

Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajemThe
American Journal of
Emergency Medicine

Principles of safety for ultrasound-guided single injection blocks in the emergency department

Arun Nagdev, MD^{*}, Andrea Dreyfuss, MD, David Martin, MD, Daniel Mantuani, MD

Alameda Health System/Highland General Hospital, Department of Emergency Medicine, United States of America

ARTICLE INFO

Article history:

Received 11 March 2019

Accepted 27 March 2019

Available online xxxx

ABSTRACT

Ultrasound-guided nerve blocks (UGNBs) allow emergency physicians an opportunity to provide optimal pain management for acute traumatic conditions. Over the past decade, a growing body of literature has detailed the novel ways clinicians have incorporated UGNBs for analgesia and an alternative to procedural sedation. UGNBs are considered a relatively safe procedure, and have been shown to increase rates of success and reduce complications (as compared to older techniques). Ultrasound allows the operator needle visualization and a clear anatomic overview. Even with the presumed level of increased safety, we recommend that any clinician who performs ultrasound-guided nerve blocks be aware of complications that could arise during and after the procedure. Peripheral nerve injury (PNI) post block, local anesthetic systemic toxicity (LAST) and the role of single peripheral nerve blocks in patients with a risk for compartment syndrome are common safety issues discussed when performing ultrasound-guided nerve blocks.

© 2019 Published by Elsevier Inc.

1. Introduction

Ultrasound-guided nerve blocks (UGNBs) allow emergency physicians an opportunity to provide optimal pain management for acute traumatic conditions. Over the past decade, a growing body of literature has detailed the novel ways clinicians have incorporated UGNBs for analgesia and an alternative to procedural sedation. UGNBs are considered a relatively safe procedure, and have been shown to increase rates of success and reduce complications (as compared to older techniques) [1]. Ultrasound allows the operator needle visualization and a clear anatomic overview. Even with the presumed level of increased safety, we recommend that any clinician who performs ultrasound-guided nerve blocks be aware of complications that could arise during and after the procedure. Peripheral nerve injury (PNI) post block, local anesthetic systemic toxicity (LAST) and the role of single peripheral nerve blocks in patients with a risk for compartment syndrome are common safety issues discussed when performing ultrasound-guided nerve blocks.

2. Peripheral nerve injury

2.1. Definition of PNI and incidence

Peripheral nerve injury (PNI) post ultrasound-guided nerve blocks (USGNB) are relatively rare. Published cases from the surgical/

anesthesia literature are uncertain in regards to if PNI was caused from regional anesthesia or surgical factors (tourniquet compression, patient positioning, or limb manipulation). Defined as persistent motor or sensory deficits and/or pain post-nerve block, the incidence is unclear (ranging from 0.5% to 2.4%). Commonly a transient post block neuropraxia can persist with 95% resolving within 6 weeks and 99% resolving within one year [2]. Even with the low incidence, PNI is a real concern when performing ultrasound guided nerve blocks, and clinicians should be aware of the postulated mechanisms of injury and techniques to reduce the incidence.

2.2. Mechanism

The mechanism of PNI is unclear, with three commonly cited theories: mechanical/injection injury, chemical cytotoxicity, and vascular injury. Mechanical trauma from direct needle contact may stretch or lacerate nerve fascicles leading to post block pain and neurologic deficits. Intra-nerve injections may elevate intrafascicular pressures leading to a compartment pressure exceeding that of the vascular capillary pressure, resulting in nerve ischemia. Also, chemical cytotoxicity can occur with any anesthetic, directly by exerting toxic effects on nerve fibers, especially with intrafascicular injection. In each theory, intraneural or more specifically, intrafascicular injection is thought to worsen the deleterious effects and increase the chances of PNI. Also, patients with known underlying peripheral neuropathy (AML, ALS, diabetes, MS, spinal stenosis etc.) are at a higher risk for PNI [3,4].

^{*} Corresponding author at: Department of Emergency Medicine, Highland General Hospital, 1411 East 31st Street, Oakland, CA 94105, United States of America.
E-mail address: anagdev@alamedahealthsystem.org (A. Nagdev).

2.3. Low pressure injections

When a high-pressure injection (>20 psi) is performed in the intraneural space, many believe that there is an increased risk for PNI. In animal and human cadaver models, high injection pressures (>20 psi) correlate with potentially harmful intraneural needle tip placement [5]. Practitioner's cannot reliably feel the subtle tactile resistance that suggests high-pressure intraneural injections, leading to some anesthesiologists advocating the use of pressure measuring devices such as in-line manometers attached to the injection apparatus [6]. In-line manometry can be helpful when performing blind landmark based techniques or using nerve stimulators, however, in the era of direct ultrasound needle guidance, this added safety benefit is likely minimal. Regardless, any resistance during injection should alert the practitioner of possible intraneural LA deposition and the need to halt the procedure.

