority of these complications are preventable with rigorous compliance with established protocols [9, 29].

Moreover, the manuscript highlights the multifactorial etiology of neurological complications associated with RA and pain interventions, including patient, anesthetic, and surgical factors. Furthermore, the main mechanisms of neurological injury include mechanical trauma, vascular compromise, LA-induced toxicity, and inflammatory responses. Fortunately, most of these neurological complications are preventable and appear to resolve with time. While the overall incidence of severe and long-term neurologic complications remains low, even transient complications can significantly impact the patient recovery and the quality of life [10, 29].

Understanding the mechanisms behind these complications and implementing preventive measures can enhance patient safety and improve patient outcomes following RA and pain interventions. While deviations from established clinical guidelines and technical errors significantly contribute to the risk of neurological injuries. Improper patient selection, inadequate patient assessments, failure to utilize imaging guidance, and technical errors during procedure are the key risk factors for complications. Additionally, other factors such as pre-existing neuropathies, patient positioning during surgery, orthopedic procedures, and prolonged tourniquet time can exacerbate neurological complications [64–66].

Effective preventive strategies also involve proper patient selection, comprehensive preoperative assessment, and adherence to clinical guidelines are essential for reducing the possible risks of complications. Proper utilization of the imaging tools such as US, nerve stimulator or fluoroscopic guidance enhances accuracy of the needle placement, minimizes direct nerve trauma, and reduces the risk of intravascular injections. Direct communications with the patient and continuous monitoring during RA and pain procedures, helps in early detection of neurological symptoms, and allowing for immediate intervention. Additionally, appropriate training and continuous education can significantly improve the skill of the anesthesiologists. Moreover, regular follow-up and continuous auditing of clinical practices, can improve overall outcomes in regional anesthesia and pain interventions [38, 53, 67, 68].

Limitations

This narrative review compiles relative studies, but does not include systematic quantitative synthesis or meta-analysis with pooled statistics. Performing meta-analysis could enhance a more understanding of the true incidence and risk factors associated with neurological complications. While the review broadly examines various complications and preventive strategies, it lacks a detailed analysis of specific risk factors or mechanisms. Additionally, the article offers a broad set of preventive strategies, but lacks the specific challenges of the high-risk groups, such as elderly patients with multiple comorbidities, including patients with diabetes and diabetic neuropathies or those with pre-existing neurological and musculoskeletal deficits.

Furthermore, this review relies solely on published articles, which may have introduced publication bias. This may include studies vary in methodology, patient populations, and outcome measures, making it difficult to generalize findings. Another limitation is related to data on long-term functional recovery and quality of life following neurological complications, which deserves further investigations.

CONCLUSION

The most effective strategy for preventing neurological complications associated with regional anesthesia and pain interventions is strict adherence to evidence-based clinical guidelines. Key preventive measures include appropriate patient selection, comprehensive preoperative assessments, proper utilization of the imaging tools, and continuous monitoring of the patients. Additionally, early recognition of neurological deficits is crucial for immediate interventions and improved patient outcomes. Effective management of neurological deficits requires multidisciplinary teamwork, including anesthesiologists or pain specialists, neurologists, physical therapists, and rehabilitation programs to enhance patient safety and ensure optimal recovery.

ACKNOWLEDGEMENTS

Authorship. All authors meet the International Committee of Medical Journal Editors (ICMJE) criteria for authorship for this article.

Medical Writing and Editorial Assistance. The authors would like to acknowledge Jo Ann K LeQuang (NEMA Research, Inc., Naples, FL, USA) for her valuable contribution in reviewing and editing the manuscript. They also extend their gratitude to Fahriziya T Dahum, RN, (King Khalid University Hospital, Riyadh, Saudi Arabia), for her assistance in reviewing and editing the section on the nursing role in patient monitoring and management. No financial compensation was provided.

