Journal of Pain Research

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REVIEW

Pain Control with Regional Anesthesia in Patients at Risk of Acute Compartment Syndrome: Review of the Literature and Editorial View

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Abstract: Acute compartment syndrome (ACS) is a devastating complication that can happen in almost every part of the human body, most noticeably after long bone fractures. The cardinal symptom of ACS is pain in excess of what would otherwise be expected from the underlying injury and unresponsive to routine analgesia treatment. There is paucity of literature on major analgesic management strategies including opioid analgesia, epidural anesthesia, and peripheral nerve blocks with regard to their differential efficacy and safety of pain management in patients at risk of developing ACS. The lack of quality data has led to recommendations that are perhaps more conservative than they should be, particularly when it comes to peripheral nerve blocks. In this review article, we attempt to make recommendations in favor of regional anesthesia in this vulnerable group of patients and strategies that will optimize adequate pain control and improve surgical outcome without jeopardizing patient safety.

Keywords: regional anesthesiology, trauma, nerve blocks, acute compartment syndrome

Introduction

Despite the many well documented benefits associated with regional anesthesia in pain management as compared to opioids, controversy remains surrounding its use in certain settings where acute compartment syndrome is of concern. This includes post-trauma pain management in the emergency room as well as perioperative acute pain management. The medical management of trauma patients is a fundamental component of the practice of medicine. Trauma accounts for almost thirty percent of all life years lost in the US, which is greater than the combination of cancer, heart disease and HIV.[1] The treatment of trauma patients must continue to advance. Given the variety of traumatic injuries as well as the economic burden of these patients which accounts for over $400 billion annually in the United States, new methods and treatment options should be considered and developed.[2] One of these being the institution of regional anesthesiology nerve blocks and to lay to rest the speculation about their safety. Use of regional techniques in trauma patients, however, has been a controversial topic since the start because these patients are at higher risk of acute compartment syndrome (ACS) that can occur in many parts throughout upper extremity, lower extremity, and abdomen (Table 1). Those that argue against the use of regional anesthesia in these cases argue that hiding or blunting pain can mask one of the presenting symptoms of ACS.[3] In this review, we argue in favor of the use of regional anesthetic techniques in trauma patients, specifically in favor of single-shot or lower doses of continuous peripheral nerve blocks over epidural or patient controlled analgesia (PCA).

Pain management in trauma patients is often disregarded and sidelined in favor of saving the life/limb of a patient. In the cases where pain management can be addressed, systemic opioids are by far the most utilized option given their potency and effectiveness in managing generalized pain. However, systemic opiates bring about secondary consequences that may hinder the provider's ability to stabilize a patient. Many opiates lead to vasodilation and hypotension which is detrimental to a patient

Received: 20 November 2022
Accepted: 15 February 2023
Published: 2 March 2023

Table 1 Compartments of the Body and Their Innervation. This Chart Also Lists the Most Common Causes of Compartment Syndrome by Upper Extremity, Lower Extremity, and Abdominal Divisions, as Well as Possible Pain Control Modalities in These Areas