2.4. Techniques for prevention of PNI

The physiologic plausibility of the proposed mechanisms is still to be proven in the clinical setting, but most believe that delivering small volume injection slowly outside the perineurium is advisable. Providers should also inject with low pressure and stop the procedure if there is any pain or paresthesia during the injection. For more novice providers, we recommend targeting anesthetic injection into the fascial planes that contain the targeted nerve. This method permits a "stay away" approach, and may be a reasonable solution to reduce the incidence of inadvertent intraneural injection [7]. Hydrodissection of these fascial planes can act as a conduit for LA to reach and surround the nerve even when injected 1–2 cm away (Fig. 1). Additionally, strict adherence to safe US-guided needle technique is mandatory; do not advance the needle or inject without visualization of the needle tip. And finally, we always recommend to only perform UGNBs in patients without pre-existing neurologic deficits (either baseline or from the acute injury)

and are able to perform a clear neurologic examination (not obtunded or intoxicated).

2.5. Needle selection to reduce PNI

In regards to preventing PNI, the literature is unclear whether blunt tip (short 45° bevel angle ex. Touhy/block needles) or cutting (long 14° bevel angle ex. standard hypodermic/spinal needle) needles are safer. In animal models, when accidental contact with a nerve fascicle occurs, blunt tip needles are more likely to push away the nerve rather than penetrate the surrounding protective layers of connective tissue. However, when nerve impalement does occur, histologic damage is more severe with blunt short bevel needle [8]. Despite a clear consensus as to which needle type is safest, we generally prefer blunt tip needles and have adopted a "stay away" approach to the targeted nerve (Fig. 2).

2.6. Management of PNI

Patients who return with persistent neurologic complaints after 48 h should be referred to a neurologist for further evaluation and testing. Mild or resolving deficits from PNI with no objective neurologic deficits under two weeks in duration typically have an excellent prognosis [9]. To reduce confusion, all patients who undergo a block in the ED should have a clearly documented neurologic exam performed before the block is performed.

2.7. Summary

PNI are an uncommon complication from ultrasound-guided nerve blocks. Presentation can be mild to severe motor and sensory deficits, as well as continued pain in the distribution of the nerve block. UGNBs should not be performed on patients with pre-existing neuropathy or those who are sedated. Patients should be aware of the possibility of a PNI and understand the risks of the procedure. We recommend placing small low-pressure volumes of LA in the fascial planes that surround the