Author Contributions. All authors reviewed the results and approved the final version of the manuscript. Salah N. El-Tallawy (Corresponding Author): concept and design, writing, searching, and supervision for all steps. Rania S. Ahmed: searching, study screening, editing, and approving the final copy. Gehan I Salem: Help in writing and editing. Performing physical therapy and rehabilitation part, and approving the final copy. Tariq A Alzahrani: Editing, reviewing the manuscript, supervising the other parts on regional anesthesia, and approving the final copy. Mamdouh M. Haddara: design, searching, supervising the part on pain interventions, and approving the final copy. Radwa H. Ahmed: Searching, writing, editing, and approving the final copy. Mohamed S. Nagiub: searching, study screening, editing, and approving the final copy. Abdullah T. Alsubaie: Searching, writing, and approving the final copy. Mohamed M

Aly: Searching, writing, and approving the final copy. Mahmoud M Elbasha: Searching, writing, and approving the final copy. Ahmed A. Ahmed: Searching, writing, and approving the final copy.

Funding. No funding or sponsorship was received for this study or publication of this article.

Data Availability. Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Conflict of Interest. All authors (Salah N. El-Tallawy, Rania S. Ahmed, Gehan I. Salem, Tariq A. Alzahrani, Mamdouh M. Haddara, Radwa H. Ahmed, Mohamed S. Nagiub, Abdullah T. Alsubaie, Mohamed M. Ali, Mahmoud M. Elbasha, and Ahmed A. Ahmed) declare no conflict of interest.

Ethical Approval. This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

REFERENCES

1. Macías AA, Finneran JJ. Regional anesthesia techniques for pain management for laparoscopic surgery: a review of the current literature. Curr Pain Headache Rep. 2022;26(1):33–42. https://doi.org/10.1007/s11916-022-01000-6.

2. EL-Tallawy SN, Pergolizzi JV, Albasher MJ, Alghamdi NS, Salem GI, Ahmed RS, KaKi AM, Thallaj AK, Alwahabi AH, Amer AM, Ahmed RH. Non-adherence to clinical practice guidelines in regional anesthesia and pain interventions: insights from a comprehensive case series review. Cureus. 2024;16(12): e75847. https://doi.org/10.7759/cureus.75847.

3. Hutton M, Brull R, Macfarlane AJR. Regional anaesthesia and outcomes. BJA Educ. 2018;18(2):52–6. https://doi.org/10.1016/j.bjae.2017.10.002. (**Epub 2017 Nov 27. PMID: 33456810; PMCID: PMC7807931**).

4. Chitnis SS, Tang R, Mariano ER. The role of regional analgesia in personalized postoperative pain management. Korean J Anesthesiol. 2020;73(5):363–71. https://doi.org/10.4097/kja.20323. (**Epub 2020 Aug 5. PMID: 32752602; PMCID: PMC7533178**).

5. Neal JM, Barrington MJ, Brull R, et al. The second ASRA practice advisory on neurologic complications associated with regional anesthesia and pain medicine: executive summary 2015. Reg Anesth Pain Med. 2015;40(5):401–30. https://doi.org/10.1097/AAP.0000000000000286.

6. Agarwal A, Kishore K. Complications and controversies of regional anaesthesia: a review. Indian J Anaesth. 2009;53(5):543–53 (**PMID: 20640104; PMCID: PMC2900086**).

7. Alastair D, Santosh P. Neurological complications in obstetric regional anesthetic practice. J Obstet Anaesth Crit Care. 2016;6(1):3–10. https://doi.org/10.4103/2249-4472.181055.

8. Fettes PDW, Wildsmith JAW. Cruel to be kind? Regional block before or after induction of general anaesthesia. Curr Anaesth Crit Care. 2003;13:287–92. https://doi.org/10.1054/cacc.2002.0423.

9. Bais K, Guirguis F, Guirguis M. Nerve injury following regional nerve block: a literature review of its etiologies, risk factors, and prevention. Curr Pain Headache Rep. 2024;28:863–8. https://doi.org/10.1007/s11916-024-01268-w.

10. Radkowski P, Fadrowska-Szleper M, Podhorodecka K, Mieszkowski M. Neurological complications of regional anesthesia: an updated review

with clinical guidelines. Med Sci Monit. 2023;29: e940399. https://doi.org/10.12659/MSM.940399.

11. Watson JC, Huntoon MA. Neurologic evaluation and management of perioperative nerve injury. Reg Anesth Pain Med. 2015;40:491–501. https://doi.org/10.1097/AAP.0000000000000185.

