Regional Anesthesia and Analgesia for Acute Trauma Patients

Ron E. Samet, MD[a,*], Elisabeth B. Powelson, MD, MSc[b], Christopher R. Parrino, MD[c], Ian R. Slade, MD[d]

KEYWORDS

• Trauma • Trauma pain • Analgesia • Regional anesthesia • Peripheral nerve block • Injury

KEY POINTS

- Peripheral nerve blockade (PNB) skills are increasingly being taught to prehospital, emergency medicine, and acute care providers with direct benefit to acute trauma patients.
- Compared to traditional analgesic modalities, PNB provides trauma patients with superior acute pain relief targeted to the site(s) of injury.
- PNB use in trauma may decrease morbidity and mortality, promote favorable surgical outcomes, and decrease length of stay in some circumstances.
- PNB decreases acute opioid use, avoiding related side effects, important for patient safety and comfort.

INTRODUCTION

The role of regional anesthesia in the injured patient has grown exponentially in the last decade. Rapid advancements in techniques and nerve localization via high-fidelity ultrasound combined with a proliferation of online educational materials, enhanced curricula, and simulation have made learning peripheral nerve blockade (PNB) more accessible.[1,2] Regional anesthetics have become an integral component of many enhanced recovery after surgery protocols,[3] and by extension are now gaining popularity in what we will term Enhanced Treatment and Recovery After Injury (ETRAI) algorithms.[4,5]

[a] Division of Trauma Anesthesia, R Adams Cowely Shock Trauma Center, University of Maryland School of Medicine, 22 South Greene Street, Baltimore, MD 21201, USA; [b] Department of Anesthesiology, Harborview Medical Center, 4225 Roosevelt Way Northeast, Box 354692, Seattle, WA 98015, USA; [c] Department of Anesthesiology, University of Maryland Medical Center, 22 South Greene Street, Baltimore, MD 21201, USA; [d] Department of Anesthesiology, Harborview Medical Center, 325 9th Avenue, Box 359724, Seattle, WA 98104, USA
* Corresponding author.
E-mail address: rsamet@som.umaryland.edu

Anesthesiology Clin 43 (2025) 707–738
https://doi.org/10.1016/j.anclin.2025.07.009 **anesthesiology.theclinics.com**

Abbreviations	
ACS	acute compartment syndrome
ATLS	advanced trauma life support
ED	emergency department
EMS	emergency medical service
ETRAI	enhanced treatment and recovery after injury
PENG	pericapsular nerve group
PLP	phantom limb pain
PNB	peripheral nerve blockade
TEA	thoracic epidural analgesia

Military trauma care units, in particular, employ PNB to deliver targeted limb analgesia and enable surgical interventions in resource-scarce environments, often while preserving airway patency, mental status, and hemodynamics.[6,7] The superior stability and patient comfort permit easier evacuation of wounded patients to higher levels of care.[8,9] Since the turn of the millennium, new techniques and more ubiquitous use of ultrasound guidance across multiple subspecialities have reinvigorated the role of targeted PNB in civilian trauma care. Anesthesiologists, prehospital providers, advanced practice nurses, and physicians in the emergency department (ED), and trauma bays have employed these techniques with remarkable safety, precision, and efficacy, forming the basis of ETRAI protocols for combat and civilian trauma management.[10–16] Scala and colleagues reviewed 12 regional anesthesia protocols for hip fracture patients with detailed descriptions to promote nerve blocks in the multimodal treatment and recovery for fractured hips.[5] Impressive case reports such as the administration of erector spinae blocks in prehospital and retrieval medicine or interscalene brachial plexus, popliteal sciatic, and fascia iliaca blocks during cave rescue missions showcase the far-reaching analgesic potential ultrasound-guided regional anesthesia provides injured patients.[17,18]

Anecdotal evidence and small case reports have inspired larger studies to evaluate benefits of regional anesthesia beyond acute analgesia in the trauma population. Aside from standard metrics such as pain scores, total opioid consumption, and hospital length of stay, newer data seek to elucidate clinically important measures such as patient satisfaction, rebound pain after resolution of PNB, ease of fracture reduction, functional surgical outcomes, ability to detect early symptoms of acute compartment syndrome, differences in the development of chronic pain post injury and/or post surgery, and most impactfully, morbidity and mortality outcome differences.[19–22] It remains an opportune time for further clinical research to better delineate block-specific PNB indications with optimal technique modifications to improve safety and patient outcomes. This article will review the current literature and discuss future directions of regional anesthesia in the acute trauma patient.

ADVANTAGES OF REGIONAL ANESTHETIC TECHNIQUES

Analgesia

The most recognized indication for regional anesthesia in trauma patients is to provide acute pain relief and/or dense anesthesia to a specific injured area of the body. Rapid and sometimes complete pain relief achieved via regional block provides compassionate analgesia, often enables timely bedside examination, wound exploration, and fracture and dislocation reduction and is reported to be safer with shorter length of stays than traditional approaches using systemic opioids and sedatives.[20,23,24] Anecdotally, patients, bedside trauma nurses, and emergency medicine, trauma, and orthopedic physicians all laud implementation of short acting PNB when clinically

feasible to alleviate pain and facilitate injury stabilizing interventions. However, the superiority of PNB analgesia over systemic medications is appropriately challenged when, for example, patients experience rebound pain following cessation of short-acting blocks and ironically require increased opioids 24 to 48 hours after block resolution or when dense long-acting local anesthetics impair early physical therapy goals.[25,26] Thus, an emphasis on multimodal analgesic regimens with regional anesthesia technique as just one of numerous modalities is essential for patient care. Thoughtful applications and adaptations of PNB dosing and technique with attention to primary and secondary outcomes, both positive and negative, should be the focus of future data and dictate best practice.[27]

Secondary Benefits

Despite a lack of large population data, trauma teams are expanding use of PNB techniques, believing that the benefits of selected blocks outweigh risks of systemic analgesics for certain patients. As safe, teachable, and generally reproducible interventions that require little time to perform, PNB can provide excellent analgesia without disruptions in hemodynamics or respiratory status. Gawel and colleagues reported on 5 studies that compared procedural sedation and analgesia versus ultrasound-guided PNB for shoulder dislocations in the emergency department and found a remarkably lower risk of adverse events (3.9% vs 24.9%; $P<.001$), especially respiratory complications (0% vs 14.7%; $P<.001$), in the PNB group.[20] Arguably, these findings are due to lower opioid and systemic sedation requirements for the closed shoulder reductions. Similarly, a recent meta-analysis reviewed procedural sedation and analgesia versus PNB for 256 patients who underwent reduction of fractures and dislocations in the emergency department and found fewer adverse events and shorter lengths of stay in the PNB group.[28] In austere environments, regional anesthesia plays an even more significant role in reducing resource-heavy and costly general anesthesia, systemic medications, and time to patient readiness for transport.[29]

Other secondary benefits may not be as scientifically proven. For example, in our experience, PNB facilitates a technically easier reduction of fracture dislocations owing to the induced temporary flaccid muscle paralysis compared to intravenous sedation often provided in the emergency room setting. However, there are currently no large data sets that prove this finding. Older studies suggesting that early PNB can reduce the incidence and severity of chronic post-traumatic pain syndromes[30,31] are being questioned by newer data[32,33] with a request for more rigorous scientific testing.[27] Likewise, while sympathetic inhibition and an indirect decrease in catecholamine release from PNB have the potential to improve regional vascular flow and decrease vasospasm,[34] it remains unclear whether these findings provide clinical benefit in trauma patients.

Anecdotally, PNB remains a *provider favorite* presumably to decrease morbidity and mortality when patients are at increased risk of aspiration, present with a difficult airway (with or without a cervical collar), or have multiple comorbid diseases that stratify them at higher risk of complications from general anesthesia or deep sedation. Ultimately, clearly defined benefits, indications, and ETRAI protocols are yet to be established and standardized, perhaps leading to current underutilization of PNB by many trauma practitioners.

Neuraxial Block

Before the widespread use of PNB, neuraxial blockade was the primary regional analgesic for thoracic, abdominal, and lower extremity trauma. Spinal blockade allowed for dense rapid anesthesia with preservation of the awake state, and continuous

epidural block provided long lasting analgesia for painful injuries. However, catastrophic block-related complications owing to traumatic hypovolemia and hemodynamic instability, coagulopathy, neurologic deficit, or elevated intracranial pressure limited their use.[35] Furthermore, insertion and management of neuraxial techniques require skilled providers, special patient positioning, and greater monitoring and time, mostly confining these techniques to in-hospital anesthesiology services. With the need for thromboprophylaxis in recumbent trauma patients or therapeutic anticoagulation after vascular injuries, careful coordination of initiation and discontinuation of neuraxial blocks is necessary to reduce risk of epidural hematoma and preventable thrombotic events. Given these concerns, a thorough risk/benefit analysis is essential, with consideration of peripheral nerve and newer fascial plane blocks as alternatives.

Most commonly, thoracic epidural analgesia (TEA) is requested by trauma surgical teams for older adults with multiple rib fractures, and lumbar neuraxial anesthesia is administered for older adults with hip fractures. However, data showing benefit of these techniques in the elderly population are questionable. The Eastern Association for the Surgery of Trauma and the Chest Wall Injury Society published a joint practice management guideline in 2022 for analgesic strategies in older adults with rib fractures and could make no recommendation for or against TEA in these patients. After a thorough systematic review and meta-analysis, they concluded that TEA for rib fractures did not reduce pneumonia risk or mortality, and it increased hospital length of stay, albeit with low-quality evidence.[36] In centers that have employed ultrasound-guided regional techniques, TEA has largely been replaced by paravertebral, transversus abdominis plane, intercostal, serratus anterior plane, and erector spinae plane blocks, with promising results.[37–42] Noninferiority studies comparing plane blocks to TEA have boasted similar analgesic efficacy with fewer side effects and contraindications, making plane blocks a popular first-line treatment.[43,44] Further research is needed to refine analgesic strategies and protocols for rib fracture management based on risk and benefits of specific techniques relative to injury severity, location, and morbidity.