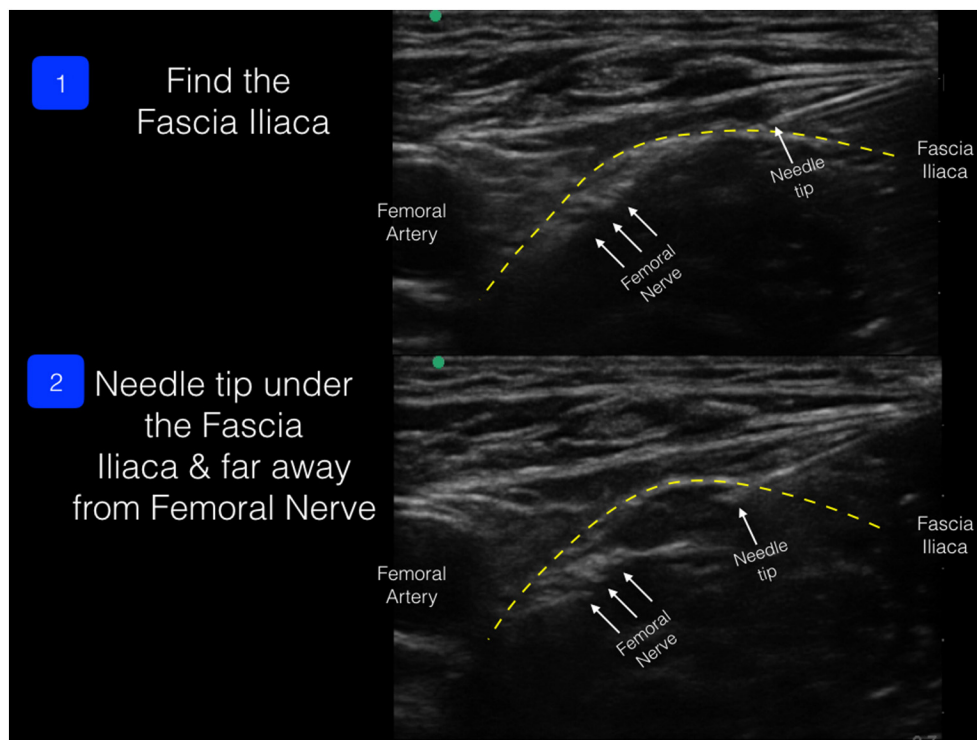


Fig. 1. When performing a left ultrasound-guided femoral nerve block, note the needle tip entering under the fascia iliaca (dashed yellow line) lateral to the femoral nerve. Low pressure injection of anechoic anesthetic allows clear visualization and an optimal "stay away" from the nerve technique.

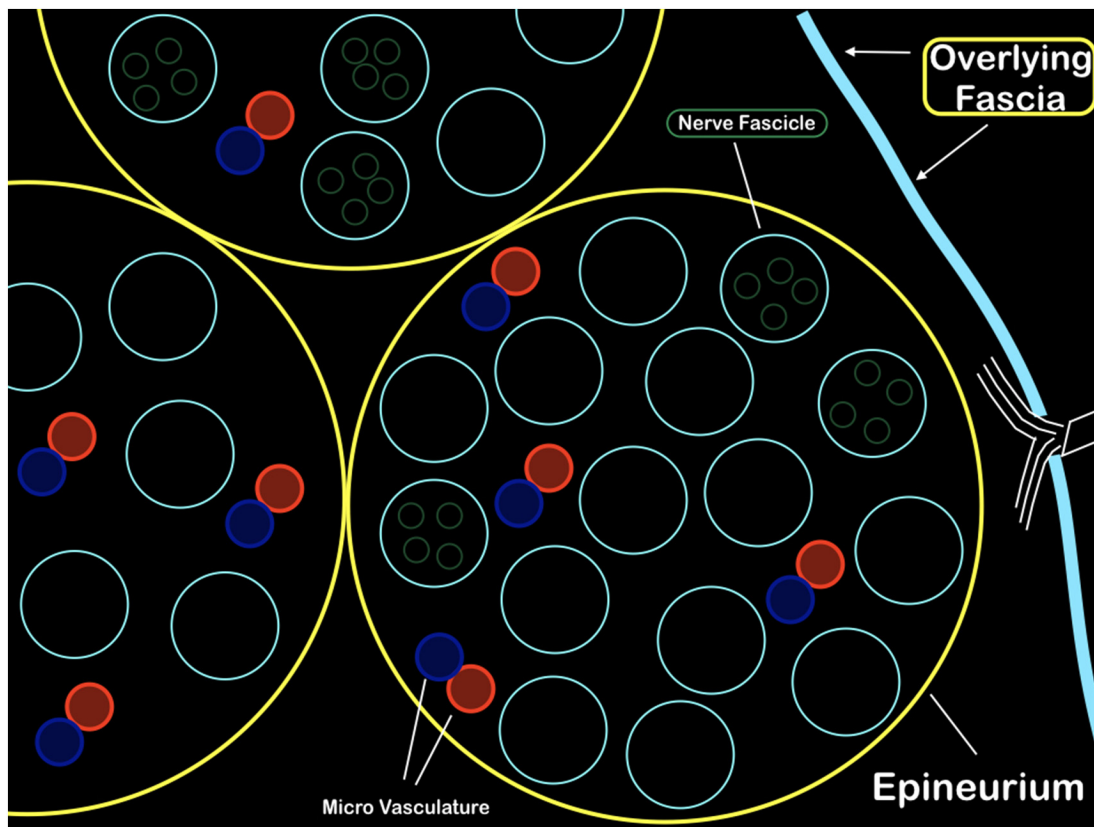


Fig. 2. To reduce the chances of PNI, we recommend trying to place anesthetic under the fascial plane, and not in under the epineurium or in the fascial sheath.

nerve and always trying to stay outside the perineurium. All clinicians performing UGNBs should be aware of a mechanism in which patients can return if persistent neurologic complications develop [9].