	Compartment	Nerve	Common Trauma/ Procedures Leading to Compartment Syndrome in this Area (Divided by Upper, Lower, and Abdomen)	Regional Anesthesia Used for these Procedures (Divided by Upper, Lower, and Abdominal)	Other Modalities of Pain Control
Upper arm	Anterior	Musculocutaneous	Supracondylar humerus fracture[28]	Brachial plexus (interscalene, axillary, supraclavicular, infraclavicular) catheter or single shot PNB[29] Wrist block[30] or individual nerve block for the compartment	Opioid based analgesia such as PCA
	Posterior	Radial	Intraosseous fluid administration[28]		
	Deltoid	Axillary			
Forearm	Mobile wad	Radial	Distal radial/ulnar fracture[28]		
	Volar	Median	Radial artery puncture[28]		
	Dorsal	Radial (posterior interosseous)			
Hand	Four dorsal interossei	Ulnar	Carpometacarpal fracture-dislocation[31]		
	Three palmar interossei	Ulnar			
	Thenar	Median, ulnar			
	Hypothenar	Ulnar			
	Adductor pollicis	Ulnar			
Abdomen	Abdominal	Intercostal nerves	Coagulopathy and postoperative hemorrhage (trauma), pregnancy, abdominal aortic repair, liver transplantation[32]	Truncal peripheral block such as transverse abdominal plane, rectus sheath, quadratus lumborum, erector spinae, paravertebral PNBs, spinal/epidural[33]	
Lower Leg	Anterior	Deep peroneal	Tibial fracture[10]	Sciatic, femoral, adductor canal, saphenous, lateral femoral cutaneous, ankle,[34] PNBs, spinal/ epidural[29]	
	Lateral	Superficial peroneal	Fibular fracture[16]		
	Superficial posterior	Tibial			
	Deep posterior	Tibial			
Thigh	Anterior	Femoral	Acute muscle overuse, burns, arterial ischemia, compression[35]		
	Posterior	Tibial			
	Medial	Obturator			
Foot	Medial	Tibial	Crush injury, falling from height[36]		
	Lateral	Tibial			
	Central				
	Interosseous				

in shock. Moreover, in patients with altered mentation, the effects of respiratory depression and subsequent airway compromise may also be detrimental to these patients. The myriad of patient presentations that stem from trauma in combination with opiates are difficult to manage including polysubstance/baseline altered mentation which may be exacerbated with opiates. An accurate neurological exam is crucial especially in head trauma patients which can be skewed in the

context of these medications. On a structural level, the variety of providers in an Emergency Department and staff turnover makes continuity and assurance of proper medical management difficult in these acute settings which can either lead to olio-analgesia or to overdosing patients on opiates.[4]

Regional Blocks

In the surgical setting, the implementation of regional anesthesia has yielded tremendous results both for intra and postoperative management of patients. The ability to provide site-specific analgesia allows for fewer systemic medications to be utilized which bring about their own side effects including sedation and hemodynamic changes. There have been multiple studies that demonstrate the benefits of the utilization of site-specific anesthesia including improvement in wound healing, decreased stressed responses on cardiovascular symptoms, and improved localized blood flow—all components that would be beneficial to trauma patients.[1] From an institutional standpoint, there are also financial incentives as an enhancement in patient recovery will allow for an earlier discharge and shorter duration of hospital stay.[5]

Nonetheless, the widespread implementation of regional blockades into common practice has not occurred due to several concerns from trauma surgeons/providers. Given certain patient presentations, neurologic exams are crucial to determine motor and sensory deficits from trauma which are often evaluated throughout patient care: from preoperatively, intraoperatively, and postoperatively. As such, the utilization of regional blocks may distort accurate patient exams as the effects of local anesthetic blockade can alter sensorium and muscle strength. This can put these patients at increased risk for falls. In addition, the effectiveness, duration, as well as variety of blocks utilized is operator dependent. Consequently, the variability in patient results unfortunately alters the general perception of the utilization of this modality in this patient care setting. Aligned with the operator dependent efficacy of regional blockades, the timing of doing these factors is often a concern for surgeons. In most surgical settings, regional blockades are well integrated into the flow of a surgery where the anesthesiologist provider has the time to appropriately perform the procedure. However, in the setting of trauma patients, there may be concern for delayed starts to the operating room.[6]

Compartment Syndrome

One of the greatest obstacles to the universal implementation of regional anesthetics into trauma surgery is the concern of compartment syndrome. Compartment syndrome involves the accumulation of bleeding/swelling of tissues within anatomical compartments that leads to high pressures. This can decrease blood flow and lead to substantial damage to surrounding nerves, muscles, and tissues.[7] It is associated with all forms of trauma, from orthopedic, vascular reperfusion injuries/hemorrhages, and crush injuries of the soft tissues, to iatrogenic etiologies such as from arterial/venous puncture in anticoagulated patients. This pathology is a medical emergency that can be easily managed with a fasciotomy but requires emergent treatment to prevent permanent damage.[8]