Regarding hip fractures in older adults, there is a similar debate as to whether intraoperative neuraxial anesthesia provides improved outcomes compared to traditional anesthetic management. While early studies proposed reduced early mortality, deep vein thrombosis, postoperative confusion, and respiratory complications with neuraxial anesthesia compared to general anesthesia,[45] 2 recent randomized controlled trials failed to demonstrate differences in mortality or postoperative delirium for older adults undergoing surgery for hip fractures.[46,47] Furthermore, recent meta-analyses fail to show statistical significance for any of these benefits.[48,49] Moreover, managing an elderly patient undergoing hip surgery with a neuraxial block is not trivial and risks secondary complications. There are the challenges in maintaining the proper level of sedation, a patent airway, comfortable lateral positioning, an adequate block for an extended surgical procedure, and optimal blood and fluid management in elderly patients with, at times, poor baseline cardiorespiratory function. Nonetheless, common practice is to consider neuraxial anesthesia when patients may be considered high-risk for a general anesthetic and do not have any contraindications for neuraxial technique. The proliferation of femoral nerve blocks and fascial plane blocks, such as the suprainguinal fascia iliaca block or the pericapsular nerve group (PENG) block, are important adjuncts to strict general or neuraxial anesthesia by reducing or eliminating the need for systemic opioids, known to cause deleterious side effects in this population.[50,51] Accordingly, a Cochrane systematic review and meta-analysis demonstrated a reduced risk of acute confusional state (risk ratio 0.67) following PNB with a high certainty of evidence in 1072 patients.[52] Ultimately, the choice of anesthetic should be individualized, taking into account the patient's health status, the

surgeon's preference, and the anesthesiologist's expertise, to optimize outcomes and minimize risks.[53]

CURRENT TRENDS IN REGIONAL ANALGESIA FOR TRAUMA

Historically, regional anesthesia techniques were primarily in-hospital procedures for perioperative anesthesia or analgesia and were administered almost exclusively by anesthesia providers. However, with the increasing proficiency in ultrasound skills and the corresponding training across various health care disciplines, there is now greater confidence in the safety of these techniques among nonanesthesia personnel. This development benefits acute trauma patients, as the increased familiarity and experience of trauma providers, including prehospital and emergency medicine practitioners, have led to a broader adoption of these techniques in patient care. A summary of these trends is presented in **Table 1**.

Prehospital

As noted in the introduction, military use of prehospital regional block techniques is well-described.[8,54] In some civilian locales, on-scene PNB can achieve rapid analgesia in injured patients. For example, in Europe and Australia, prehospital providers have published reports of acute trauma victims benefiting from femoral,[11] fascia iliaca,[13,14] sciatic,[55] and interscalene[56] PNB. In 2 of these studies, paramedics or emergency medical service (EMS) nurses were trained to perform fascia iliaca compartment blocks to significantly reduce pain scores from femur fractures and allow for more comfortable hospital transport.[13,14] Increasing interest has been seen in developing protocols for the prehospital provision of regional anesthesia,[57] including in disaster settings and rescue operations.[18,58] A recent systematic review and meta-analysis of 257 prehospital fascia iliaca blocks for proximal femur fractures found the procedure to be safe and effective with resultant significant reductions in nonverbal pain scores.[59] PNB across the included studies were performed by physicians, paramedics, and emergency medicine nurses with specialized training. In Germany, a small randomized controlled trial compared PNB to analgosedation for prehospital reduction or splinting of an isolated extremity injury and found 1/18 (5.6%) experienced pain in the PNB group compared to 7/12 (58.3%) in the analgosedation cohort.[60] No significant adverse effects were reported in these studies.

Emergency Department

With *oligoanalgesia* quite common among adult and pediatric trauma patients in prehospital and emergency medicine,[61,62] many efforts are focused on improving early pain management after traumatic injury. The Joint Commission's most recent Comprehensive Accreditation Manual for Hospitals published in 2025 continues to stress early and adequate pain management for trauma patients as an important metric in providing high quality health care.[63] Citing potential benefits such as early healing, reduced stress response, shortened length of stay, and decreased morbidity and mortality, some authors advocate for the introduction of the letter P (for pain) in the advanced trauma life support (ATLS) algorithm alphabet.[64] Challenges in meeting adequate analgesic goals are exacerbated in the wake of the current opioid epidemic and in the large proportion of trauma patients with substance use disorder in whom standard intravenous medications may be unsatisfactory.[65] The need to address acute trauma pain with alternative modalities has grown and requires a better approach.[66]

Table 1
Summary of current trends in regional anesthesia for trauma

Primary Objectives	Provider Groups	Peripheral Nerve Blockade Techniques Reported	Challenges
Prehospital			
• Early analgesia • Decrease need for opioids and sedatives • Facilitate smooth transport to hospital	• Paramedics • EMS nurses • Prehospital physicians	• Interscalene • Femoral • Fascia iliaca • Sciatic • Erector Spinae Plane Block	• Diagnostic accuracy of injury and thorough neurologic examination before block • Appropriateness of patient selection • Consistency of training, experience, and oversight • Preparedness for recognizing and treating LAST • Limited opportunity for ultrasound guidance • Time needed to perform block vs urgency of transport
Emergency Department			
• Address concerns of oligoanalgesia in trauma care • Decrease need for opioids and sedatives • Provide superior analgesia, effective even in opioid-tolerant patients • Preserve consciousness and airway protection • Reduce pain from distracting injury & enable further assessment of concurrent injuries • Avoid deep sedation for ED procedures and the need for close monitoring during sedation recovery; shorten ED length of stay	• Anesthesiologists • CRNAs • Emergency medicine physicians • Trauma and orthopedic surgeons • Advanced practice nurses	• Most of the common PNB techniques for upper and lower extremities • Non-neuraxial truncal blocks • Neuraxial block (sparingly and often by anesthesia providers only)	• Prioritization of primary survey and early resuscitation • Consistency of training, experience, and oversight • Preparedness for recognizing and treating LAST • Availability of equipment, space, and time • Satisfactory patient positioning and monitoring

Perioperative			
• Can avoid airway and hemodynamic consequences of deep sedation or general anesthesia • Facilitate positioning (eg, femoral block prior to performing spinal anesthesia for femur fracture) • Continuous PNB can facilitate repeated painful procedures (wound care) • Decreased reliance on opioids and their side effects • Improved comfort promotes greater mobility and participation in rehabilitative therapies • Improve blood flow to injured extremity • May protect fresh neurovascular or tendon repairs	• Anesthesiologists • CRNAs	• All PNB techniques for upper and lower extremities • Non-neuraxial truncal blocks • Neuraxial block	• If PNB is intended as primary anesthetic, must be prepared for block failure and need for rapid GA conversion • Continuous PNB placement may interfere with surgical approach • Consideration of anticoagulant needs, higher VTE prophylactic dosing, and timing with neuraxial techniques • PNB may interfere with post-procedure sensorimotor assessments of blocked region

Abbreviations: CRNA, certified registered nurse anesthetist; GA, general anesthesia; LAST, local anesthetic systemic toxicity, VTE, venous thromboembolism.

Inspired by the ease and safety of newly described ultrasound-guided regional anesthesia techniques in perioperative medicine, emergency medicine early adopters have appreciated the benefits that PNB provides their patient population. Blaivas and colleagues achieved excellent analgesia via interscalene blocks for treating shoulder dislocations in the ED without any intravenous sedation,[67] and Stewart and colleagues obtained superb analgesia by continuous femoral nerve block catheters in children with femur fractures in the ED.[68] In another randomized trial of 60 patients, ultrasound-guided PENG block performed in the ED for hip fractures demonstrated superior analgesia compared to systemic opioid medications.[69] A proliferation of recent studies from emergency medicine report similar results,[70,71] leading some to advocate for more universal training for regional anesthesia in emergency medicine curricula and training programs.[72] Furthermore, the secondary benefits of regional anesthesia, such as decreasing side effects from systemic analgesics and lengths of stay by several hours, have garnered additional interest in busy and resource-limited EDs.[73] With ultrasound diagnostics rapidly expanding in acute trauma care (E-FAST examinations, transcranial ultrasound, fracture determination, among others), and as more nonanesthesiology-trained providers use this technology,[74] continued growth of PNB is likely to occur in the ED setting as a standard of care.[75]

Perioperative

Approaches to PNB vary when considering patients with isolated extremity injuries versus multiextremity or multiorgan injured patients. The role of PNB also varies across phases of care (acute presentation, initial surgery, and the first several days of recovery).

Isolated extremity injuries

As described in the subsections previously, the bulk of literature about PNB in the prehospital and ED settings focuses on isolated extremity fracture/dislocation to alleviate pain and facilitate reduction. For perioperative care in isolated limb injury, PNB may be used as part of a multimodal approach to analgesia or as the sole anesthetic, offering superb pain relief and a better side effect profile compared to sedation or general anesthesia.[76] For example, the Agency for Healthcare Research and Quality Safety Program for Improving Surgical Care and Recovery, conducted a full review of interventions for hip fracture patients and emphasized the benefits of early local anesthetic-based techniques in providing superior analgesia.[77] Indeed, the Association of Anaesthetists of Great Britain and Ireland officially recommends regional anesthesia as part of their 2020 guideline for the management of hip fractures.[78] A 2023 Cochrane review of PNB for hip fractures demonstrated significantly improved pain scores on movement 30 minutes after PNB placement.[52] Similarly, a systematic review and network meta-analysis of 63 randomized controlled trials examining preoperative PNB for hip fractures reported significant improvements in pain scores; interestingly, opioid consumption was not decreased in the 2 hours following the block.[79]

In the operating room, PNB may be useful in positioning patients with painful fractures. Four studies demonstrated that performing femoral nerve, fascia iliaca, or PENG blocks to facilitate placement of spinal anesthesia for femur fracture patients afforded lower pain scores and better positioning for neuraxial block when compared with intravenous opioids.[19,80–82]

Postoperatively, PNB may help prevent undesired movements of freshly repaired structures via motor block and provide analgesia to facilitate better tolerance of physical therapy.[83] Early placement of PNB catheters after significant extremity injury has

been shown to allow patients to tolerate repeated dressing changes without the need for adjunctive sedation or general anesthesia.[7,84] This has been especially attractive for pediatric trauma patients for whom the extended use of PNB catheters has demonstrated safety and improved satisfaction among patients and their families.[84,85]