3. Local anesthetic systemic toxicity (LAST)

3.1. Define LAST

Local anesthetics (LA) have been used for many years and generally have an extremely low side effect profile. Unfortunately, when large doses are inadvertently placed into the vascular system, or when supratherapeutic levels of LA are reached in tissue and blood, local anesthetic systemic toxicity (LAST) can occur [10]. While a definite mechanism is still unclear, it is theorized to primarily occur due to LA's binding affinity for sodium channel in the CNS and heart (potassium and calcium channels are also theorized to be involved). Clinicians performing ultrasound-guided nerve blocks should be aware of this infrequent complication, recognize the early signs and symptoms, and understand the current accepted treatment [11].

Ultrasound-guided nerve blocks use low volumes of targeted anesthetic, but in cases of inadvertent vascular deposition, higher than expected doses of anesthetic can be directly delivered to CNS and cardiac tissue. The incidence of LAST with UGNBs by EPs is unknown. A recent review of case reports and registries in the anesthesia literature report the incidence of LAST as 0.03%, but the study included higher risk procedures not commonly performed by EPs such as pediatric penile nerve blocks (highest incidence), neuraxial blockade, and the use of continuous nerve block catheters [12]. As a preventative measure, we recommend using the lowest possible dose of anesthetic, always visualizing the needle tip during the procedure, aspiration to ensure lack of vascular puncture before injection and incremental slow 3–5 ml injections. Also, if the clinician is unable to visualize the anechoic spread of

anesthetic fluid on the ultrasound screen during injection, the procedure should be halted. The provider must assume that the non-visualized fluid is being placed in a vessel. The operator should ensure needle tip localization and look for the anesthetic spread of fluid with a small test dose (1 cm) of anesthetic before continuing the procedure. Clinicians should be aware that even with these standard measures, inappropriate intravascular injection could occur [11].

3.2. Clinical signs and symptoms

Clinicians performing ultrasound-guided nerve blocks should be aware of the early signs of LAST. Classically, patients initially have CNS excitement such as auditory changes, perioral numbness, metallic taste, and agitation that then progress to seizure and/or CNS depression (coma and respiratory arrest). Unfortunately, if LA is placed in large central arteries (carotid artery or other central arteries) cardiac symptoms may occur before any CNS symptoms. Similarly, initial cardiac excitation (hypertension, tachycardia and/or ventricular dysrhythmia) can be followed by cardiac depression (bradycardia, decreased contractility, conduction blocks, asystole). Most cases reports document symptoms between 1 and 5 min after injection, but delayed presentations as long as one hour has been documented [13]. The provider should be aware of the variation of timing and ensure adequate cardiac monitoring for all patients after UGNBs. Again, awareness of the clinician of the subtle signs and symptoms of LAST is important for both stopping the procedure as well as choice of medications if the patient continues to seizure activity or signs of cardiac instability. Because patients in the emergency department who are undergoing UGNBs should be awake and communicative, we recommend asking the patient to inform the provider if any neurologic symptoms present during the block. This is another safety measure we have instituted during all of our UGNBs.

3.3. Choice of local anesthetic/dosing

Short acting anesthetics (chloroprocaine/lidocaine) have a better safety profile than long acting lipophilic anesthetics (ropivacaine/bupivacaine) that have a strong affinity to the sodium gated channels of the CNS and myocardium, especially when injected intravascularly. Although the clinical objective dictates the choice of short versus long acting LA, bupivacaine is the most lipophilic of anesthetics (rapidly binds to sodium channels and slowly exists). We recommend that novice providers, use lidocaine (a much safer anesthetic with few reported cases of LAST) until proficient with UGNBs. The vasoconstriction of adjunct epinephrine delays systemic uptake of LA, prolongs the sensory blockade, and theoretically reduces the risk of LAST. Furthermore, accidental intravascular injection of epinephrine will immediately cause tachycardia that may alert the provider to stop the procedure. We advocate using readily available weight-based dosing charts for commonly used LAs over a range of patient weights (<http://highlandultrasound.com/med-guide>). This can reduce the cognitive load to providers in a busy Emergency Department and may help prevent dosing errors. Again, we recommend that novice providers who are not comfortable with clear needle visualization, use lidocaine with or without epinephrine for UGNBs. Our department has been fortunate to have access to ropivacaine and mepivacaine (both theoretically safer than bupivacaine), but still are vigilant in taking precautions in regards to LA selection.