The incidence of compartment syndrome occurring after injuries is approximately 3.1 per 100,000 with a predominance in younger males (30–35 years old) with larger muscle masses stemming from high energy activities/accidents.[9,10] The most common injuries leading to compartment syndrome are tibial shaft fracture, soft tissue injury, and forearm shaft fracture.[11–13] In the pediatric population, older male trauma patients, those who experience firearm injury, and lower limb fracture have increased risk of compartment syndrome.[14] Another subset of the patient population that experiences compartment syndrome is the geriatric population, where initial clinical presentation can be easily masked by multiple medical comorbidities and altered mental status.[15]

The diagnosis of compartment syndrome is clinical and traditionally revolves around six signs and symptoms including pain, paresthesia, paresis, pallor, pulselessness, and poikilothermia.[16] Paresthesia is often the earliest sign of compartment syndrome and should prompt urgent evaluation to ensure a good outcome. Given higher risk demographics, the age and gender of patients is also important in appropriately diagnosing this pathology. From there, the mechanism of injury should be evaluated to help direct patient management. The utilization of a transducer catheter can help confirm the diagnosis if the pressure of the area of concern is more than 30mmHg. An intercompartmental pressure of 10mmHg to 30mmHg of the patient's diastolic blood pressure can also be indicative of inadequate blood perfusion and relative ischemia.[17,19]

The diagnosis of compartment syndrome in pediatric patients can be a challenging one, particularly in those who are non-verbal or unable to fully communicate their symptoms. In this population, the 3 A's (anxiety, agitation, and increased analgesic

requirements) are often cited as presenting symptoms instead of the traditional symptoms seen in the adult population.[18] There are also reports of "silent" compartment syndrome in pediatric patients, where patients present with painless swelling and are found to have elevated compartment pressures when taken to the operating room for fasciotomy.[19]

With continued integration of regional anesthetic into the standard of care, there remains some concern that local nervous blockade can inhibit/delay the diagnosis of compartment syndrome. There is a paucity of randomized controlled trials on the effect of regional anesthesia on compartment syndrome, but one study by Chen et al took healthy volunteers randomized to receive adductor canal block alone or in conjunction with either low or high concentration sciatic nerve block to see if the blocks affected the patients' ability to sense 6/10 pain induced by prolonged pressure.[20] This study showed that all blocks increased the pressure-pain threshold to varying extents. Further study through randomized controlled trials is necessary.

Statements from Major Anesthesia Societies

A literature review by E. Driscoll in 2016 evaluated 34 articles with the majority (75%) demonstrating that regional anesthesia did not put the patient at an increased risk of delayed diagnosis of compartment syndrome.[7,8] In evaluating these patients who had a diagnosis of compartment syndrome, there were more than enough clinical presentation factors that would be of concern to evaluate for this pathology. However, it was found that neither regional anesthetics nor the implementation of Patient Controlled Analgesia (PCA) contributed to this.[7] The efficacy of regional anesthesia has made leaps and bounds with improvements in ultrasound technology and user skill set, leading to a more accurate placement of local anesthetics which also allows for lower concentrations to be utilized.

In Table 2, we detail all cases of compartment syndrome with regional anesthesia, PCA, or epidural anesthesia found in the literature and whether these modalities of pain control were seen as contributing to delayed diagnosis of compartment syndrome. In several case reports, there have been concerns that peripheral nerve blocks lead to the delay in the diagnosis of compartment syndrome although these claims are often unjust or inaccurate. There have been additional case reports that attribute epidural anesthesia and patient-controlled analgesia pumps to the delay of compartment syndrome diagnoses.[21] In contrast, other studies support the claim that peripheral nerve blocks aid in diagnosis, as they do not completely block ischemic pain, therefore if a patient with a nerve block is having pain out of proportion to exam, it is more likely a pathologic process.[22,23] Fundamentally, ischemic pain cannot be completely categorized as nociceptive and neuropathic as there is likely a sympathetic component which follows blood vessels and nerves. As such, there is the need to question the likelihood of completely blocking ischemic pain through regional anesthesia where systemic opiates (spinal/supraspinal) and epidurals may likely have greater/systemic effects than peripheral nerve blocks.[24] Consequently, it would be more prudent to determine what patients are being offered for pain management in these cases rather than focusing on regional anesthetics as the sole offender for delayed intervention.[25]