Polytraumatic injuries

For polytrauma patients, the potential hazards of sedation, general anesthesia, and intubation are often amplified by hypovolemia, full stomach, and impeded airway access due to cervical spine mobility precautions. Opioids contribute to respiratory depression, hemodynamic derangement, nausea, pruritis, and delirium, potentially compromising safety and interfering with the frequent neurologic assessments vital in trauma critical care. Selective use of PNB in polytrauma patients can alleviate distracting pain and preserve consciousness, allowing for better participation in secondary and tertiary trauma surveys and expediting evaluation and treatment of injuries.[86] In addition to PNB, ultrasound-guided fascial plane blocks may be performed in the trauma bay, operating room, or in the recovery room to offer adjunctive pain relief to systemic opioid therapy and have demonstrated effective pain relief in truncal and abdominal trauma.[87]

Potential longer-term peripheral nerve blockade benefits

Despite no published evidence that PNB improves long-term tissue viability or function in trauma surgery, trauma teams and anesthesiologists extrapolate from higher rates of graft and fistula patency reported in microvascular and arteriovenous fistula creation surgery[88] to suggest that PNB can enhance blood flow to injured tissue, both via a regional sympathectomy and by improved pain relief decreasing catecholamine release. Interestingly, the degree of increased blood flow is directly related to the concentration of local anesthetic administered with more concentrated local anesthetics generating more blood flow. Li and colleagues demonstrated that maximal sympathetic block for increased blood flow to the upper extremity after supraclavicular block required higher concentration ropivacaine than doses needed for complete sensory block.[34] Those seeking increased perfusion via PNB sympathetic inhibition should consider more concentrated local anesthetic infusions.

When considering the incidence and severity of chronic pain syndromes after trauma such as complex regional pain syndrome or phantom limb pain (PLP), studies have shown that early nerve blockade may significantly reduce challenging pain symptoms months to years after the injury.[30,31] A case series of 10 trauma patients with upper limb amputation reported reduced intensity of PLP symptoms after a continuous brachial plexus PNB and memantine were provided.[89] A multicenter randomized controlled trial evaluated a 6-day-long ambulatory PNB in patients with posttraumatic PLP and demonstrated a significant reduction in pain scores 4 weeks after treatment, as well as less pain-induced physical and emotional dysfunction with a greater degree of longitudinal improvement in pain scores.[90,91] These findings are in contradiction to a review of 14 studies by Droog and colleagues that failed to find differences in pain intensity greater than 3 months after upper extremity surgery when patients were afforded regional anesthesia rather than general anesthesia.[32,33] Additional research with larger cohorts would clarify the role of both early and late PNB in mediating symptoms of chronic pain after trauma.

SPECIAL CONSIDERATIONS IN TRAUMA

Despite PNB's many advantages, acute trauma patients present a unique set of challenges compared to elective surgical patients (**Table 2**). For example, the presence of

Table 2
Summary of special considerations in trauma

Topic	Challenges	Potential Approaches
Informed Consent	• Impaired consciousness • Judgment impaired by psychiatric condition, substance use, or iatrogenic medicines • Acute distress impairs comprehension and capacity for voluntary agreement • Life-threatening conditions take priority; insufficient time for risk/benefit discussion with patient/surrogate • PNB usually seen as elective, nonessential intervention	• If PNB benefits seem likely to outweigh risks of alternative methods, seek informed consent from surrogate (and assent from patient, when possible) • If patient requires an urgent procedure for a condition that threatens life or limb, and sedation and/or opioids present an added risk of complications, may be able to ethically justify PNB as suitable alternative. Best to document rationale
Impaired Consciousness	• Common in trauma patient due to intoxication, brain injury, shock state, or need for sedation or general anesthesia in acute injury • Controversy about heightened risk of nerve injury in *asleep* patient • Impaired consciousness complicates assessment of block safety and efficacy	• Ultrasound may theoretically avoid needle-to-nerve contact, if desired • Consider fascial plane blocks, when indicated, to avoid direct neural contact
Prioritizing Resuscitation	• Critical to act quickly to preserve life and prevent secondary injury • ATLS protocols vital for organized and comprehensive assessment; may not have time for safe regional anesthetic	• Work with trauma team to complete necessary steps of primary and secondary survey • Participate in shared decision-making about risks, benefits, and alternatives of pain management strategies, and consider if/when regional analgesia may have a role
Patient Positioning	• Most trauma patients need to be supine for assessment, treatment, and maintaining safe hemodynamics • Neuraxial blocks and PNB requiring posterior approach may not be feasible • Injury may make certain positioning intolerable • Cervical collar may interfere with access for some PNB in the neck	• Ultrasound permits ready visualization of targets for PNB in many regions of the body without needing repositioning • For injury to trunk, consider peripheral truncal blocks rather than neuraxial or paraneuraxial approach • Prudent to set up all regional equipment before positioning patient

Coagulopathy	• Acquired coagulopathy is present in many trauma patients • Unknown medical history and whether patient is chronically coagulopathic • Effects of newer anticoagulant drugs may not be evident from routine blood testing • Bleeding consequences from neuraxial block may cause paralysis • Life-threatening hemorrhage possible if undetected bleeding in deep blocks • Paucity of evidence regarding safety of PNB in the presence of varying anticoagulant/antiplatelet drugs/doses • Unclear whether provider experience or ultrasound use alters bleeding risk	• Avoid neuraxial and paraneuraxial procedures in acute trauma until sufficient information known about coagulation status and medical history • Have informed discussion with patient or surrogate when considering PNB in the presence of any coagulopathy • If PNB still indicated over alternatives, may consider superficial PNB in regions that are compressible should bleeding occur • Discuss DVT prophylaxis and any plans for therapeutic anticoagulation with trauma team to coordinate block with medication initiation and discontinuation
Nerve Injury	• Acute nerve injury may be present in acute trauma, with or without fracture • Trauma patients may have unknown baseline nerve injury • Impaired consciousness and distracting injury complicate assessment for preexisting nerve injury • Theoretic concern of *double-crush* phenomenon leading to permanent injury if block performed to a previously injured nerve • PNB possibly interferes with subsequent neurologic assessment by trauma/surgical team	• Perform and document thorough neurologic assessment before performing any neuraxial or PNB • Avoid PNB at preexisting injury site • Consider alternate analgesic modes when nerve function is unknown • Coordinate with trauma and surgical team to clarify plans for further neurologic assessment. Consider placing nerve catheter but not injecting local anesthetic until after neurologic assessment is completed • Consider use of short-acting, low-dose local anesthetics to facilitate more rapid block regression, if return to baseline examination becomes necessary
Acute Compartment Syndrome	• Certain patterns and mechanisms of injury increase risk for ACS, especially involving tibial plateau or shaft fracture or radius fracture • Diagnosis of ACS requires frequent, vigilant examination • Failure to diagnose ACS early can result in permanent injury, tissue loss, or amputation • Historic hesitation to offer PNB to patients with ACS risk due to concern of masking early symptoms	• Discuss individual patient risks for ACS with trauma/surgical team • Discuss alternate analgesic modes if PNB is not desired • If using continuous PNB, consider low-concentration, short-acting local anesthetic infusions • Ischemic pain still readily detected with low-density PNB • Recent evidence suggesting low-density PNB may actually aid in early ACS detection from ischemic breakthrough pain in an otherwise previously effective analgesic block

(*continued on next page*)

Table 2
(*continued*)

Topic	Challenges	Potential Approaches
Infection Risk	• Trauma patients are at increased risk of infection of any type • No large cohort analyses describe overall neuraxial or PNB infection risk factors in trauma patients • Injured extremities may have skin breakdown near desired block site, potentially increasing infection risk • Stress response to trauma (leukocytosis and low-grade fever) may mimic signs of systemic infection	• Assess for signs of local or systemic infection before block placement • Maintain sterile technique for all neuraxial or PNB procedures • Examine PNB catheter sites at regular intervals for early signs of infection • Consider catheter removal if infection risk has increased
Rebound pain	• Potential for patients with pain relief from PNB to experience significant pain after local anesthetics metabolize	• If no immediate operative plans, consider local anesthetic dilution (lower concentration) with appropriate systemic analgesics administered as adjuncts

Abbreviation: DVT, deep venous thrombosis.

brain injury, emotional distress, distracting painful injuries, chemical impairment, hemodynamic instability, and coagulopathy are common in the polytrauma patient. Such conditions may alter patients' ability to participate in decision-making or safely cooperate with block placement and may interfere with providers' ability to assess block efficacy and potential complications. For a full listing of special considerations by specific block technique, see **Table 3**.

Informed Consent

Obtaining informed consent may be difficult or even impossible in the presence of the distress accompanying acute trauma. Even patients who are conscious and communicative may have life-threatening injuries that require emergent management, without time for a detailed discussion of indications, risks, benefits, and alternatives of proposed interventions with them or their surrogate. Some treatments can be ethically justified under the principles of implied consent when there is immediate threat to life, limb, or vision. While PNB is generally safe and improves patient comfort, it is frequently considered an elective intervention. However, in some circumstances, alternate modes of analgesia and anxiolysis may have greater likelihood of causing harm. For example, performing targeted PNB for emergent fracture reduction to preserve limb/tissue viability may offer less risk than possible airway or hemodynamic compromise from deep sedation or general anesthesia in a full-stomach trauma patient. Institution-based protocols regarding surrogate consent or implied consent should be followed, with documented justification for a particular PNB intervention in the emergent setting, as practiced in the authors' institutions.