12. Moen V, Dahlgren N, Irestedt L. Severe neurological complications after central neuraxial blockades in Sweden 1990–1999. Anesthesiology. 2004;101:950–9.

13. Lee JH, Lee JK, Seo BR, Moon SJ, Kim JH, Kim SH. Spinal cord injury produced by direct damage during cervical transforaminal epidural injection. Reg Anesth Pain Med. 2008;33:377–9.

14. Benzon HT, Chew TL, McCarthy R, Benzon HA, Walega DR. Comparison of the particle sizes of the different steroids and the effect of dilution: a review of the relative neurotoxicities of the steroids. Anesthesiology. 2007;106:331–8.

15. Rathmell JP, Michna E, Fitzgibbon DR, Stephens LS, Posner KL, Domino KB. Injury and liability associated with cervical procedures for chronic pain. Anesthesiology. 2011;114:918–26.

16. Kennedy DJ, Plastaras C, Casey E, et al. Comparative effectiveness of lumbar transforaminal epidural steroid injections with particulate versus nonparticulate corticosteroids for lumbar radicular pain due to intervertebral disc herniation: a prospective, randomized, double-blind trial. Pain Med. 2014;15:548–55.

17. Forget P, Borovac JA, Thackeray EM, Pace NL. Transient neurological symptoms (TNS) following spinal anaesthesia with lidocaine versus other local anaesthetics in adult surgical patients: a network meta-analysis. Cochrane Database Syst Rev. 2019;12(12):CD003006. https://doi.org/10.1002/14651858.CD003006.

18. Verlinde M, Hollmann MW, Stevens MF, Hermanns H, Werdehausen R, Lirk P. Local anesthetic-induced neurotoxicity. Int J Mol Sci. 2016;17(3):339. https://doi.org/10.3390/ijms17030339. (**PMID: 26959012; PMCID: PMC4813201**).

19. Nouette-Gaulain K, Capdevila X, Rossignol R. Local anesthetic in-situ toxicity during peripheral nerve blocks: update on mechanisms and prevention. Curr Opin Anaesthesiol. 2012;25:589–95.

20. Werdehausen R, Fazeli S, Braun S, Hermanns H, Essmann F, Hollmann MW, et al. Apoptosis induction by different local anaesthetics in a neuroblastoma cell line. Br J Anaesth. 2009;103:711–8. https://doi.org/10.1093/bja/aep236.

21. Sakura S, Kirihara Y, Muguruma T, Kishimoto T, Saito Y. The comparative neurotoxicity of intrathecal lidocaine and bupivacaine in rats. Anesth Analg. 2005;101:541–7. https://doi.org/10.1213/01.ANE.0000155960.61157.12.

22. Jeng CL, Torrillo TM, Rosenblatt A. Complications of peripheral nerve blocks. Br J Anaesth. 2010;105(S1):i97–107. https://doi.org/10.1093/bja/aeq273.

23. Neal JM, Hebl JR, Gerancher JC, Hogan QH. Brachial plexus anesthesia; essentials of our current understanding. Reg Anesth Pain Med. 2002;27:4002–8.

24. Fredrickson MJ, Kilfoyle DH. Neurological complication analysis of 1000 ultrasound guided peripheral nerve blocks for elective orthopaedic surgery: a prospective study. Anaesthesia. 2009;64:836–44.

25. Lupu CM, Kiehl TR, Chan VW, et al. Nerve expansion seen on ultrasound predicts histologic but no functional nerve injury after intraneural injection in pigs. Reg Anesth Pain Med. 2010;35:132–9.

26. Mims SC, Tan HS, Sun K, Pham T, Rubright S, Kaplan SJ, Habib AS. Long-term morbidities following unintentional dural puncture in obstetric patients: a systematic review and meta-analysis. J Clin Anesth. 2022;79: 110787. https://doi.org/10.1016/j.jclinane.2022.110787.ISSN0952-8180.

27. Schyns-van den Berg AMJV, Lucas DN, Leffert LR. Postdural puncture headache: beyond the evidence. Best Pract Res Clin Anaesthesiol. 2024;38(3):267–77. https://doi.org/10.1016/j.bpa.2024.11.004.