Table 3 further details the existing society statements on use of regional anesthesia when compartment syndrome is likely or present. Although there is no universal consensus, the Association of Anesthetists of Great Britain and Ireland have stated that compartment syndrome is not a contraindication for usage of regional anesthesia modalities.[3] Pain is not the only criteria for its diagnosis. Another factor being that patient's complaints of pain are subjective and are not a reliable benchmark for an instant, definitive diagnosis.[32] With this mindset that there is no evidence that regional anesthesia increases risks/delays acute compartment syndrome, the European Society of Regional Anesthesia and Pain Therapy (ESRA) in conjunction with the American Society of Regional Anesthesia and Pain Medicine (ASRA) joint committee have helped establish guidelines for best practices in pediatric patients[26] (Box 1).

Box 1 ESRA and ASRA Joint Committee Statement

Six Best Practice Rules for Use of Regional Anesthesia in Pediatric Patients
1. A single injection peripheral nerve block or neuraxial concentration of 0.1% to 0.25% bupivacaine, levobupivacaine, or ropivacaine.
2. Continuous peripheral nerve block or neuraxial concentrations of 0.125% bupivacaine, or 0.1–0.2% ropivacaine at a rate of 0.1–0.3 mg/kg/hr.
3. Exercise caution with local anesthetic adjuvants as they can increase the duration and intensity of a block.
4. In high-risk acute compartment syndrome areas such as the tibia: restrict the volume and concentration of local anesthetic.
5.Patients should follow up regularly with the acute pain service.
6. If acute compartment syndrome is suspected, urgent compartment pressure measurement should be performed.

Table 2 A Summary of Current Case Reports on Compartment Syndrome

Case Reports	Analgesia Type	Block Type	Age (yr)	Sex	Injury/ Procedure	Local Anesthetic Used	Diagnosis	Symptoms	Compartment Pressure	Pain level	Sequelae	Relation to Diagnosis of ACS
Peripheral Nerve Block												
Aguirre et al 2013[37]	PNB	Infraclavicular catheter: no anesthetic until after extubation: bolused ropivacaine	47	Female	Complex distal humerus fx	Ropivacaine 0.5%	14 hours after: received additional block	Pain	40mmg	10/100–>90/100	Two hematomas, no compartments under tension: no disabilities	Association but not fault
Cometa et al 2011[38]	PNB	Femoral and sciatic PNB w/ ropivacaine infusion	15	Male	Elective distal femur/proximal tibia osteotomy w/ external-fixation	0.2%ropivacaine	POD#2	Pain	x>30mmhg	0-->10/10	Tissue loss from fasciotomy	Did not delay ACS diagnosis
Ganeshan et al 2015[39]	PNB	Axillary PNB s/p 2 weeks after initial insult for revision	75	Male	Distal radius fx	Not listed	24hrs after revision	Edematous, blisters	46mmHg, 50		Strength loss	Patient was discharged before nerve block had worn off, initially represented with painless blistering, PNB masked pain
Hyder et al 2006[40]	PNB	Femoral/ obturator/ lateral cutaneous nerve of thigh	28	Male	Closed fracture of tibia	Bupivacaine 0.5%	48hours	Altered sensory sensation and inability to extend big toe	108mmhg	0	Rhabdomyolysis in anterior compartment: patient now requires orthosis	PNB masks pain
Kucera et al 2014[41]	PNB	SS femoral and sciatic PNB	29	Male	Elective right lateral ankle ligament	30 mL 0.5% ropivacaine for sciatic block and 20 mL of 0.75% ropivacaine for femoral	90min s/p cast application	Pain in ankle	n/a	Severe	Resolution of symptoms thought 2/2 ischemia	PNB does NOT block ischemic pain

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https://doi.org/10.2147/JPR.S397428 DovePress

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Table 2 (Continued).