Blocks and Impaired Consciousness

The relative safety of placing blocks in awake patients compared to those with impaired consciousness—due to intoxication, brain injury, sedation, or general anesthesia—remains a controversial topic. The American Society of Regional Anesthesia and Pain Medicine (ASRA PM) guidelines continue to advocate for the performance of regional anesthetics in awake and cooperative adult patients,[92] with particular concern for interscalene or neuraxial procedures after old case reports posit a heightened association between postblock nerve injuries and the unresponsive state of a patient at the time of the block.[93–95] A retrospective registry analysis of 42,654 patients found that while sedated patients report improved satisfaction with block placement, PNB placement under general anesthesia was associated with a higher risk of a bloody tap, and neuraxial block placement under general anesthesia had a higher risk of catheter-related paresthesias. The authors concluded that general anesthesia-placed blocks should be reserved for special situations by experienced anesthesiologists.[96] Others argue that, when indicated, an anesthetized patient may provide more optimal conditions to allow for a safe and controlled targeted technique, especially in the age of high-resolution ultrasound-guided needle placement.[97] Regional blocks in anesthetized children are well-established with an analysis of over 100,000 patients from the Pediatric Regional Anesthesia Network supporting the safety of placing both neuraxial and PNB.[98] Anecdotally, the authors consider acute adult trauma patients to have potential indications and advantages for asleep blocks when excessive pain or decreased mental status preclude performance in the awake, responsive state. With appropriate informed consent as previously discussed, performance of neuraxial or PNB in the anesthetized trauma patient is individually assessed and performed on a case-by-case basis in the authors' institutions.

Table 3
Specific block techniques and considerations in acute trauma

Body Region	Block	Indications/Benefits	Special Considerations in Acute Trauma
Head and Neck	Branches of trigeminal, deep/superficial cervical plexus, and occipital nerves	• Irrigation and repair of lacerations to head, face, and neck	• Horner's syndrome may confuse examination of evolving brain injury • Need operator with detailed head/neck neuroanatomy expertise • Many injuries are amenable to field block by surgeon
Thorax			
Midline or bilateral chest	High thoracic epidural	• Reliable coverage of large anatomic areas • Visceral analgesia	• Sympathectomy may jeopardize safety in hypovolemic patient • Contraindicated in coagulopathy, hypovolemia, spine fracture, and high ICP • Positioning limitations and access for block placement • Theoretic spinal cord blood flow compromise in spine trauma • Possible increased risk of DVT and length of stay (primarily in rib fracture patients who remain sedentary)
Unilateral chest injuries	PVB ES plane, Serratus anterior plane (SA)	• Similar coverage to epidural, but with selective laterality and lower risk of sympathectomy or epidural hematoma	• Coagulopathy and risk of occult bleeding (PVB) • Positioning limitations and access for block placement • Pneumothorax risk could further compromise respiratory function (less problematic in patients with preexisting chest tube) (PVB) • Possible neuraxial spread could cause sympathectomy (PVB) • Ultrasound may facilitate successful placement • Bilateral injuries can be addressed with bilateral blocks

Anterior chest wall, distal clavicle, axilla	SA Interpectoral and PECS plane PECS I and PECS II ES	• Possible role for anterior rib fractures (SA), clavicle fractures (PECS), and chest tube pain (SA and ES) or posterior and lateral injuries (ES) • Anterior approach (for PECS and SA) is superficial and compressible • Ultrasound speeds learning techniques (SA, PECS, and ES)	• Limited data in trauma population • Coverage may vary • Further studies needed to describe roles of specific blocks for certain injury types
	Intercostal nerves	• Temporary analgesia for selected number of ribs • Chest tube placement	• For multiple rib fractures, multiple blocks may lead to LAST • Pneumothorax risk could further compromise respiratory function • Ultrasound may be useful diagnostic confirmatory tool to localize fracture and improve block accuracy
	Intrapleural	• Selective laterality • Avoids sympathectomy	• Increased local anesthetic absorption increases LAST risk and limits use of technique • Other techniques with lower LAST risk are likely preferable
Abdomen/Pelvis/Acetabulum			
Midline or bilateral lower trunk	Low thoracic epidural	• Reliable coverage of large anatomic areas • Visceral analgesia	• Contraindicated in coagulopathy, hypovolemia, spine fracture, high ICP • Position for block placement may not be feasible in acute trauma • Theoretic spinal cord blood flow compromise in spine trauma
Anterior abdominal wall	Rectus abdominis sheath (RA) Transversus abdominis plane (TAP) Ilioinguinal/iliohypogastric	• May help post-laparotomy tidal volumes (RA, TAP) • Avoids neuraxial risks/side effects • Anterior approaches; superficial and compressible • Ultrasound speeds learning techniques	• Trauma or surgery may complicate tissue plane identification • Injuries, incisions, dressings, drains may impede access • Bilateral large-volume LA injection increases LAST risk • Visceral pain not covered • Coverage may vary • Limited data in trauma population

(*continued on next page*)

Table 3
(*continued*)

Body Region	Block	Indications/Benefits	Special Considerations in Acute Trauma
Low thoracic to hip	QLB	• Able to perform in supine position (QLB 1 block) • Potential supra- and infra-umbilical coverage • Possible component of visceral coverage • Reported coverage of acetabulum and femoral neck	• Trauma or surgery may complicate tissue plane identification • Depth of target and proximity to retroperitoneum and kidneys in QLB 3 block poses risk of renal or colon puncture or retroperitoneal bleeding; consider other analgesic approaches in coagulopathic patients • Coverage may vary • Limited data in trauma population
Upper extremity			
Shoulder girdle & upper arm	Brachial plexus: Interscalene approach	• Covers distal clavicle • Shoulder fracture or dislocation; can facilitate reduction • Humeral fractures	• Cervical immobilization impedes access to neck and limits head rotation for optimal block placement; ultrasound may help • Horner's syndrome may confuse examination of evolving brain injury • Hemidiaphragm paralysis is likely; may exacerbate respiratory compromise, especially with contralateral thoracic trauma; consider targeted low-volume block or other approaches to brachial plexus • Dilute low-volume block may facilitate nerve function examination after reduction

Upper Arm to digits	Brachial plexus: Supraclavicular approach	• Rapid analgesia for majority of arm/hand • Immobilizes freshly repaired structures and provides regional sympathectomy after limb or digit salvage procedures	• Lower incidence of hemidiaphragm paralysis than interscalene, but possible • Easiest to perform with arm at side or adducted across body; can be quite challenging if pain precludes this positioning • Preexisting subcutaneous emphysema (as in some pneumothoraces) can interfere with ultrasound visualization • Inadvertent subclavian arterial puncture poses difficulty for hemostasis
Elbow to digits	Brachial plexus: Infraclavicular approach	• Usually spares phrenic nerve • Greater depth of target may improve nerve catheter fixation	• Inadvertent arterial puncture poses difficulty for hemostasis • Consider other approaches if in proximity to known vascular injury or central venous catheter insertion site
Forearm to digits	Brachial plexus: Axillary approach	• Avoids phrenic nerve palsy • Can select nerves for targeted analgesia	• Placement requires arm abduction, possibly limited by pain • Transarterial approach risks impeding distal blood flow
	Midhumeral and forearm blocks of radial, median, and ulnar nerves	• Can block specific nerves for selective analgesia • Preserves upper arm motor function	• Block site may be covered by dressing or splint
Hand, digits	Intravenous regional (Bier block)	• Targeted hand/digit anesthesia for short procedures • Easy to learn, quick to perform • Preserves upper arm motor function	• Requires exsanguination of limb with Esmarch bandage; existing injuries can make this quite painful (may need brief sedation) • Tourniquet use required for block function; tourniquet pain may be intolerable and require sedation, higher risk if patient with full stomach

(*continued on next page*)

Table 3
(*continued*)

Body Region	Block	Indications/Benefits	Special Considerations in Acute Trauma
			• Relies on short procedure duration; procedures outlasting block need LA supplementation, sedation, or GA conversion • Need alternate postop analgesia strategy, as block resolves rapidly with tourniquet deflation
Lower Extremity			
Bilateral lower extremities and pelvis	Lumbar epidural	• Reliable coverage of large anatomic areas • Useful in bilateral lower extremity or pelvic trauma	• Contraindicated in coagulopathy, hypovolemia, spine fracture, high ICP • Position for block placement may not be feasible in acute trauma • Theoretic risk of compromised spinal cord blood flow with coexisting spine trauma
Acetabulum, proximal thigh, femur, and knee	Lumbar plexus – psoas compartment	• Selective laterality • Covers entire lower extremity when combined with proximal sciatic block	• Position for block placement may not be feasible in acute trauma • Deep transmuscular approach is often painful; consider aspiration risk if sedation provided to patient with full stomach • Approach risks renal puncture, retroperitoneal bleed, or neuraxial spread; consider alternatives in coagulopathy or hypovolemia • Selective femoral, obturator, and lateral femoral cutaneous, or fascia iliaca block may be more appropriate when analgesia is desired distal to femoral head

Anterior and lateral thigh, hip, femur, knee, lower leg	FIB FNB LFCN PENG QLB	• FIB: easy to learn, minimal equipment; option for prehospital or ED care • FNB: easy access in supine patient; fast • PENG/FIB/FNB/QLB for hip fractures • FIB/FNB: excellent for mid- and distal femur, also for femoral/tibial traction pins; may need LFCN for lateral coverage	• Quadriceps motor block impairs ambulation; counsel patients about increased fall risk (FNB, FIB) • PENG block with benefits of motor-sparing block for hip fractures • Consider adductor canal block for injury at or distal to knee • Use of dilute LA may offer analgesia with less motor block • Use of dense LA could mask compartment syndrome of the thigh in high-risk injury patterns (FIB, FNB)
Knee/medial lower leg, ankle, and foot	Adductor canal/subsartorial	• Pure sensory block • Preserves quadriceps function, allowing better mobility	• Target adjacent to large vessels and can be deep, difficult to compress • Consider more superficial block in coagulopathy (FNB or superficial saphenous approach distal to knee)
Posterior hip, thigh, femur, knee, lower leg, foot (except saphenous distribution)	Sciatic nerve (parasacral, transgluteal, infragluteal, anterior inguinal, midfemoral, and popliteal)	• Multiple approach options depending on location of injury or surgery • Coverage distal to tibial plateau, offers complete lower extremity analgesia in combination with saphenous or FNB • Facilitates ankle reduction in ED • Anterior inguinal, midfemoral, and popliteal approach allow supine position	• Some approaches are deep, adjacent to noncompressible vessels, higher risk in coagulopathy • When target is deep, ultrasound imaging may be difficult; nerve stimulation possible but can increase pain in injured limb • Motor block of hamstring in proximal approaches limits crutch use; counsel patients about increased fall risk • Lateral or prone position needed for very proximal approaches; may not be feasible in acute trauma • Concern over use of dense and long-acting LA masking compartment syndrome of lower leg in high-risk

(*continued on next page*)

Table 3
(*continued*)

Body Region	Block	Indications/Benefits	Special Considerations in Acute Trauma
			injury patterns (tibial plateau/shaft fractures) • Frequent, meticulous compartment monitoring, in coordination with primary team, may permit dilute LA infusions for somatic analgesia while not blocking ischemic pain (recent studies demonstrating safety)
Midfoot, toes	Ankle block	• Major or minor procedures on foot • Ultrasound optional	• Need multiple injections for complete coverage; may be more unpleasant for patient than single shot sciatic popliteal block • If tourniquet is needed, should consider more proximal block or added sedation

Abbreviations: ES, erector spinae plane; FIB, fascia iliaca block; FNB, femoral nerve block; GA, general anesthesia; ICP, intracranial pressure; LA, local anesthetic; LAST, local anesthetic systemic toxicity; LFCN, Lateral femoral cutaneous nerve; PECS, pectoserratus; QLB, quadratus lumborum; RA, rectus abdominis sheath; SA, serratus anterior plane; TAP, transversus abdominis plane; additional abbreviations listed in table.