3.4. Treatment

Based on anecdotal and animal data, the American Society of Regional Anesthesia and Pain Medicine (ASRA) has recommended a protocol for resuscitation of patient who have signs and symptoms of LAST. Benzodiazepines are recommended for the acute seizure, similar to standard therapy. In cases of cardiac dysfunction (dysrhythmia, cardiac depression, hypotension, asystole, etc.), recommendations are to administer intravenous 20% lipid emulsion (IVLE) (Intralipid™) therapy (lipidrescue.com). The highly lipophilic LA is theorized to bind to the vascular lipid infusion, and act as a "lipid sink". Classic ACLS protocol should be performed (cardiac compression, etc.), but IVLE should be substituted for other pharmacologic therapies (epinephrine, vasopressin, etc.). Animal studies have shown moderate efficacy, with multiple human case reports detailing return of spontaneous circulation after rapid administration of IVLE in cases of LAST [11]. The dose is suggested to be 1.5 ml/kg bolus with a continued infusion of 0.25 ml/min, a sticker with IVLE dosing guide placed on the lipid emulsion bag is recommended to prevent any delays in treatment if this rare but potentially lethal event occurs. It is requisite that lipid emulsion (20%) must be near and readily available (kept in the ED pyxis or "block cart") if performing any UGNB; storage does not require refrigeration.

3.5. Monitoring and safety

Cardiac monitoring and securing IV access is strongly recommended for all UGNBs. Certain UGNBs carry a higher risk of LAST: blocks of the neck (superficial cervical plexus) and those that either use long acting anesthetics (mepivacaine, ropivacaine, and bupivacaine) or are moderate to large volume (brachial plexus blocks, fascia iliaca/femoral, distal sciatic, and plane blocks (serratus anterior/erector spinae/transversus abdominis). Acute changes in vital signs and the development of cardiac arrhythmias may not be immediately apparent in early LAST. In the crashing LAST patient, any delay to treatment by having to move the patient to a monitored bed or obtaining IV access may be detrimental. With lower risk small-volume blocks (maximum 3–5 ml total LA) using only lidocaine or chloroprocaine (forearm blocks, posterior tibial, etc.), the practitioner may consider forgoing cardiac monitoring.

3.6. Summary

LAST is an uncommon but real possibility whenever performing an ultrasound-guided nerve block. Awareness of the associated anesthetic, common technique errors and early signs and symptoms can prevent inappropriate intravascular administration. The use of weight based local anesthetic dose charts may reduce medication errors leading to LAST. Lipid emulsion (20%) should be readily available whenever performing an ultrasound-guided peripheral nerve block, and used when there are any signs and symptoms of cardiac dysfunction. Labels of LAST treatment dosing should be placed on bags of lipid emulsion stored in the ED to prevent delays in care in the rare event of LAST.

4. Acute compartment syndrome (ACS) in the setting of ultrasound-guided regional anesthesia

4.1. What is acute compartment syndrome?

The ability of regional anesthesia and specifically single injection peripheral nerve block to mask the presence of an acute compartment syndrome (ACS) is debated. ACS is defined as a rise in the pressures in a closed compartment to a point where the arteriovenous pressure gradient is decreased. When the pressure in the confined compartment rises close to 20 to 30 mm Hg of the diastolic pressure, the flow to the distal extremity may be compromised, leading to further edema and worsening of the swelling. The controversy stems from the belief that pain management with a peripheral nerve block in the injured patient will obscure the clinical exam, masking the presentation of ACS. Unfortunately there are no current randomized controlled trials comparing the effect of regional anesthesia on the detection of ACS after high-risk injuries. Instead most practice patterns are based on opinions without any clear scientific recommendations, leading to poor pain management in patient's with significant injuries [14,15].

4.2. Who should be worry about and how do we detect it?

What is clear regarding ACS includes the fact that this process can occur in any closed compartment, but most commonly after orthopedic trauma, specifically tibial shaft fracture (40%), soft tissue tibial trauma (23%) and forearm fractures (18%). Early recognition (<6 h) from first presentation and surgical decompression via fasciotomy reduce both morbidity and mortality. Unfortunately, reliance on clinical signs and symptoms for the diagnosis is inaccurate and not sensitive detecting cases early in their course. The most common clinical findings include unremitting pain and/or pain out of proportion to the injury, but multiple cases have been documented of painless ACS [16]. Also, there are published cases of ACS after an upper extremity PNB and only two cases after lower extremity PNB. In both of the lower extremity cases, it was unclear if the block was associated with the delay in diagnosis, with one case of a femoral nerve block linked to a calf ACS (an area not innervated by the femoral nerve) [17].