	PNB	C7 paravertebral block	45	Female	Ischemic pain requiring finger amputation	0.2% ropivacaine continuous infusion	N/A	Pain	n/a	Severe	Nerve block was utilized after ischemic fingers diagnosed in an attempt to control ischemic pain	PNB does not affect ischemic pain
LaReau et al 2012[42]	PNB	Femoral PNB catheter:	73	Male	TKA	0.375% bupivacaine with epi	POD#1	Pain	50mmHG		None	Thinks reduced sensation led to masked pain
Munk-Andersen et al 2013[43]	PNB	Continuous distal Sciatic nerve block	12	Male	External fixation of tibia and fibula	Lidocaine 2% w/ ropivacaine 0.2%		Pain			None	PNB did not mask breakthrough pain
Noorpuri et al 2000[44]	PNB	SS ankle block	37	Female	Revisional arthroplasty foot	0.25% bupivacaine		Pain/ decreased sensation/ paresthesias	N/A		None	LA obscure clinical presentation of CS
Rauf et al 2013[45]	PNB	Supraclavicular PNB	19	Male	Right radius fracture (ORIF)	10 mL 2% lidocaine, 10 mL / 0.5% bupivacaine	2hrs s/p block (20min s/p extubation)	Severe pain/ swelling/loss radial pulse	n/a	10/10	None	LA did not mask clinical presentation of CS
Sermeus et al 2015[46]	PNB	Infraclavicular PNB	4	Male	Resection of forearm osteochondroma	0.125% bupivacaine w/ PCA	POD#1	Pain/reduced motor function/ disturbed capillary refill			No fasciotomy: remove cast was cause of clinical features	Use of low concentration was helpful in determine CS
Soberon et al 2016[47]	PNB	Perineural injection (median, ulnar, radial): proximal forearm	44	Male	(ORIF) distal radial fracture	15 mL 1.3% Liposomal bupivacaine and 30 mL 1.5% mepivacaine with hydromorphone PCA	POD#1	Numbness/ worsening pain			Emergency fasciotomy, all sensation recovered	Did not result in delay
Torrie et al 2017[48]	PNB/Spinal	Spinal w/ periarticular local w/ Adductor canal catheter	56	Male	Elective primary TKA	0.2% ropivacaine	6 Hours after surgery	Tightness	47mmgHG	10/10 pain	None: emergency fasciotomy	Did not delay