Prioritizing Resuscitation

Measures to preserve life and avoid secondary injury take priority in the management of trauma patients. A systematic approach to initial patient assessment is standardized through ATLS protocols and decision-making algorithms. Regional blocks can take time and adequate resources (eg, personnel, equipment, and space) to perform safely. Trauma patients' emotional or physiologic distress may warrant induction of general anesthesia and airway securement to safely complete the primary and secondary surveys and initiate immediate resuscitative pathways. In those cases, modes of analgesia should be instituted when appropriate and agreed upon by the multidisciplinary team of trauma providers.

Patient Positioning

In general, block techniques requiring a posterior approach may be difficult or impossible due to the need for supine positioning during most of the ATLS primary and secondary survey, and often for many hours after beginning initial resuscitation. Regional analgesia for lateral and anterior portions of the chest and abdomen may be feasible via ultrasound-guided fascial plane approaches. Cervical immobilization makes interscalene and supraclavicular blocks slightly more challenging with an inability to turn the neck to facilitate procedural access. Block approaches that require limb manipulation, such as the axillary approach to the brachial plexus, and subgluteal or popliteal approaches to the sciatic nerve, can be extremely painful in patients with extremity fractures. In many cases, ultrasound guidance may achieve rapid visualization of the targeted structures or may reveal an alternate approach with minimal or no need of modifying patient position. Finally, when modifying an injured patient's position is necessary for a regional technique, it is highly recommended to set up all the needed equipment in advance for efficiency and to minimize patient discomfort from unnecessarily prolonged block performance.

Coagulopathy

Although clinically significant bleeding events from regional block procedures are rare, they can occasionally produce devastating permanent injury when perineural bleeding occurs after neuraxial or deep intramuscular procedures, such as lumbar plexus block.[99] With many patients taking direct oral anticoagulants and antiplatelet agents due to chronic medical conditions, trauma patients may have preexisting coagulopathies that are undetectable by routine blood and coagulation testing. The literature is insufficient to quantify bleeding risks of individual blocks in the presence of particular antiplatelet agents and anticoagulants, although overall risk is believed to be low.[100] Patients with severe injuries may have trauma-induced coagulopathies due to hemorrhage, hemodilution, hypothermia, brain injury, or acute coagulopathy of trauma.[101] Deep blocks (eg, neuraxial, paravertebral, and psoas compartment blocks) are typically avoided in the presence or suspicion of coagulopathy, or when the prescription drug history of a patient cannot be determined.

As a guide, the ASRA PM recently published the fifth edition of their evidence-based guidelines for regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy.[102] They deliberately maintain a conservative *antihemorrhagic* approach focused on patient safety and have modified their description of anticoagulant therapy to *low versus high* rather than *prophylactic and therapeutic* dosing. However, their guidelines aptly recognize the conflicting approach by the American College of Chest Physicians management guidelines,[103] which stress an *antithrombotic* philosophy, especially for patients at risk for venous thromboembolic events. Multidisciplinary

teams caring for traumatic injuries should weigh the risk benefit ratios in their specific patient populations and develop institutional guidelines when conflicting patient safety needs are present.

Many practitioners will consider placing non-neuraxial, superficial PNB in the presence of mild coagulopathy after appropriate discussion of risks and benefits with the patient or surrogate.[104] A small study evaluating femoral nerve blocks for hip fracture patients on anti-Xa direct oral anticoagulants did not show a significant difference in bleeding events compared to patients who did not have femoral block.[105] A single-center retrospective study of erector spinae plane blocks in patients with blunt chest wall injury did not show difference in bleeding complications in the presence of venous thromboembolism prophylaxis.[106] Tsui and colleagues published a 2019 practice advisory based on evidence review and expert consensus to attempt to classify PNB and fascial plane blocks as low, intermediate, or high risk for bleeding complications.[107] The authors used a bleeding risk score system previously published by Tsui that considered proximity to critical structures, the ability to control bleeding noninvasively (compressibility), and ease or difficulty of assessing for the presence of bleeding.[108] In addition to considering a patient's anticoagulant state at the time of block performance, providers should understand if there is a plan for subsequent use of therapeutic anticoagulation. It is important that closed-loop communication occur between the primary trauma team and pain management team if anticoagulation needs change during hospitalization to reassess risk and coordinate possible nerve catheter removal. At present, there is insufficient evidence to quantify any alteration in bleeding risk when blocks are performed under ultrasound guidance versus landmark-based approaches.

Nerve Injury

Recognizing preexisting nerve injuries and avoiding secondary injury are important considerations in the acute trauma setting. Some trauma patients present with acute nerve injury either via direct nerve involvement or secondary trauma to associated structures, such as radial nerve palsies from humeral shaft fractures or peroneal nerve injuries after fibular fractures. Controversy exists as to whether proximal block of an injured nerve may lead to the *double crush* occurrence with increased risk of permanent neuropathy; however, an objective pathophysiologic explanation of this phenomenon is debated.[109] It is vital that a thorough sensory and motor assessment is conducted before performing a block, as some preexisting nerve deficits may not have been recognized yet by the patient or members of the team.[92] Other injury patterns pose increased risk for intraoperative iatrogenic injury. In some cases, with clear communication among all care providers, it may still be appropriate to perform PNB with a dilute, short-acting local anesthetic that allows for earlier block regression and functional assessment.

Acute Compartment Syndrome

High energy or ballistic injuries with significant soft tissue damage or vascular injuries to the extremities as well as some fracture patterns and operative repair may place trauma patients at increased risk of developing acute compartment syndrome (ACS). Tibial and radial fractures are among the most common orthopedic injuries with ACS rates reportedly as high as 27% in high-energy tibial fractures in 1 retrospective study.[110] While conventional teaching has implicated regional anesthetics in masking the initial symptoms of disproportionate pain and thus have discouraged nerve blocks in these patients,[111] modifications in regional anesthetic technique using ultrasound-guidance and low-volume, low-concentration local anesthetics have

significantly challenged old dogma.[112–114] Recent retrospective studies from Chembrovich and Kakalecik from the University of Florida at Gainesville highlight the safety of using 0.2% ropivacaine for the majority of their extremity fracture patients within a vigilant monitoring protocol for ACS.[22,115] Some authors have even suggested that dilute local anesthetic solutions via continuous PNB can in fact aid the early detection of ACS.[116] Ultimately, ACS remains a diagnosis of vigilance where frequent serial examinations are necessary for the timely detection and intervention of ACS in trauma patients. Collaborative decision-making with surgeons and predetermined ACS protocols are vital to plan pain management strategies that allow for early ACS identification without resulting in undue patient suffering.

Infection Risk

Infections from single-injection or continuous PNB are uncommon in nontrauma patients, with reported rates between 0% and 3%.[117] Alakkad and colleagues reviewed 7476 patients who received ultrasound-guided single shot PNB using a sterile-transparent transducer cover over a 10-year period and found no evidence of an infection from the PNB.[118] For continuous regional anesthesia via PNB catheters, Bomberg and colleagues in Germany reviewed data from 44,555 patients across 25 centers and appreciated an inflection point at 4 days of catheter duration when the infection-free catheter state began to decrease. Only 31 patients (0.07%) in their cohort suffered from severe infections requiring surgical irrigation and debridement, with 5 of those having displayed early signs of catheter site infection, but unfortunately the catheters were left in situ.[119]

For trauma patients, there is heightened concern of infection due to penetrating injuries, nonsterile emergent procedures, iatrogenic interventions, altered immune responses and perfusion, blood component transfusion, and mechanical ventilation. Introducing PNB, especially continuous neuraxial and nerve block catheters, warrants appropriate risk assessment as they may introduce another nidus of infection in these patients. In critically ill trauma patients who are at increased risk for nosocomial infections, it is essential to conduct daily reappraisal of the risks and benefits provided by PNB. Furthermore, findings of low-grade fever and leukocytosis, presumed to be part of a normal physiologic trauma stress response, may be underappreciated as signs of a developing infection.