28. Probasco J, Sahin B, Tran T, Chung TH, Rosenthal LS, Mari Z, Levy M. The preoperative neurological evaluation. Neurohospitalist. 2013;3(4):209–20. https://doi.org/10.1177/1941874413476042. (**PMID: 24198903; PMCID: PMC3810828**).

29. Neal JM, Woodward CM, Harrison TK. The American Society of Regional Anesthesia and pain medicine checklist for managing local anesthetic systemic toxicity: 2017 version. Reg Anesth Pain Med. 2018;43(2):150–3.

30. Doan LV, Blitz J. Preoperative assessment and management of patients with pain and anxiety disorders. Curr Anesthesiol Rep. 2020;10(1):28–34. https://doi.org/10.1007/s40140-020-00367-9. (**Epub 2020 Jan 10. PMID: 32435161; PMCID: PMC7222996**).

31. Shaydakov ME, Tuma F. Operative risk. [Updated 2023 May 2]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024. https://www.ncbi.nlm.nih.gov/books/NBK532240/

32. Chaudhary F, Ahmed Z, Agrawal DK. Critical assessment of the neurological complications during high-risk anesthesia procedures. J Surg Res (Houst). 2024;7(2):250–66 (**Epub 2024 Jun 6. PMID: 38947250; PMCID: PMC11213287**).

33. William B, Shukri K, Maureen P, Kwan H, William H, John D, Jennifer D. Identifying patient preoperative risk factors and postoperative adverse events in administrative databases: results from the department of veterans affairs national surgical quality improvement program. J Am Coll Surg. 2002;194:257–66. https://doi.org/10.1016/S1072-7515(01)01183-8.

34. Parikh KS, Seetharamaiah S. Approach to failed spinal anaesthesia for caesarean section. Indian J Anaesth. 2018;62(9):691–7. https://doi.org/10.4103/ija.IJA_457_18. (**PMID: 30237594; PMCID: PMC6144559**).

35. Guay J, Suresh S, Kopp S. The use of ultrasound guidance for perioperative neuraxial and peripheral nerve blocks in children. Cochrane Database Syst Rev. 2019;2:CD011436. https://doi.org/10.1002/14651858.CD011436.pub3.

36. Armin S. Positioning injuries in anesthesia: an update. Adv Anesth. 2008;26:31–65. https://doi.org/10.1016/j.aan.2008.07.009.

37. Vieira EM, Goodman S, Tanaka PP. Anesthesia and rheumatoid arthritis. Rev Bras Anestesiol. 2011;61:367–75. https://doi.org/10.1016/S0034-7094(11)70044-7.

38. Marhofer P. Regional blocks carried out during general anesthesia or deep sedation: myths and facts. Curr Opin Anaesthesiol. 2017;30:621–6. https://doi.org/10.1097/ACO.0000000000000504.

39. Horlocker TT, Abel MD, Messick JM Jr, Schroeder DR. Small risk of serious neurologic complications related to lumbar epidural catheter placement in anesthetized patients. Anesth Analg. 2003;96(6):1547–52. https://doi.org/10.1213/01.ANE.0000057600.31380.75.

40. Sekimoto K, Tobe M, Saito S. Local anesthetic toxicity: acute and chronic management. Acute Med Surg. 2017;4(2):152–60. https://doi.org/10.1002/ams2.265. (**PMID: 29123854; PMCID: PMC5667269**).

41. Fettes PD, Jansson JR, Wildsmith JA. Failed spinal anaesthesia: mechanisms, management, and prevention. Br J Anaesth. 2009;102:739–48. https://doi.org/10.1093/bja/aep096.

42. Hippalgaonkar AV, Kudalkar AG, Gaikwad SM, Modak S, Gupta HB, Tendolkar BA. Successful management of a broken epidural catheter. Saudi J Anaesth. 2017;11(2):228–31. https://doi.org/10.4103/1658-354X.203029. (**PMID: 28442966; PMCID:PMC5389246**).

43. Suvarna K, Anusha LJ, Illickal AA, Arjun A. Strategies to overcome a stuck epidural catheter: a case report. JCA Adv. 2024;1(3–4):100062. https://doi.org/10.1016/j.jcadva.2024.100062. (**ISSN 2950-5534**).