Walker et al 2012[49]	PNB	Popliteal catheter w/ additional saphenous nerve block	19	Female	Calcaneal lengthening osteotomy and achilles tendon lengthening	0.2% ropivacaine continuous infusion	POD 2	Pain and tightness	Not measured			Cast was split and spacers applied due to worsening pain prompting ED visit. Breakthrough pain despite working popliteal catheter prompted diagnosis.
Uzel et al 2009[50]	PNB	SS Femoral nerve	26	Male	Closed femoral fracture internal fixation	Ropivacaine 0.5% 20 mL	POD#1	Pain/ tightness/ discoloration	54mmhg	severe	Emergent fasciotomy	May have delayed, but no functional deficits
Ivra												
Ananthanarayan et al 2000[51]	IVRA	107 min tourniquet time	57	Male	Left dupuytren contracture	360 mg lidocaine w/ tourniquet	Minutes of tourniquet release	Muscle tension/hand anesthesia/ pallor/limited motor	Clinical eval		None	Unclear etiology
	IVRA	64 Min tourniquet time	73	Female	Dupuytren fasciotomy	200 mg lidocaine		Pain and forearm swelling	Clinical eval	Severe	Emergency fasciotomy with eventual complete recovery	Unclear etiology
Hastings et al 1987[52]	IVRA	85 min tourniquet time	54	Female	Multiple trigger fingers	1% Lidocaine 20 mL with 20 mL hypertonic saline	POD#0 after tourniquet release	Skin blebs/ swelling	N/A	Severe	Persistent neuritis of median nerve w/ carpal tunnel	Inadvertent injection of hypertonic saline leading to iatrogenic CS
	IVRA	67 Min tourniquet time	22	Female	Synovectomy of index finger	1% Lidocaine 20 mL with 20 mL hypertonic salinen/a	POD#0 after tourniquet release	Swelling	N/a	Moderate pain/ swelling	NONE	Inadvertent injection of hypertonic saline (same day/ anesthesiologist as case described above) did not result in any permanent sequelae
	IVRA	25 Miin tourniquet time	37	Female	Colles fracture (closed fixation)	Xylocaine with hypertonic saline	POD # after tourniquet release	Severe swelling/pain	50 mmhg	Severe	Stiffness w/ strength loss	Inadvertent hypertonic saline injection leading to iatrogenic CS
Mabee et al 1994[53]	IVRA	40 Minute tourniquet time Bier block	26	Male	Bennet fracture: closed reduction	0.5% lidocaine 41 mL with 20 mL hypertonic saline	30/40 min: cast removed	Pain/tightness	49mmHg	Severe	None s/p fasciotomy	Inadvertent hypertonic saline injection leading to iatrogenic CS: osmotic increase in ECF
Quigley et al 1981[54]	IVRA	IVRA (bier)	25	Male		Hypertonic saline	n/a	Pain/fever	n/a			

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Table 2 (Continued).

Epidural/CSE											
Beerle et al 1993[55]		Epidural	74	Female	Radical cystectomy	0.125% bupivacaine and fentany 3mcg/cc at 8cc/hrl	POD#0: 30min after extubation (7.5hr surgery)	Tense, swollen, left leg with distal pallor			None s/p fasciotomy (kept use of epidural)	Epidural did not mask CS
Bezwada et al 2005[56]		CSE	60	Male	Bilateral total knee joint replacement	Bupivacaine and fentanyl						
Chittoodan et al 2009[57]		Epidural	17	Female	Bowel resection	Fentanyl w/ LA	POD#0	Left leg pain			None: no residual weakness	Patient was able to verbalize her discomfort which helped lead to the diagnosis early on
Osteen et al 2010[58]		CSE	52	Male	Right TKA	0.75% Bupivacaine (subarachnoid space)/ fent 2mcg/cc ropivacaine 0.2% ropi	POD#1	Numbness of left buttock with progressive LE numbness/ POD#2 based on labs	n/a		None	
Price et al 1996[59]		Epidural	16	Male	b/l corrective osteotomies (genu varum)	Fentanyl	18hrs	Swelling/ tense	64mmHg (Left)			
Strecker et al 1986[60]		Epidural	45	Male	Infected non-union of L tibia	0.125% Bupivacaine	POD 8	Pain, swelling			Unable to evert foot	Diagnosed on day 8, epidural discontinued day 4. Writers believe epidural anesthesia masked the pain of CS.
Sorrentino, F. et al 1998[61]		Epidural	19	Male		Bupivacaine	POD#3	Painful swollen ant compartment	100mgHg		Palsy of dorsiflexion of foot	Not masked–patient had breakthrough pain
Tang, W. M., and Chiu, K. Y. 2000[62]		Epidural	62	Female	(Post dislocation): TKA	0.125% bupivacaine	POD#2	Poor circulation/ swelling	65,75,75,80 (ant/ peroneal/ superficial/deep)	None	Severe muscle necrosis	Pain on passive flexion concerning for CS: epidural contraindicated for complex TKA

