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TITLE:

Evidence-Based Guideline for Peripheral Nerve Block Administration in Patients at Risk of Acute Compartment Syndrome

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This clinical practice guideline on peripheral anesthesia nerve blocks for acute compartment syndrome (ACS) is an evidence-based framework to guide the analgesic plan for patients at risk of compartment syndrome. The guideline assists patients, nurses, surgeons, and anesthesia providers in clinically treating this patient population. The Appraisal of Guidelines for Research & Evaluation II tool was used to ensure rigorous methodology and guideline validity. This guideline advises on peripheral nerve block (PNB) use for patients to preserve sensory nerve function hence pain perception during ACS progression. The question directing the evidence for this guideline is as follows: In patients at risk for developing ACS, do peripheral nerve blocks affect the presentation?

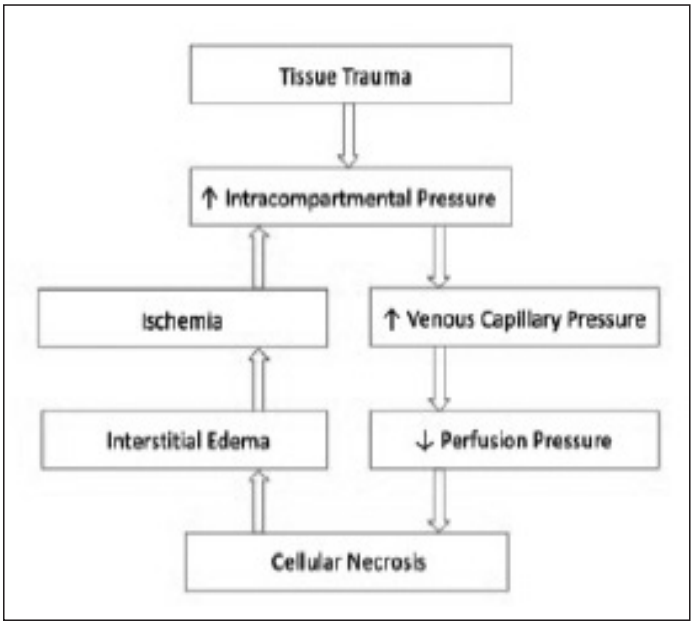
The benefits of peripheral nerve blocks (PNB) for orthopedics procedures and the challenges of ACS have been described in the literature; however, no single guideline which synthesizes both ACS sequela and recommendations for PNB dosage was found when our literature search was conducted.[3,4] Regional anesthesia blocks are increasingly being utilized for improved perioperative acute pain control, decreased opioid usage, and decreased hospital stays; but, debate exists regarding the utilization of PNBs for ACS due to the risk of delaying diagnosis by masking pain.[3]

There has been controversy over whose expertise predominates when ACS is suspected.[3,4] The consequences of a missed compartment syndrome diagnosis are devastating for the patient and have severe psychological, professional, and medicolegal consequences for all clinicians involved.[5] While the surgeon has valid concerns regarding the masking of the symptoms and potential delay of ACS diagnosis, the anesthesia provider must advocate for the patient's fundamental right to ethical pain control.[3,4] This document addresses the importance of multidisciplinary team building, ACS risk factors, staff education, diagnostic testing, compartment assessment monitoring, comorbidities, and medications as well as recommendations for using PNB techniques and subsequent local anesthetic dosage concentrations.[3-12]

Background

Acute compartment syndrome is a life-threatening, but reversible, orthopedic surgical emergency caused by a severe injury producing an increase in interstitial pressure within a non-compliant tissue compartment leading to tissue ischemia and eventual cell death.[3,5,9] Rapid limb swelling caused by bleeding and edema within the myofascial compartment decreases tissue blood flow and leads to permanent nerve injury, contracture, and loss of function.[5,9] Acute compartment syndrome leads to increased incidence of infections, amputation, recurrent surgeries, and death.[5] See Figure 1.