4.3. Recommendations

In cases with a high clinical suspicion for developing ACS, we recommend a clear discussion with the consulting service in regard the ideal method for pain management. Single injection nerve blocks with a short acting agents, frequent re-evaluations and/or continuous intracompartment pressure monitors may be the ideal method to aide in the early diagnosis of ACS in those patient who will be admitted to an inpatient service for management. It is our recommendation that in patients who are not being admitted to monitor compartment pressures, single injection nerve blocks can be an ideal method to be a part of the multimodal method for pain control.

5. Conclusion

UGNBs have become a standard aspect of modern emergency care. POCUS fellowship requirements outline the need for training in UGNBs, and there more than a decade of published literature detailing the use of UGNBs for acute injuries. Even though there is very little data on complication rate from UGNBs in the ED setting, clinicians should be aware to both inform their patients as well as develop methods to reduce risk. As a multimodal strategy for pain management evolves, we hope to safely incorporate UGNBs into emergency care to provide optimal care to all patients with acute traumatic injuries.

Funding or outside support

None.

References

- [1] Walker KJ, McGrattan K, Aas-Eng K, Smith AF. Ultrasound guidance for peripheral nerve blockade. *Cochrane Database Syst Rev* 2009;4:CD006459.
- [2] Auroy Y, Benhamou D, Barges L, Ecoffey C, Falissard B, Mercier FJ, et al. Major complications of regional anesthesia in France: the SOS Regional Anesthesia Hotline Service. *Anesthesiology* 2002 Nov;97(5):1274–80.
- [3] Hogan QH. Pathophysiology of peripheral nerve injury during regional anesthesia. *Reg Anesth Pain Med* 2008 Oct;33(5):435–41.
- [4] Brull R, Hadzic A, Reina MA, Barrington MA. Pathophysiology and etiology of peripheral nerve injury following peripheral nerve blockade. *Reg Anesth Pain Med* 2015 Sept–Oct;40(5):479–90.
- [5] Vermeylen K, Hermans M, Soetens F, et al. Opening injection pressure is higher in intraneural compared with perineural injections during simulated nerve blocks of the lower limb in fresh human cadavers. *Reg Anesth Pain Med* 2017 May–Jun;42(3):362–7.
- [6] Caludio R, Hadzic A, Shih H, et al. Injection pressures by anesthesiologists during simulated peripheral nerve block. *Reg Anesth Pain Med* 2004; May–Jun;29(3):201–2015.
- [7] Swenson JD, Davis JJ. Ultrasound-guided regional anesthesia: why can't we all just stay away from the nerve? *Anesthesiology* 2008 Oct;109(4):748–9 [author reply 753].
- [8] Hewson DW, Bedforth NM, Hardman JG. Peripheral nerve injury arising in anaesthesia. *Anaesthesia* 2018 Jan;73(Suppl. 1):51–60.
- [9] Neal JM, Bernardis CM, Hadzic A, Hebl JR, Hogan QH, Horlocker TT, et al. ASRA practice advisory on neurologic complications in regional anesthesia and pain medicine. *Reg Anesth Pain Med* 2008 Oct;33(5):404–15.
- [10] Neal JM, Mulroy MF, Weinberg GL. American Society of Regional Anesthesia and Pain Medicine checklist for managing local anesthetic systemic toxicity: 2012 version. *Reg Anesth Pain Med* 2012 Feb;37(1):16–8.
- [11] Mercado P, Weinberg GL. Local anesthetic systemic toxicity: prevention and treatment. *Anesthesiol Clin* 2011 Jun;29(2):233–42.
- [12] Gitman M, Barrington MJ. Local anesthetic systemic toxicity: a review of recent case reports and registries. *Reg Anesth Pain Med* 2018 Feb;43(2):124–30.
- [13] El-Boghdadly K, Pawa A, Chin KJ. Local anesthetic systemic toxicity: current perspectives. *Local Reg Anesth* 2018 Aug 8;11:35–44.
- [14] McQueen MM, Gaston P, Court-Brown CM. Acute compartment syndrome. Who is at risk? *J Bone Joint Surg Br* 2000 Mar;82(2):200–3.
- [15] Mannion S, Capdevila X. Acute compartment syndrome and the role of regional anesthesia. *Int Anesthesiol Clin* 2010;48(4):85–105.
- [16] Badhe S, Bajju D, Elliot R, Rowles J, Calthorpe D. The “silent” compartment syndrome. *Injury* 2009 Feb;40(2):220–2.
- [17] Olson SA, Glasgow RR. Acute compartment syndrome in lower extremity musculoskeletal trauma. *J Am Acad Orthop Surg* 2005 Nov;13(7):436–44 cited 2012 May 27.