Infection data specifically for regional anesthesia in trauma are sparse. Walter Reed Army Medical Center reported 7 of a cohort of 361 (1.9%) trauma patients with a continuous PNB developed a related infection, all being superficial skin infections that resolved with catheter removal.[120] In combat care, longer duration of an indwelling perineural catheter (4–11 days) was associated with risk of infection in a case series of 5 soldiers for whom PNB catheters were placed with sterile technique.[121] An assessment of bacterial cultures from the tips of epidural and peripheral nerve catheters from United Kingdom military personnel showed colonization in 34% and 29% of catheters, respectively, but only 1 patient with a positive catheter-tip culture had a clinically confirmed infection.[122] Finally, a single-center retrospective study of erector spinae plane catheters for chest trauma patients reported 2/244 catheters that developed erythematous insertion sites, but required no further intervention after catheter removal.[123]

In 2020, the Brazilian Society of Anesthesiology analyzed 129 articles and published recommendations to reduce regional anesthesia-related infections.[124] They emphasized the importance of aseptic technique, hand washing, sterile gloves, appropriate skin antisepsis, and mask wearing by providers when performing regional anesthesia techniques. While not focused on regional anesthesia in the trauma patient, adherence

to these measures in injured patients is perhaps more essential for the reasons described earlier. The ASRA PM also recently published extensive consensus guidelines addressing infection control practices for regional anesthesia and interventional pain procedures.[125] Summarizing their recommendations is beyond the scope of this article; however, it is important for trauma teams to be aware of this advisory and optimize multidisciplinary methodologies to prevent, monitor, detect, and treat infections related to regional anesthetic techniques.

FUTURE DIRECTIONS

Not all trauma care systems have staffing models to support extensive anesthesiology involvement in early resuscitation aside from airway management and availability for emergent surgical needs. As trauma teams increasingly incorporate regional anesthetic techniques earlier in patient care, interest in developing expertise in these analgesic modalities has grown, particularly in fields outside of anesthesiology.

Anesthesiologists are poised to lead other health professionals, not only in key principles of patient assessment for block candidacy and technical aspects of procedure performance but also in refining trauma pathways to include considerations of regional anesthetic options to improve patient comfort and potentially avoid problematic side effects of other interventions. With appropriate medical training, there may be a role for teaching prehospital providers block techniques for select injury patterns. Additionally, more regional anesthesia experience in trauma should yield outcome data for circumstances when PNB has the greatest benefit. In the present opioid epidemic, data about post-traumatic chronic pain, opioid use, and dependence will clarify whether PNB can make an impact on this important public health issue.

SUMMARY

Peripheral nerve blockade can be challenging in trauma due to competing priorities in early resuscitation and surgical care, and due to the complexity of the polytrauma patient. In many instances, PNB offers a more favorable side effect profile than systemic opioids and often provides superior analgesia. Because of these advantages, further research is warranted to assess the impact of PNB for specific indications in trauma, with attention to surgical outcomes, length of stay, morbidity and mortality benefits, development of chronic pain, and opioid dependence. The rapid expansion of ultrasound availability and increasing provider comfort with use of this technology for multiple point-of-care purposes have generated broader interest in learning ultrasound-guided nerve blocks. Prehospital and emergency medicine providers are important partners with anesthesiology-trained members of the trauma care team in bringing the advantages of regional anesthetic techniques to a greater proportion of trauma victims.

CLINICS CARE POINTS

- Incorporate regional anesthesia into trauma protocols in the emergency department and prehospital settings, where trained providers can safely perform blocks to improve early pain control and reduce sedation needs.
- For patients with extremity fractures, consider PNBs to facilitate reduction, manipulation or surgical procedures, but anticipate and manage rebound pain with multimodal analgesia strategies.

- Avoid dense or long-acting local anesthetics in patients at risk for acute compartment syndrome (ACS); instead, use dilute infusions and maintain vigilant monitoring to detect breakthrough ischemic pain.
- In patients with multiple injuries or altered mental status, consider the ethical use of implied consent for PNBs, especially when alternative analgesia poses greater risk.
- In trauma patients with coagulopathy or unknown anticoagulant status, avoid neuraxial and deep plexus blocks; consider superficial, compressible PNBs after risk-benefit discussion with the trauma team.
- Use ultrasound-guided fascial plane blocks (e.g., ESP, TAP, QLB) as alternatives to neuraxial techniques in patients with contraindications such as coagulopathy, spine injury, or hemodynamic instability.
- When managing trauma patients with suspected nerve injury, perform and document a thorough neurologic exam before block placement, and consider short-acting agents to allow for early reassessment.
- Monitor for infection risk in trauma patients with indwelling nerve catheters, especially in those with open wounds, prolonged catheter duration, or immunosuppression; remove catheters promptly if signs of infection arise.

DISCLOSURE

Dr R.E. Samet has a consultant relationship with Butterfly Network, LLC. Dr E.B. Powelson, Dr I.R. Slade, and Dr C.R. Parrino have nothing to disclose.

REFERENCES

1. Kim TE, Tsui BCH. Simulation-based ultrasound-guided regional anesthesia curriculum for anesthesiology residents. Korean J Anesthesiol 2019;72(1):13–23.
2. Prineas S, Cuyx L, Smet J. e-Learning in regional anesthesia. Curr Opin Anaesthesiol 2021;34(5):626–33.
3. Mancel L, Van Loon K, Lopez AM. Role of regional anesthesia in enhanced recovery after surgery (ERAS) protocols. Curr Opin Anaesthesiol 2021;34(5):616–25.
4. Simic A, Nesek Adam V, Rošić D, et al. Peripheral nerve blocks for hip fractures in emergency medicine. Acta Clin Croat 2022;61(Suppl 1):78–83.
5. Scala VA, Lee LSK, Atkinson RE. Implementing regional nerve blocks in hip fracture programs: a review of regional nerve blocks, protocols in the literature, and the current protocol at the queen's medical center in Honolulu, HI. Hawaii J Health Soc Welf 2019;78(11 Suppl 2):11–5.
6. Twerdahl EH, Lum AG, Keuski BM, et al. Safe and effective use of peripheral nerve blocks in the ROLE 2 maritime expeditionary environment. J High Threat Austere Med 2024;6(1):9–13.
7. Fontana C, Rocco M, Vetrugno L, et al. Long-term placement of continuous popliteal nerve block catheter for management of a wounded patient in a combat field environment: a case report. Local Reg Anesth 2019;12:67–70.
8. Gelfand HJ, Kent ML, Buckenmaier CC. 3rd. Management of acute pain of the war wounded during short and long-distance transport and "Casevac Techniques in Orthopaedics 2017;32(4):263–9.
9. Gelfand HJ, Tracy EA, Bell AG. Pain in extreme situations: the battlefield and disasters. In: Christo PJ, Gallagher RM, Katzman JG, et al, editors. Pain

management in vulnerable populations. New York: Oxford University Press; 2024. p. 280–300.
10. Todd KH. A review of current and emerging approaches to pain management in the emergency department. Pain Ther 2017;6(2):193–202.
11. Gros T, Viel E, Ripart J, et al. Prehospital analgesia with femoral nerve block following lower extremity injury. A 107 cases survey. Ann Fr Anesth Reanim 2012;31(11):846–9 [in French].
12. Simpson PM, McCabe B, Bendall JC, et al. Paramedic-performed digital nerve block to facilitate field reduction of a dislocated finger. Prehosp Emerg Care 2012;16(3):415–7.
13. Dochez E, van Geffen GJ, Bruhn J, et al. Prehospital administered fascia iliaca compartment block by emergency medical service nurses, a feasibility study. Scand J Trauma Resuscitation Emerg Med 2014;22:38.
14. McRae PJ, Bendall JC, Madigan V, et al. Paramedic-performed fascia iliaca compartment block for femoral fractures: a controlled trial. J Emerg Med 2015;48(5):581–9.
15. Wroe P, O'Shea R, Johnson B, et al. Ultrasound-guided forearm nerve blocks for hand blast injuries: case series and multidisciplinary protocol. Am J Emerg Med 2016;34(9):1895–7.
16. Clattenburg E, Herring A, Hahn C, et al. ED ultrasound-guided posterior tibial nerve blocks for calcaneal fracture analagesia. Am J Emerg Med 2016;34(6): 1183.e1–3.
17. Ibbotson WJ, Greenberg R, Brendt P. Erector Spinae block for chest trauma in aeromedical prehospital and retrieval medicine. Prehospital Disaster Med 2020; 35(4):454–6.
18. Moser A, Wagner S, Habegger K, et al. From the operating room to the cave: ultrasound-guided locoregional anesthesia in the setting of cave Rescue-A description of 2 cases. Wilderness Environ Med 2023;34(4):553–7.
19. Aygun H, Tulgar S, Yigit Y, et al. Effect of ultrasound-guided pericapsular nerve group (PENG) block on pain during patient positioning for central nervous blockade in hip surgery: a randomized controlled trial. BMC Anesthesiol 2023;23(1):316.
20. Gawel RJ, Grill R, Bradley N, et al. Ultrasound-guided peripheral nerve blocks for shoulder dislocation in the emergency department: a systemic review. J Emerg Med 2023;65(5):e403–13.
21. Li L, Li CX, Zhang H, et al. Nerve block reduces the incidence of 3-year post-operative mortality: a retrospective cohort study. Front Surg 2024;11:1284892.
22. Chembrovich S, Ihnatsenka B, Smith C, et al. Incidence of acute compartment syndrome with routine use of regional anesthesia for patients with long bone fractures: a large single-center retrospective review from a level I trauma tertiary academic institution. Reg Anesth Pain Med 2024;49(7):505–10.
23. Richman JM, Liu SS, Courpas G, et al. Does continuous peripheral nerve block provide superior pain control to opioids? A meta-analysis. Anesth Analg 2006; 102(1):248–57.
24. Gabriel RA, Swisher MW, Sztain JF, et al. State of the art opioid-sparing strategies for post-operative pain in adult surgical patients. Expet Opin Pharmacother 2019;20(8):949–61.
25. Cunningham DJ, Paniaugua AR, LaRose MA, et al. Regional anesthesia does not decrease inpatient or outpatient opioid demand in distal femur fracture surgery. Arch Orthop Trauma Surg 2022;142(8):1873–83.