FIGURE 1



Prompt diagnosis and intervention via fasciotomy are indicated when ACS is suspected because permanent ischemic damage can begin within 2 to 3 hours after injury onset.[3,5] The diagnosis of ACS can be formidable because of the variation of symptom presentation and the rarity of the syndrome.[5] The most frequent symptom in 90% of cases of ACS is a complaint of overwhelming pain out of proportion to clinical findings.[3,6] The non-treatment of pain associated with ACS has presented an ethical dilemma, while the use of opioids and neuraxial techniques delay diagnosis.[3,4,6,7]

Professional Society Consensus

The guideline is a foundational offering to promote a robust collegial dialogue and a patient-focused framework for the development of a perioperative analgesia plan for ACS. Clear dialogue between all stakeholders concerning the difference between an analgesic and an anesthetic PNB. Addressing this difference will promote a better understanding of how PNBs can be utilized as a part of a multimodal pain treatment plan. One author included the recommendation by the French Society of Anaesthesia which encourages the use of PNBs for ACS analgesia due to increased blood flow via mild sympathetic blockade.[6] The Association of Anaesthetists of Great Britain and Ireland suggests dense and long-acting PNBs should be avoided, however, lower concentration and short-acting can be used if aligned with the surgery length.[18] The American Academy of Orthopedic Surgeons discourages neuraxial anesthesia but does recognize the current literature suggesting regional anesthesia could both possibly delay diagnosis of ACS or does not mask timely diagnosis of ACS.[18] No other domestic or international professional societies have consensus statements at the time of this literature review.

Peripheral Nerve Block for Compartment Syndrome Guideline Synthesis

Multidisciplinary Approach

Another interesting finding in the literature included the difficulties of diagnosing ACS related to the extreme variability of ACS case presentation.[6,7,9] A significant finding reported was the importance of planning for patients before admission at risk for ACS by forming practice committees to develop protocols, train staff, and allocate capital to obtain compartment monitors.[3,4,11] Smaller community hospital committees could strategically plan by pre-establishing relationships and aligning protocols with larger research hospitals for stabilization and prompt transfer.[4,11] Communicating with the pharmacist, nurses, surgeons, radiologists, intensivists, physical therapists, occupational therapists, and social work colleagues to develop PNB-inclusive protocols to achieve better outcomes promotes professionalism, teamwork, and patient satisfaction.[3,4,11]

The importance of a multidisciplinary team with advanced compartment pressure monitoring skills and assessment training for detecting and interpreting the complex and inconsistent presentation of ACS was a consistent recommendation across the literature.[3,4,6-12] Tran et al., recommend only administering a peripheral nerve block for ACS in a well-structured long-term controlled research milieu using the Idea, Development, Exploration, Assessment (IDEAL) study framework for stage development.[11] By using the IDEAL framework, data collection can provide an initial framework and subsequent progression of high-level studies using consistent compartment assessment techniques, as well as collecting direct and indirect compartment monitoring data.[11] A multidisciplinary team approach recommended by Nathanson et al. includes assigning a risk level for PNB used for orthopedic trauma fractures and surgeries associated with ACS by location of injury.[4] All data should be collected and

interpreted every hour, while suspicious trends or sudden abnormal values should be relayed to team decision-makers immediately.[8,11]

Table 2
Causes of Compartment Syndrome, Aguirre et al[3]

External Compression

- Constriction by casts, splint, pneumatic antishock garments
- Excessive traction to fractures.
- Early surgical closure of fascial defects
- Third-degree burns (thermal, electric)

Secondary increased compartment pressure

- Iatrogenic injection
- Infiltrated intravenous catheters/inadvertent intra-arterial drug injection
- Intercompartmental hemorrhage
  - Bleeding after injury
  - Spontaneous bleeding due to hereditary bleeding disorders
  - Anticoagulation therapy
- Trauma from fracturs (open or closed), osteotomies, vessel laceration
- Intramedullary nailing
- Gunshot
- Soft tissue trauma
- Prolonged positioning during surgery (lithotomy position)
- Crush injuries
- Ergotamine ingestion
- Drug overdose
- Prolonged tetany
- Interosseous fluid administration in children
- Use of pumps during arthroscopy
- Postischemic
  - Ischemia-reperfusion (after embolectomy, clamping of arteries,etc)
  - Tourniquet
- Arterial injury/arterial spasm
- Tissue ischemia after snakebite
- Thrombosis/embolization
- Limb reimplantation

Compartment Assessment and Monitoring

The continuous assessment of the "6 P's" of ACS, in addition to compartment monitoring, includes early-stage symptoms of pain, paresthesia, pallor, and poikilothermia while late-stage symptoms include pulselessness and paralysis.[2-6,9-10] Due to the need for surgical intervention within a 6-hour window, assessments are recommended to be done hourly by trained clinicians.[4,11] Allodynic pain is an important sign of the progression of ACS, however, pain as a stand-alone marker for surgical treatment was not recommended because pain is not a symptom in 10% of ACS cases.[8-10] The lack of pain with trauma could result from nerve damage and endorphin release.[4] An early symptom presenting as a tingling or burning paresthesia can also occur with compartment syndrome.[19] The progressive loss of two-point discrimination or diminished vibration sense measured with a 256 cycle per second tuning fork are both reliable diagnostic indicators of the loss of sensory nerve function.[19] A "wood-like" feeling of a compartment upon deep palpation during assessment is also an early diagnostic finding of ACS.[19] Similar to using pain as a sole indicator, the probability of ACS diagnosis with one symptom is 25% accurate while three increases the probability of ACS to a 93% rate of occurrence.[3,7-9] See Table 4 for clinical examination recommendations.