44. Beh ZY, Au Yong PS, Lye S, Eapen SE, Yoong CS, Woon KL, Cheng Lim JG. Continuous spinal anaesthesia: a retrospective analysis of 318 cases. Indian J Anaesth. 2018;62(10):765–72. https://doi.org/10.4103/ija.IJA_387_18. (**PMID: 30443059; PMCID: PMC6190429**).

45. Horlocker TT. Complications of regional anesthesia. Eur J Pain Suppl. 2010;4(4):227–34. https://doi.org/10.1016/j.eujps.2010.09.019. (**ISSN 1754-3207**).

46. El Tallawy SN, Ali WA, Thallaj AK, Ahmed RS, Manaa EM, Mostafa MS, Aljasser FF, Amlih HF, Hassanin AA. Comparative study between surgical wound catheter, femoral nerve block, and adductor canal block for postoperative analgesia after knee arthroplasty: a double blind randomized clinical trial. Saudi J Anesth. 2023;17(3):359–67. https://doi.org/10.4103/sja.sja_894_22.

47. Anderson SL, Buchko JZ, Taillon MR, Ernst MA. Chondrolysis of the glenohumeral joint after infusion of bupivacaine through an intra-articular pain pump catheter: a report of 18 cases. Arthroscopy. 2010;26:451–61.

48. Marino J, Sikachi RR, Ramkumar PN, et al. Discharge from the postanesthesia care unit with motor blockade after spinal anesthesia safely optimizes fast track recovery in primary total hip and knee arthroplasty. J Arthroplasty. 2024;39(1):44–8. https://doi.org/10.1016/j.arth.2023.06.038.

49. Christie IW, McCabe S. Major complications of epidural analgesia after surgery: results of a six-year survey. Anaesthesia. 2007;62:335–41.

50. Drasner K. Spinal anaesthesia: a century of refinement, and failure is still an option. Br J Anaesth. 2009;102(6):729–30. https://doi.org/10.1093/bja/aep085. (**ISSN 0007-0912**).

51. Mert S. The significance of nursing care in the post-anesthesia care unit and barriers to care. Intensive Care Res. 2023;3:272–81. https://doi.org/10.1007/s44231-023-00052-5.

52. Neal JM. ASRA practice advisory on neurologic complications associated with regional anesthesia. Rev Mex Anesth. 2019;42(Suppl 1):244–7.

53. Hussain S, Mubeen I, Ullah N, Shah SSUD, Khan BA, Zahoor M, Ullah R, Khan FA, Sultan MA. Modern diagnostic imaging technique applications and risk factors in the medical field: a review. Biomed Res Int. 2022;2022:5164970. https://doi.org/10.1155/2022/5164970.

54. Jepsen JR. Clinical neurological examination vs electrophysiological studies: reflections from experiences in occupational medicine. World J Methodol. 2015;5(2):26–30. https://doi.org/10.5662/wjm.v5.i2.26.

55. Watson JC, Huntoon MA. Neurologic evaluation and management of perioperative nerve injury. Reg Anesth Pain Med. 2015;40:491–501.

56. Matthew B. Development of guidelines for early implementation of regional anesthesia in united states personnel with peripheral injuries. Doctor of Nursing Practice Scholarly Projects; 2023. https://digitalcommons.otterbein.edu/stu_doc/109

57. Mariano ER, Loland VJ, Bellars RH, et al. Ultrasound guidance versus electrical stimulation for infraclavicular brachial plexus perineural catheter insertion. J Ultrasound Med. 2009;28:1211–8.

58. Fredrickson MJ, Ball CM, Dalgleish AJ. A prospective randomized comparison of ultrasound guidance versus neurostimulation for interscalene catheter placement. Reg Anesth Pain Med. 2009;34:590–4.

59. Kopp SL, Jacob AK, Hebl JR. Regional anesthesia in patients with preexisting neurologic disease. Reg Anesth Pain Med. 2015;40:467–78.

60. Kent CD, Bollag L. Neurological adverse events following regional anesthesia administration. Local Reg Anesth. 2010;3:115–23. https://doi.org/10.2147/LRA.S8177.

61. NYSORA: Neuraxial anesthesia techniques. https://www.NYSORA.com/topics/abdomen/epidural-anesthesia-analgesia/. Accessed November 17, 2024.