26. McClain RL, Porter SB, Arnold SM, et al. Peripheral nerve blocks and postoperative physical therapy: a single-institution survey of physical therapists' preferences and opinions. Rom J Anaesth Intensive Care 2017;24(2):115–24.
27. Ferry J, Lewis O, Lloyd J, et al. Research priorities in regional anaesthesia: an international Delphi study. Br J Anaesth 2024;132(5):1041–8.
28. Kuypers MI, Veldhuis LI, Mencl F, et al. Procedural sedation and analgesia versus nerve blocks for reduction of fractures and dislocations in the emergency department: a systematic review and meta-analysis. J Am Coll Emerg Physicians Open 2023;4(1):e12886.
29. Hughey S, Cole J, Drew B, et al. Regional anesthesia in resource-limited and disaster environments: a daring discourse. Reg Anesth Pain Med 2025;50(8):686–9.
30. Kent ML, Hsia HLJ, Van de Ven TJ, et al. Perioperative pain management strategies for amputation: a topical review. Pain Med 2017;18(3):504–19.
31. Jenson MG, Sorensen RF. Early use of regional and local anesthesia in a combat environment May prevent the development of complex regional pain syndrome in wounded combatants. Mil Med 2006;171(5):396–8.
32. Chua M, Ratnagandhi A, Seth I, et al. The evidence for perioperative anesthetic techniques in the prevention of new-onset or recurrent complex regional pain syndrome in hand surgery. J Personalized Med 2024;14(8).
33. Droog W, Walbeehm ET, Konijn JB, et al. A systematic review on long-term postsurgical pain outcomes; what is the effect of upper extremity regional anesthesia? Anesth Analg 2023;137(2):365–74.
34. Li T, Ye Q, Wu D, et al. Dose-response studies of ropivacaine in blood flow of upper extremity after supraclavicular block: a double-blind randomized controlled study. BMC Anesthesiol 2017;17(1):161.
35. Courington FW, Calverley RK. Anesthesia on the Western front: the anglo-american experience of World War I. Anesthesiology 1986;65(6):642–53.
36. Mukherjee K, Schubl SD, Tominaga G, et al. Non-surgical management and analgesia strategies for older adults with multiple rib fractures: a systematic review, meta-analysis, and joint practice management guideline from the Eastern Association for the Surgery of Trauma and the Chest Wall Injury Society. J Trauma Acute Care Surg 2023;94(3):398–407.
37. Bossolasco M, Bernardi E, Fenoglio LM. Continuous serratus plane block in a patient with multiple rib fractures. J Clin Anesth 2017;38:85–6.
38. Kunhabdulla NP, Agarwal A, Gaur A, et al. Serratus anterior plane block for multiple rib fractures. Pain Physician 2014;17(4):E553–5.
39. Hamilton DL, Manickam B. Erector spinae plane block for pain relief in rib fractures. Br J Anaesth 2017;118(3):474–5.
40. Malekpour M, Hashmi A, Dove J, et al. Analgesic choice in management of rib fractures: paravertebral block or epidural analgesia? Anesth Analg 2017;124(6):1906–11.
41. Mohta M, Verma P, Saxena AK, et al. Prospective, randomized comparison of continuous thoracic epidural and thoracic paravertebral infusion in patients with unilateral multiple fractured ribs–a pilot study. J Trauma 2009;66(4):1096–101.
42. Truitt MS, Murry J, Amos J, et al. Continuous intercostal nerve blockade for rib fractures: ready for primetime? J Trauma 2011;71(6):1548–52 [discussion: 1552].
43. Singh S, Avinash R, Jaiswal S, et al. Comparison of safety and efficacy of thoracic epidural block and erector spinae plane block for analgesia in patients

with multiple rib fractures: a pilot single-blinded, randomised controlled trial. Indian J Anaesth 2023;67(7):614–9.
44. Mostafa SF, Eid GM. Ultrasound guided erector spinae plane block versus thoracic epidural analgesia in traumatic flail chest, a prospective randomized trial. J Anaesthesiol Clin Pharmacol 2023;39(2):250–7.
45. Luger TJ, Kammerlander C, Gosch M, et al. Neuroaxial versus general anaesthesia in geriatric patients for hip fracture surgery: does it matter? Osteoporos Int 2010;21(Suppl 4):S555–72.
46. Neuman MD, Feng R, Carson JL, et al. Spinal anesthesia or general anesthesia for hip surgery in older adults. N Engl J Med 2021;385(22):2025–35.
47. Li T, Li J, Yuan L, et al. Effect of regional vs general anesthesia on incidence of postoperative delirium in older patients undergoing hip fracture surgery: the RAGA randomized trial. JAMA 2022;327(1):50–8.
48. Zheng X, Tan Y, Gao Y, et al. Comparative efficacy of neuraxial and general anesthesia for hip fracture surgery: a meta-analysis of randomized clinical trials. BMC Anesthesiol 2020;20(1):162.
49. Cheung KY, Yang TX, Chong DYC, et al. Neuraxial versus general anesthesia in elderly patients undergoing hip fracture surgery and the incidence of postoperative delirium: a systematic review and stratified meta-analysis. BMC Anesthesiol 2023;23(1):250.
50. Thompson J, Long M, Rogers E, et al. Fascia iliaca block decreases hip fracture postoperative opioid consumption: a prospective randomized controlled trial. J Orthop Trauma 2020;34(1):49–54.
51. Wu H, Yang RZ, Chen Y, et al. The effect of pericapsular nerve group (PENG) block on postoperative analgesia in elderly patients who underwent proximal femoral nail anti-rotation surgery: a prospective, randomized-controlled trial. BMC Anesthesiol 2024;24(1):421.
52. Guay J, Kopp S. Peripheral nerve blocks for hip fractures in adults. Cochrane Database Syst Rev 2020;11(11):CD001159.
53. Moppett I. Individualised care or anaesthetist preference: an uncomfortable question. Br J Anaesth 2022;128(3):408–10.
54. Trelles Centurion M, Van Den Bergh R, Gray H. Anesthesia provision in disasters and armed conflicts. Curr Anesthesiol Rep 2017;7(1):1–7.
55. Gros T, Dareau S, Causse L, et al. Sciatic nerve block in prehospital care without nervestimulator. Ann Fr Anesth Reanim 2007;26(4):381–3 [in French].
56. Gros T, Delire V, Dareau S, et al. Interscalene brachial plexus block in prehospital medicine. Ann Fr Anesth Reanim 2008;27(10):859–60 [in French].
57. Gaik C, Schmitt N, Schubert AK, et al. [Regional Anaesthesia in the Prehospital Setting]. Anasthesiol Intensivmed Notfallmed Schmerzther 2024;59(6):386–99.
58. Lippert SC, Nagdev A, Stone MB, et al. Pain control in disaster settings: a role for ultrasound-guided nerve blocks. Ann Emerg Med 2013;61(6):690–6.
59. Slade S, Hanna E, Pohlkamp-Hartt J, et al. Efficacy of Fascia Iliaca compartment blocks in proximal femoral fractures in the prehospital setting: a systematic review and meta-analysis. Prehospital Disaster Med 2023;38(2):252–8.
60. Buttner B, Mansur A, Kalmbach M, et al. Prehospital ultrasound-guided nerve blocks improve reduction-feasibility of dislocated extremity injuries compared to systemic analgesia. A randomized controlled trial. PLoS One 2018;13(7):e0199776.
61. Albrecht E, Taffe P, Yersin B, et al. Undertreatment of acute pain (oligoanalgesia) and medical practice variation in prehospital analgesia of adult trauma patients: a 10 yr retrospective study. Br J Anaesth 2013;110(1):96–106.

62. Noble J, Zarling B, Geesey T, et al. Analgesia use in children with acute long bone fractures in the pediatric emergency department. J Emerg Med 2020; 58(3):500–5.
63. Joint Commission Resources. Comprehensive Accreditation Manual for Hospitals: The Official Handbook. Oakbrook Terrace (IL): Joint Commission Resources; 2025.
64. Saranteas T, Kostroglou A, Anagnostopoulos D, et al. Pain is vital in resuscitation in trauma. SICOT J 2019;5:28.
65. Farley P, Abraham P, Griffin RL, et al. Pain in trauma patients: measurement and predisposing factors. J Surg Res 2023;291:321–9.
66. Fortune S, Frawley J. Optimizing pain control and minimizing opioid use in trauma patients. AACN Adv Crit Care 2021;32(1):89–104.
67. Blaivas M, Adhikari S, Lander L. A prospective comparison of procedural sedation and ultrasound-guided interscalene nerve block for shoulder reduction in the emergency department. Acad Emerg Med 2011;18(9):922–7.
68. Stewart B, Tudur Smith C, Teebay L, et al. Emergency department use of a continuous femoral nerve block for pain relief for fractured femur in children. Emerg Med J 2007;24(2):113–4.
69. Sahoo S, Sahoo NK, Hansda U, et al. Ultrasound-guided pericapsular nerve block compared with IV opioids in hip injuries: a randomised controlled trial. Am J Emerg Med 2024;81:99–104.
70. Tezel O, Kaldirim U, Bilgic S, et al. A comparison of suprascapular nerve block and procedural sedation analgesia in shoulder dislocation reduction. Am J Emerg Med 2014;32(6):549–52.
71. Shinde V, Penmetsa P, Dixit Y. Application of nerve blocks in upper and lower extremity trauma patients presenting to the emergency department of a tertiary care hospital: a prospective observational study. Cureus 2024;16(7):e65664.
72. Kong B, Zabadayev S, Perese J, et al. Ultrasound-guided fascia iliaca compartment block simulation training in an emergency medicine residency program. Cureus 2024;16(1):e52411.
73. Perlman R, Bonge S. Regional anesthesia in trauma patients: a quality improvement study. Eur J Trauma Emerg Surg 2023;49(1):495–504.
74. Saga E, Falk RS, Bing-Jonsson PC, et al. Nurse-led ultrasound-guided femoral nerve block: a randomised controlled trial of two different patient flow systems in an emergency department. Int J Orthop Trauma Nurs 2024;52:101074.
75. Shamala NSK, Mohd LH, Siti RJ, et al. Development of ultrasound guided regional anaesthesia in the emergency department, Hospital Kuala Lumpur. Med J Malaysia 2024;79(3):370–3.
76. O'Donnell BD, Ryan H, O'Sullivan O, et al. Ultrasound-guided axillary brachial plexus block with 20 milliliters local anesthetic mixture versus general anesthesia for upper limb trauma surgery: an observer-blinded, prospective, randomized, controlled trial. Anesth Analg 2009;109(1):279–83.
77. Soffin EM, Gibbons MM, Wick EC, et al. Evidence review conducted for the agency for Healthcare Research and Quality Safety Program for improving surgical care and recovery: focus on anesthesiology for hip fracture surgery. Anesth Analg 2019;128(6):1107–17.
78. Griffiths R, Babu S, Dixon P, et al. Guideline for the management of hip fractures 2020: guideline by the Association of Anaesthetists. Anaesthesia 2021;76(2): 225–37.