Pollard R.L.E., O'Broin E 2009[63]		Epidural	44	Female	Left breast flap reconstruction with deep inferior epigastric perforator (DIEP) flap	Bupivacaine 0.1% and fentanyl 2 μg mL	POD#4	b/l leg cramps with finding of b/l Leg ACS (chronic)	n/a		Physiotherapy	PCA and epidural masked pain too well and delayed dx
PCA												
Harrington, P. et al 2000[64]		PCA	53	Male	Isolated open oblique fracture of the mid tibia shaft (no neurovascular deficit)	Morphine	36hr	Tense	x>50mmHg	2/3 out of 10	None s/p fasciotomy	PCA delayed dx: utilization was meant to allow patient to dictate own pain control
Mannion et al 2017[65]		PCA	21	Male	Closed displaced tibia fracture	Morphine	26hrs	Inability to dorsiflex toes/cold ischemic limb	n/a	None	BKA	Could have dx earlier despite use of PCA (15 year later evaluation)
O'Sullivan, M. J. et al 2002[66]		PCA	21	Male	Closed displaced fracture of tibia	Morphine*dosing unavailable	7–18hrs	Pale/numb/ cold/inability to dorsiflex	n/a	Inability to dorsiflex	BKA	Ortho team did not react to findings despite clinical evidence of ACS
Ploumis et al 2010[67]		PCA	53	Female	Anterior interbody and posterior L3-S1 instrumented fusion	Hydromorphone	POD #1	Pain w/ pressure ecchymosis	n/a		Anterolateral tibia ACS requiring fasciotomy w/ residual weakness and recurrent right foot edema	PCA masked symptoms of limb ischemia
Richards, H. et al 2004[68]		PCA	28	Male	Displaced oblique fracture of tibial diaphysis	Morphine (10mg-20)	18hrs	Tense/foot drop		0	Clawing of toes s/p fasciotomy	PCA delayed dx
		PCA	27	Male	Building transverse midshaft tibia fx	Morphine (13mg)	26hr	Unable to move toes/ altered sensation	x>40mmHg		Toe clawing and tightness	PCA delayed dx
		PCA	20	Male	Displaced obluqe fracture of tibia	Morphine (15mg)	16hrs	Altered sensorium	x>50mmHg	None	Permanent foot drop	PCA delayed dx

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Table 2 (Continued).

		PCA	26	Male	Oblique displaced diaphyseal tibial fracture	Morphine (17mg)	18hrs	Tense calf/ altered sensorium	n/a	None	48s/p fasciotomy dead tissue: loss of power of dorsiflexion and toe clawing	PCA delayed dx
Yang J. et al 2010[69]		PCA	10	Male	Left midshaft compound fracture	Morphine 20 μg/ kg w/ 5 min lockout	POD1	Swelling, pain on passive stretching	n/a	5–6 out of 10	Slight decrease in forearm power	Does not delay diagnosis just needs better monitoring
			7	Male	Supracondylar fx	Morphine PCA	POD#0-1 prior to PCA	Pain on active/passive movement	n/a		Decrease in elbow ROM	Poor capillary refill requiring arteriotomy and vein patch graft
Teen M. et al 2017[70]		PCA	29	Male	Metatarsal crush injury	0.125% Bupivacaine	No additional details provided					NO FINDINGS OF ACS despite concerns for swelling
			45	Male	Metatarsal crush injury	0.125% bupivacaine	No additional details provided					NO FINDINGS OF ACS despite concerns for swelling
McLaughlin et al 2016[70]		PCA	67	Female	Ischemic limb	0.1% ropivacaine	No additional details provided					NO FINDINGS OF ACS despite concerns for swelling

Abbreviations: PNB, peripheral nerve block; SS, single shot; POD, postoperative day; S/P: status post; ORIF, open reduction internal fixation; Fx, fracture; ACS, acute compartment syndrome; IVRA, intravenous regional anesthesia; CSE, combined spinal epidural; PCA, patient-controlled analgesia.