Table 4	Clinical Examination
C:	Check for distal pulses
O:	Observe for skin lesions, swelling, and color change
M:	Motor function evaluation
P:	Palpate affected limb for tightness and wood-like feeling
A:	Assess sensations
R:	Reassess for change in the pattern of sensation
T:	Test for temperature/tension/tenderness
M:	Measure compartment pressure – Delta Pressure < 30mmHg
E:	Examine the unaffected limb and compare it with the affected limb
N:	Neurovascular examination
T:	Testing two-point discrimination and vibration sense

Sonawane et al.[19]

Compartment pressure monitoring has been described as the "gold standard" for detecting ACS; however, one author advised using pressure monitoring as only part of the clinical decision-making process.[5,6] The range for normal compartment pressures ranges from 0 to 10 mmHg.[3] Measuring the Delta Pressure (DP = Diastolic BP – Compartment Pressure) or employing the use of the non-invasive near-infrared spectroscopy monitoring technology to measure tissue perfusion via oxygenated hemoglobin was important to prevent unnecessary fasciotomies.[3,9] A Delta Pressure < 30mmHg is considered a supportive data point in the diagnosis of compartment syndrome.[3,9,10,19] Placing the monitoring needle in the central part of the compartment with measurements taken 5cm from the location of the fracture was recommended.[3] Staff competency and the standardization of pressure monitoring equipment are important, so

Table 4
Pressure monitoring is recommended for:

- Youth
- Tibial fractures
- High-energy forearm fractures
- High-energy femoral diaphyseal fractures
- Patients with a background of bleeding disorders and/or anticoagulants
- Polytrauma patients
- High base deficit
- High lactate levels
- Transfusion requirement
- Altered level of consciousness
- Regional anesthesia or patient control analgesia
- Children or adolescence with at risk injuries
- Patients with associated nerve injuries

Table adapted from Duckworth and McQueen[21]

abnormal values can be promptly reported.[1] An additional indirect monitoring technique of measuring intramuscular pH levels for early detection of developing acidosis should also be implemented.[3,5,20] Attention to specific lab values such as complete blood count, potassium, glucose, and creatine was also recommended due to potential cardiac arrhythmia and to monitor for the development of anemia and rhabdomyolysis from reperfusion injuries.[4,8,19] See Table 4 for compartment pressure recommendations.

Peripheral Nerve Block Dosage Recommendations

Current pain theory suggests ischemic pain signals are mediated by bradykinin, adenosine, serotonin, acetylcholine, potassium ions, and hydrogen ions.[20] Authors suggest a progressive increase in hydrogen ion concentration during ischemia initiates nociceptive transmission.[3,20,22] Ischemic pain differs from neuropathic and nociceptive pain due to probable sympathetic nerve involvement.[3,13,22] Peripheral nerve blocks are less likely to block all ischemic pain pathways because some pathways follow blood vessels.[3,13,20] Authors reported low concentrations of local anesthetics such as 0.2 % Ropivacaine given via PNBs allowed breakthrough ischemic pain.[6,9] The high incidence of masked pain during ACS is attributed to sympathectomy produced by dense sensory and motor coverage such as from epidural and intrathecal techniques.[3,9,10,13] A direct practice implication and important finding was the recent application of indirectly measuring the pH level continuously inside the compartment for detecting subtle trends in hydrogen ion concentrations.[3,5] The supporting literature and application of pain theory for perceiving ischemic pain via nociceptive pathways as a result of extraordinary states of acidosis was another important finding.[3,20,22] The unchecked increase in hydrogen ions during ACS supports the majority of case reports showing how low-concentration or short-acting analgesic PNBs allow for breakthrough pain and do not delay the diagnosis of ACS.[3,13,20]

Aguirre et al., report no documented cases of delayed diagnosis of ACS with upper extremity PNB.[9] Low concentrations of local anesthetics ineffectively complete both upper and lower extremity block.[9] The upper extremity requires only one PNB while the lower extremity can require up to 3 PNBs to achieve the same outcome.[9]