62. Schug SA, Palmer GM, Scott DA, Alcock M, Halliwell R, Mott JF; APM:SE Working Group of the Australian and New Zealand College of Anaesthetists and Faculty of Pain Medicine. Acute pain management: scientific evidence. 5th ed. Melbourne: ANZCA & FPM; 2020. https://www.anzca.edu.au/resources/college-publications/acute-pain-management/apmse5.pdf

63. Sorenson EJ. neurological injuries associated with regional anesthesia. Reg Anesth Pain Med. 2008;33(5):442–8. https://doi.org/10.1016/j.rapm.2005.08.011.

64. Neal JM. ASRA practice advisory on neurologic complications associated with regional anesthesia. Rev Mex Anestesiol. 2019;42(Suppl. 1):S244–7.

65. World Health Organization: WHO Surgical Safety Checklist. World Health Organization safe surgery saves lives starter kit for surgical checklist implementation version 1.0; 2009. https://www.who.int/teams/integrated-health-services/patient-safety/research/safe-surgery/tool-and-resources. Accessed April 2

66. Singh G, Patel RH, Vaqar S, et al. Root cause analysis and medical error prevention. [Updated 2024 Feb 12]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025. https://www.ncbi.nlm.nih.gov/books/NBK570638/

67. Davidson VL, McGrath MC, Navarro S. Preventing local anesthetic systemic toxicity after administration of long-acting local anesthetics. AORN J. 2024;119(2):164–8. https://doi.org/10.1002/aorn.14085.

68. Cohen SP, Bhaskar A, Bhatia A, et al. Consensus practice guidelines on interventions for lumbar facet joint pain from a multispecialty, international working group. Reg Anesth Pain Med. 2020;45:424–67. https://doi.org/10.1136/rapm-2019-101243.

69. Bos EM, van der Lee K, Haumann J, de Quelerij M, Vandertop WP, Kalkman CJ, Hollmann MW, Lirk P. Intracranial hematoma and abscess after neuraxial analgesia and anesthesia: a review of the literature describing 297 cases. Reg Anesth Pain Med. 2021;46(4):337–43. https://doi.org/10.1136/rapm-2020-102154.

70. Liu H, Brown M, Sun L, et al. Complications and liability related to regional and neuraxial anesthesia. Best Pract Res Clin Anaesthesiol. 2019;33(4):487–97. https://doi.org/10.1016/j.bpa.2019.07.007.

71. Costa AC, Satalich JR, Al-Bizri E, Shodhan S, Romeiser JL, Adsumelli R, Abola RE, Steinberg ES, Bennett-Guerrero E. A ten-year retrospective study of post-dural puncture headache in 32,655 obstetric patients. Can J Anaesth. 2019;66(12):1464–71. https://doi.org/10.1007/s12630-019-01486-6.

72. Uppal V, Russell R, Sondekoppam RV, Ansari J, Baber Z, Chen Y, DelPizzo K, Dirzu DS, Kalagara H, Kissoon NR, Kranz PG, Leffert L, Lim G, Lobo C, Lucas DN, Moka E, Rodriguez SE, Sehmbi H, Vallejo MC, Volk T, Narouze S. Evidence-based clinical practice guidelines on postdural puncture headache: a consensus report from a multisociety international working group. Reg Anesth Pain Med. 2024;49(7):471–501. https://doi.org/10.1136/rapm-2023-104817.

73. El-Boghdadly K, Pawa A, Chin KJ. Local anesthetic systemic toxicity: current perspectives. Local Reg Anesth. 2018;11:35–44. https://doi.org/10.2147/LRA.S154512.

74. Kim EJ, Kim HY, Ahn JH. Neurotoxicity of local anesthetics in dentistry. J Dent Anesth Pain Med. 2020;20(2):55–61. https://doi.org/10.17245/jdapm.2020.20.2.55. (**Epub 2020 Apr 27. PMID: 32395610; PMCID: PMC7193059**).

75. Verlinde M, Hollmann MW, Stevens MF, Hermanns H, Werdehausen R, Lirk P. Local anesthetic-induced neurotoxicity. Int J Mol Sci. 2016;17:339. https://doi.org/10.3390/ijms17030339.