79. Hayashi M, Yamamoto N, Kuroda N, et al. Peripheral nerve blocks in the preoperative management of hip fractures: a systematic review and network meta-analysis. Ann Emerg Med 2024;83(6):522–38.
80. Diakomi M, Papaioannou M, Mela A, et al. Preoperative fascia iliaca compartment block for positioning patients with hip fractures for central nervous blockade: a randomized trial. Reg Anesth Pain Med 2014;39(5):394–8.
81. Sia S, Pelusio F, Barbagli R, et al. Analgesia before performing a spinal block in the sitting position in patients with femoral shaft fracture: a comparison between femoral nerve block and intravenous fentanyl. Anesth Analg 2004;99(4):1221–4, table of contents.
82. Ali FM, Ayub A, Darlong V, et al. Ultrasound-guided suprainguinal fascia iliaca block to position the patient for neuraxial anaesthesia in acetabular surgery - a randomized controlled pilot study. Anaesthesiol Intensive Ther 2024;56(1):54–60.
83. Liu Q, Chelly JE, Williams JP, et al. Impact of peripheral nerve block with low dose local anesthetics on analgesia and functional outcomes following total knee arthroplasty: a retrospective study. Pain Med 2015;16(5):998–1006.
84. Samet RE, Kahntroff SL, Langhammer CG, et al. Successful ultrasound-guided supraclavicular brachial plexus continuous blockade for traumatic amputation of digits in a 3-year-old child: a case report. Paediatr Anaesth 2024;34(12):1275–6.
85. Verdecchia N, Praslick A, Visoiu M. Safety assessment of prolonged nerve catheters in pediatric trauma patients: a case series study. Children 2024;11(2).
86. Dattatri R, Jain VK, Iyengar KP, et al. Anaesthetic considerations in polytrauma patients. J Clin Orthop Trauma 2021;12(1):50–7.
87. Niazi AU, Solish M, Moorthy A, et al. Use of fascial plane blocks for traumatic rib fractures: a scoping review. Reg Anesth Pain Med 2025. doi:10.1136/rapm-2024-106366. [Epub ahead of print].
88. Aitken E, Jackson A, Kearns R, et al. Effect of regional versus local anaesthesia on outcome after arteriovenous fistula creation: a randomised controlled trial. Lancet 2016;388(10049):1067–74.
89. Schley M, Topfner S, Wiech K, et al. Continuous brachial plexus blockade in combination with the NMDA receptor antagonist memantine prevents phantom pain in acute traumatic upper limb amputees. Eur J Pain 2007;11(3):299–308.
90. Ilfeld BM, Khatibi B, Maheshwari K, et al. Ambulatory continuous peripheral nerve blocks to treat postamputation phantom limb pain: a multicenter, randomized, quadruple-masked, placebo-controlled clinical trial. Pain 2021;162(3):938–55.
91. Ilfeld BM, Khatibi B, Maheshwari K, et al. Patient-centered results from a multicenter study of continuous peripheral nerve blocks and postamputation phantom and residual limb pain: secondary outcomes from a randomized, clinical trial. Reg Anesth Pain Med 2023;48(9):471–7.
92. 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.
93. Kao MC, Tsai SK, Tsou MY, et al. Paraplegia after delayed detection of inadvertent spinal cord injury during thoracic epidural catheterization in an anesthetized elderly patient. Anesth Analg 2004;99(2):580–3, table of contents.
94. Benumof JL. Permanent loss of cervical spinal cord function associated with interscalene block performed under general anesthesia. Anesthesiology 2000;93(6):1541–4.

95. Bromage PR, Benumof JL. Paraplegia following intracord injection during attempted epidural anesthesia under general anesthesia. Reg Anesth Pain Med 1998;23(1):104–7.
96. Kubulus C, Schmitt K, Albert N, et al. Awake, sedated or anaesthetised for regional anaesthesia block placements?: a retrospective registry analysis of acute complications and patient satisfaction in adults. Eur J Anaesthesiol 2016;33(10):715–24.
97. Marhofer P. Regional blocks carried out during general anesthesia or deep sedation: myths and facts. Curr Opin Anaesthesiol 2017;30(5):621–6.
98. Walker BJ, Long JB, Sathyamoorthy M, et al. Complications in pediatric regional anesthesia: an analysis of more than 100,000 blocks from the pediatric regional anesthesia network. Anesthesiology 2018;129(4):721–32.
99. Weller RS, Gerancher JC, Crews JC, et al. Extensive retroperitoneal hematoma without neurologic deficit in two patients who underwent lumbar plexus block and were later anticoagulated. Anesthesiology 2003;98(2):581–5.
100. Joubert F, Gillois P, Bouaziz H, et al. Bleeding complications following peripheral regional anaesthesia in patients treated with anticoagulants or antiplatelet agents: a systematic review. Anaesth Crit Care Pain Med 2019;38(5):507–16.
101. Kleinveld DJB, Hamada SR, Sandroni C. Trauma-induced coagulopathy. Intensive Care Med 2022;48(11):1642–5.
102. Kopp SL, Vandermeulen E, McBane RD, et al. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American Society of Regional Anesthesia and Pain Medicine Evidence-Based Guidelines (fifth edition). Reg Anesth Pain Med. 2025. [Epub ahead of print]. doi:10.1136/rapm-2024-105766.
103. Douketis JD, Spyropoulos AC, Murad MH, et al. Perioperative management of antithrombotic therapy: an American college of Chest Physicians Clinical Practice Guideline. Chest 2022;162(5):e207–43.
104. Chelly JE, Metais B, Schilling D, et al. Combination of superficial and deep blocks with rivaroxaban. Pain Med 2015;16(10):2024–30.
105. Dayan RR, Ayzenberg Y, Slutsky T, et al. Safety of femoral nerve blockade for hip fractures inAdult patients treated with Anti-Xa direct oral anticoagulants: a pilot study. Isr Med Assoc J 2021;23(9):595–600.
106. Dultz LA, Ma R, Dumas RP, et al. Safety of erector spinae plane blocks in patients with chest wall trauma on venous thromboembolism prophylaxis. J Surg Res 2021;263:124–9.
107. Tsui BCH, Kirkham K, Kwofie MK, et al. Practice advisory on the bleeding risks for peripheral nerve and interfascial plane blockade: evidence review and expert consensus. Can J Anaesth 2019;66(11):1356–84.
108. Tsui BCH. A systematic approach to scoring bleeding risk in regional anesthesia procedures. J Clin Anesth 2018;49:69–70.
109. Kane PM, Daniels AH, Akelman E. Double crush syndrome. J Am Acad Orthop Surg 2015;23(9):558–62.
110. Schneiderman BA, O'Toole RV. Compartment syndrome in high-energy tibial Plateau fractures. Orthop Clin North Am 2022;53(1):43–50.
111. Dwyer T, Burns D, Nauth A, et al. Regional anesthesia and acute compartment syndrome: principles for practice. Reg Anesth Pain Med 2021;46(12):1091–9.
112. Samet RE, Torrie AM, Chembrovich SV, et al. Pro-con debate: peripheral nerve blockade should be provided routinely in extremity trauma, including in patients at risk for acute compartment syndrome. Anesth Analg 2023;136(5):855–60.

113. Samet RE, Brookman JC, Grissom TE. Peripheral nerve blockade for tibia fractures: to block or not to block? Is it still a question? Anesth Analg 2025;140(6):1286–9.
114. Soulioti E, Pertsikapa M, Fyntanidou B, et al. Trauma patients and acute compartment syndrome: is there an ariadne's thread that can safely guide the anesthesiologist/emergency physician out of the labyrinth? Medicina (Kaunas) 2024;60(8).
115. Kakalecik J, Satchell C, Root KT, et al. Relationship between perioperative regional anesthesia and the risk of missing acute compartment syndrome following tibia fractures. Anesth Analg 2025;140(6):1290–6.
116. Hilber N, Dodi A, Blumenthal S, et al. The impact of regional anesthesia in masking acute compartment syndrome after limb trauma. J Clin Med 2024;13(6).
117. Topor B, Oldman M, Nicholls B. Best practices for safety and quality in peripheral regional anaesthesia. BJA Educ 2020;20(10):341–7.
118. Alakkad H, Naeeni A, Chan VWS, et al. Infection related to ultrasound-guided single-injection peripheral nerve blockade: a decade of experience at Toronto Western hospital. Reg Anesth Pain Med 2015;40(1):82–4.
119. Bomberg H, Bayer I, Wagenpfeil S, et al. Prolonged catheter use and infection in regional anesthesia: a retrospective registry analysis. Anesthesiology 2018;128(4):764–73.
120. Stojadinovic A, Auton A, Peoples GE, et al. Responding to challenges in modern combat casualty care: innovative use of advanced regional anesthesia. Pain Med 2006;7(4):330–8.
121. Lai TT, Jaeger L, Jones BL, et al. Continuous peripheral nerve block catheter infections in combat-related injuries: a case report of five soldiers from operation enduring freedom/operation Iraqi freedom. Pain Med 2011;12(11):1676–81.
122. Wood P, Gill M, Edwards D, et al. Clinical and microbiological evaluation of epidural and regional anaesthesia catheters in injured UK military personnel. J R Army Med Corps 2016;162(4):261–5.
123. White LD, Riley B, Davis K, et al. Safety of continuous erector spinae catheters in chest trauma: a retrospective cohort study. Anesth Analg 2021;133(5):1296–302.
124. Azi L, Fonseca NM, Linard LG. [SBA 2020: regional anesthesia safety recommendations update]. Braz J Anesthesiol 2020;70(4):398–418.
125. Provenzano DA, Hanes M, Hunt C, et al. ASRA Pain Medicine consensus practice infection control guidelines for regional anesthesia and pain medicine. Reg Anesth Pain Med 2025, [Epub ahead of print]. doi:10.1136/rapm-2024-105651.