Four articles stressed the importance of titrating dosages of local anesthetics to achieve adequate sensory block while still having the ability to perceive increases in pain progression for treatment with the goal being analgesia not anesthesia.[3,8] Professional opinion and case studies support the use of low-concentration local anesthetic dosages such as Ropivacaine 0.15 - 0.2% either in a single block or continuous catheter.[3,9-12] Two authors advocate the use of short-acting local anesthetics such as 1.5% Lidocaine, Mepivacaine 1%, Chloroprocaine 2-3% as a single-shot PNB for ACS when a high index of suspicion is present.[8,9]

Multimodal Approach

A recent article published in March of 2023 by Lam et al., advises anesthesia providers to use low-dose PNBs as part of a comprehensive multimodal approach to reduce the use of opioids.[18,19] The authors suggest including non-steroidal anti-inflammation medications, acetaminophen, gabapentin, dexmedetomidine, and ketamine to augment pain control.[18,19] Due to the nature of significant trauma associated with ACS, utilizing benzodiazepines such as valium or carbamazepine has been shown to be useful for reducing muscle spasms.[18,19]

Peripheral Nerve Block Reversal

A novel approach to reverse the effects of local anesthetics after peripheral nerve block has been described as the "wash-off technique".[23,24] Authors suggest using an ultrasound to guide and repeat an injection of 30 ml 0.9% saline to dilute or "wash off" the existing local anesthetic to achieve significant reversal of the block to restore phrenic nerve function.[23,24] Aguirre et al., suggests a similar "wash-off" technique for epidural block resolution.[9] This "wash-off" intervention could possibly be helpful to emergently dilute local anesthetics to improve sensory perception for pain associated with progressive ACS.[24] Fleming et al., suggest 30 ml of 0.9% normal saline would reduce the concentration of 8 ml of 0.75% Bupivacaine to a 0.16% concentration.[23] If the suggested concentration of 0.2% Ropivacaine to treat ACS pain could then be theoretically diluted to an even lower concentration to allow for breakthrough pain, then the use of PNB for ACS could be more widely accepted.

Future Research

Future research should focus on collecting data in large research healthcare centers using tools like the IDEAL framework to further our knowledge base.[4,11] Because of ethical barriers and the scarcity of ACS cases, a centralized reporting agency to submit case reports of ACS would also be beneficial to obtain consistent data to expand our understanding of outcomes.[3,4,6] This information could help rural critical access hospitals qualify for funds for specialized training and compartment monitoring equipment for underserved communities.[25] A centralized national database for ACS cases needs to be established so quality evidence-base data can be obtained for future research. Future patient outcomes can benefit if medical engineering companies focus on developing more non-invasive compartment monitoring technologies for ACS.

Conclusion

Until the ability to collect and interpret high-level data to enhance future research exists, the need for a guideline regarding the use of PNBs for patients at risk for ACS is an important step forward to providing a consensus on how to develop analgesic treatment strategies. Although PNBs have proven to decrease opioid use, hospital lengths of stay, and increase patient satisfaction with routine orthopedic surgeries, valid concerns regarding PNBs masking pain associated with ACS have continued to exist.[3] Novel interventions like the "wash-off" technique which diminishes the effect of a PNB could help alleviate future concerns.[23] As anesthesia providers, we must educate our colleagues while also advocating for the patient's right to pain control all within the medicolegal realm of each professional practice.[3] The importance of higher tertiary care center involvement with a multidisciplinary team approach as a means to collect data was a consistently recommended key point throughout the literature.[3,4,6,11] Advanced compartment pressure monitoring skills and compartment assessment training for detecting and interpreting the complex and inconsistent presentation of ACS were also considered to be the main objectives of multidisciplinary teams.[3,4,6,11] All stakeholders need a better understanding of current ischemic pain theories associated with ACS while also aligning the principles of how PNBs can be used pharmacologically as part of an "analgesic versus anesthetic" multimodal approach to treating ischemic pain safely without delaying the diagnosis of ACS. By incorporating surgery type, fracture type, medications, and comorbidity risk assessments and interventions, such as updated compartment pressure monitoring and assessment techniques, this PNB for ACS guideline gives clinicians evidence-based options when individualizing a patient's plan of care today and tomorrow's future researchers a foundation on which to build. See Table 5 for guideline.

Guideline Results

Evidence-Based Guideline for Peripheral Nerve Block Administration in Patients at Risk of Acute Compartment Syndrome

Rating	Explanation
A	A strong recommendation based on accepted practice or supported by low-quality evidence suggesting net clinical benefits versus no intervention or known current alternative intervention(s). Does not cause harm.
B	A moderate strength recommendation based on accepted practice or supported by low-quality evidence suggesting net clinical benefits versus no intervention or known current alternative intervention(s). Does not cause harm.
C	Recommendation possibly helpful. No case report(s) or professional consensus statement regarding intervention use for acute compartment syndrome.