Table 3 Summary Table of World Society Guidelines on Use of Regional Anesthesia and Its Effect on Compartment Syndrome

Specialty	Society	Statement
Anesthesia	Association of Anaesthetists of Great Britain and Ireland[3]	"Use of neuraxial or peripheral regional techniques that result in dense blocks of long duration that significantly exceed the duration of surgery should be avoided.single-shot or continuous peripheral nerve blocks using lower concentrations of local anaesthetic drugs without adjuncts are not associated with delays in diagnosis provided post-injury and postoperative surveillance is appropriate and effective"
	American Society of Anesthesia	No consensus statement
	American Society of Regional Anesthesia	No consensus statement in adults
	European Society of Regional Anaesthesia & Pain Therapy	No consensus statement in adults
	European Society of Regional Anaesthesia and Pain Therapy and the American Society of Regional Anesthesia and Pain Medicine (joint statement)[26]	"There is no current evidence that the use of regional anesthetics increases the risk for ACS or delays its diagnosis in children"
	French Physical and Rehabilitation Medicine (SOFMER) and Anesthesia and Intensive care (SFAR) societies[71]	"Consider the risk of the consequences of the occurrence of a hematoma: minimal in the case of a superficial hematoma, more significant in the case of a deep hematoma threatening a compartment syndrome"
	Asian & Oceanic Society of Regional Anaesthesia and Pain Medicine	No consensus statement
	African Society of Regional Anesthesia	No consensus statement
Surgery	International Orthopaedic Trauma Association	No consensus statement
	American Academy Of Orthopedic Surgeons[72]	"Risk of neuraxial anesthesia delaying and/or masking signs/symptoms associated with impending compartment syndrome. outweighs the potential benefits of this treatment modality in high risk patient populations.regional anesthesia may delay diagnosis of acute compartment syndrome and that regional anesthesia does not mask timely diagnosis. If neuraxial anesthesia is administered, we recommend that more emphasis is placed on intra-compartmental pressure monitoring as well as break through pain despite regional anesthesia".
	European Orthopaedic Research Society	No consensus statement
	Asia Pacific Orthopaedic Association	No consensus statement

In addition to the primary concern for compartment syndrome, local anesthetic blockade is not a simple procedure without any risks in which patients receiving these procedures should be evaluated on a holistic basis prior to proceeding. Local anesthetic systemic toxicity is a low risk but nonetheless should be monitored especially in cases that require multiple catheters and infusions which can be further complicated by periodic boluses. Patients prior to regional anesthesia may also present with pre-existing nerve injuries which may be challenging to determine an accurate assessment of the blockade. Coagulopathies and bleeding risks are also considered in addition to infections which are concerns for any interventional procedure.

Conclusion

The practice of acute pain management is not simply the utilization of regional blockade, but rather a comprehensive multimodal approach to anesthesia and analgesia. The addition of standard medications including acetaminophen and nonsteroidal inflammatory drugs are fundamental tenets of pain management which can be further supplemented by additional regiments including dexmedetomidine and ketamine which has gained recent popularity for its analgesic effects. Benzodiazepines also have utility as medications such as valium have been extremely helpful in reducing muscle spasms in patients post-operatively. This multimodal approach of usage of a variety of medications and nerve blockades helps in many aspects. This approach minimizes the utilization of opiates and their unwanted side effects and helps improve patient clinical outcomes and satisfaction.

Trauma pain management has substantial importance and should continue to evolve to help improve patient outcomes. With substantial improvements in regional anesthesia and greater integration into clinical practice, anesthesiologists are in a unique position to become more involved in trauma pain management in multimodal format. Given some concerns with the use of regional blockade for acute compartment syndrome diagnosis, it should be noted that peripheral nerve blocks would be the preferred method for pain management rather than usage of patient-controlled analgesia or placement of an epidural.[27] The practice of medicine is a team effort and the incorporation of new innovative procedures aligned with improved patient communication and medical colleagues is key to ensuring clinical improvements, particularly in patients at risk for the development of acute compartment syndrome.

Disclosure

The authors report no conflicts of interest in this work.

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