1. Six-Hour Window Multidisciplinary Approach

	Guideline Recommendation	Category
1.a.	Multidisciplinary patient-centered approach with collaborative ACS risk assessment upon admission for a decision to admit or transfer? Difficult to predict ACS onset with trauma; get the decision-makers involved because time is muscle.	A
1.b.	Confirm resources, monitoring, and competent staff are immediately available or on-call?	A
1.c.	Consider transfer to research level facility if possible: IDEAL Framework Structured research environment for data collection and to improve future studies recommended for PNB use for ACS.	A
1.d.	Activate pre-established ACS protocols upon admission: lab work, radiological studies, ICU admission	A
1.e.	Staff training: Assessment and Compartment monitor competencies	A

2. Acute Compartment Syndrome Risk Assessment

	Guideline Recommendation	Category
2.a.	Consider cause of injury or degree of trauma: The more risk factors involved the higher the index of suspicion for ACS. See Box 1	A
2.b.	Consider comorbidities – Hypertension, peripheral vascular disease, diabetes, obesity, cardiac arrhythmias, renal disease, decreased mobility	A
2.c.	Risk assessment by fracture type and location • High-energy impact • "Double-bone" fractures • Compound fractures See Box 2	A
2.d.	Consider secondary causes of increased compartment pressure See Box 1	A
2.e.	Consider current medications which may increase risk of compartment syndrome – anticoagulants, antihypertensives, statins	A

3. Compartment Assessment Every Hour

	Guideline Recommendation	Category
3.a.	Consistent assessment of the 6 "P's" of ACS and vigilance for subtle changes. See Box 3	A
3.b.	Progressive allodynia and paresthesia have high specificity and require immediate notification of decision-makers, allodynia and paresthesia have high specificity, requires immediate notification of decision-makers	A
3.c	Consider one symptom has 25% probability of ACS while 3 symptoms have a 93% occurrence rate	A
3.d	Loosen dressings or adjust casts when indicated	A
3.e	Post-surgical ACS risk patients require monitoring for the first 24-48 hours	A

4. Compartment Pressure Monitoring

	Guideline Recommendation	Category
4.a.	Continuous compartment pressure monitoring via direct intercompartment probe placement with transducer per institution protocol or surgeon preference using Delta Pressure measurement technology with pressures <30mm Hg.	A
4.b	Placing the monitoring needle in the central part of the compartment with measurements taken 5cm from the location of the fracture	B
4.c.	Indirect compartment monitor – pH, NIRS, labs, tactile assessment	A

5. Collaborative Analgesia Treatment Protocol

	Guideline Recommendation	Category
5.a.	Patient education and involvement focused: Provide inpatient education, analgesia options and risks discussed	A
5.b.	Outpatient education: Printed materials for discharge, verbalize understanding of ACS symptoms and urgent need for readmission, post-discharge follow-up phone call	A
5.c.	Announce expected dermatome coverage and estimation of block length during "time out" procedure for PNB	A
5.d.	Inpatient PNB analgesia plan: Admit to inpatient pain service with rounding every 12 hours for the first 24 – 48 hours. Availale by phone 24/7.	A
5.e.	Continuous catheter placement Start Ropivacaine 0.1 – 0.2% at 5ml/hr without bolus after the first compartment and physical assessment1 May bolus 5cc in 1 hour after the second assessment	B
5.f.	Single-shot PNB alignment with 6-hour window: Lidocaine 1.5% Mepivacaine 1% Chloroprocaine 2-3%	B
5.g.	Utilization of a comprehensive multimodal approach to reduce the use of opioids should include acetaminophen, gabapentin, dexmedetomidine, and ketamine to augment pain control. Also utilizing benzodiazepines such as valium or the anti-convulsant carbamazepine has been shown to be useful reducing muscle spasms.	A
5.h.	Gradual onset and/or progression of breakthrough pain with a working PNB catheter or recent single-shot PNB should be reported to all care decision-makers immediately. See 3.b.	A
5.k.	A novel approach to reverse the effects of local anesthetics after peripheral nerve block has been described as the "wash-off technique". By using an ultrasound-guide to repeat an injection of 30ml 0.9% saline to dilute or "wash off" the existing local anesthetic to achieve reversal of the block is possibly helpful.	C

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