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Regional Anesthesia for the Trauma Patient

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1. Introduction

Trauma is the sixth most common cause of death globally [WHO, 2011]. In the United States, almost 30 million patients receive medical care for trauma every year [CDC, 2011], and trauma results in 30% of intensive care unit (ICU) admissions in the United States [Mackenzie et al., 2007]. In the Emergency Department, 91% of trauma patients are in pain [Berben et al., 2008], and two-thirds of those patients are discharged from the Emergency Department with moderate to severe pain [Berben et al., 2008]. Regional anesthesia (RA) can reduce pain in many of these patients. In this chapter, common problems with managing trauma patients that can be addressed with RA, and data suggesting that regional anesthesia can improve outcomes will be presented, as well as the different challenges to using RA in this patient population. We will also look into new and controversial areas of inquiry in this field.

2. Patients with traumatic injuries who can benefit from regional anesthesia

2.1 Thoracic trauma and rib fractures

Thoracic injury accounts for 25% of deaths among trauma patients. It is second only to head injury as a cause of trauma-related deaths in the United States [Trunkey & Lewis, 1980]. Rib fractures are common, and morbidity and mortality are directly correlated with the number of rib fractures [Flagel et al., 2005].Elderly patients have a particularly high incidence of rib fractures, with a higher rate of morbidity and mortality from these fractures than younger patients [Bulger et al., 2000; Shorr et al., 1989]. Improved analgesia, by various methods, has been shown to improve pulmonary function, including peak expiratory flow, maximum inspiratory force, tidal volume, and oxygen saturation [Luchette et al., 1994; Moon et al., 1999; Osinowo et al., 2004].

Thoracic epidural analgesia (TEA) has been shown to improve outcome after multiple rib fractures [Bulger et al., 2004;Flagel et al., 2005; Moon et al., 1999; Wisner, 1990].As early as 1990, a retrospective regression analysis of a trauma database revealed decreased pulmonary complications and decreased mortality in elderly patients with rib fractures that were treated with TEA as compared to parenteral opiates [Wisner, 1990].Moon et al showed improved pulmonary mechanics and decreased levels of the proinflammatory chemoattractant, interleukin 8, in a prospective, randomized trial that compared TEA with parenteral opioids in patients with thoracic trauma [Moon et al., 1999]. Another prospective study comparing TEA and parenteral opioid analgesia for patients with rib fractures showed decreased rates of nosocomial pneumonia and a shorter duration of mechanical ventilation in the TEA group [Bulger et al., 2004].However, one frequently cited meta-analysis is noteworthy to illustrate its limitations. Carrier et al reported that there was no significant difference when using epidural analgesia over other methods in terms of mortality, ICU length of stay, and duration of mechanical ventilation [Carrier et al., 2009]. Their analysis is of limited utility, however, because they included two studies using lumbar epidural catheters and three studies using only opiate medications with the epidural infusions; these are significant departures from recommended practices. Flagel et al performed a thorough analysis of a large, sophisticated trauma database [Flagel et al., 2005].They showed that TEA was associated with a reduction in mortality for all patients who sustained rib fractures, particularly those having more than four fractures. These findings have resulted in the recommendation that TEA be included in a widely proliferated pain management guideline for blunt thoracic trauma [Simon et al., 2005].

Despite all of the enthusiasm for epidural analgesia in patients with blunt thoracic trauma, there are considerable limitations to this approach. In the previously mentioned study by Bulger et al [Bulger et al., 2004], 282 patients of 408 admitted to the hospital had to be excluded for a variety of reasons. Thoracic epidural analgesia is contraindicated in patients on anticoagulants or those who have developed a coagulopathy [Horlocker et al., 2010].Brain or spinal injuries represent, at minimum, relative contraindications to the use of TEA, as most practitioners are uncomfortable placing epidurals in the face of elevated intracranial pressure. Possible spinal cord injury, even remote from the proposed insertion site, presents a dilemma, as an epidural may obscure or alter the neurologic examination. Spinal bone injuries may also make epidural placement more technically challenging. The hypotension caused by epidurals can frequently be a significant deterrent in critically ill patients who are already hemodynamically unstable from other causes.

Thoracic paravertebral catheterization (TPVC) has emerged as an enticing answer to some, if not all of the above mentioned concerns. A small pilot study showed comparable outcomes between TEA and TPVC when they were used in patients with unilateral rib fractures [Mohta et al., 2009].These findings are bolstered by similar results in the analogous case of analgesia after thoracotomy [Davies et al., 2006; Pintaric et al., 2011; Powell et al., 2011]. Davies et al presented a systematic review and meta-analysis of 10 randomized clinical trials comparing TPVC and TEA for thoracic surgery. They found no difference in pain scores, but did note a lower incidence of pulmonary complications, urinary retention, nausea and vomiting, and hypotension in the TPVC groups [Davies et al., 2006]. A large, prospective multicenter study of pneumonectomy in the United Kingdom found that TEA was associated with a higher incidence of major complications compared to TPVC [Powell et al., 2011]. A recent prospective randomized study comparing TEA and TPVC, with a primary endpoint of hemodynamic stability, found that TPVC was associated with similar analgesia levels to TEA, but with greater hemodynamic stability [Pintaric et al., 2011].

Should TPVC supplant TEA as the primary modality for providing analgesia for blunt thoracic trauma? A few caveats are in order. Epidural spread has been reported with thoracic paravertebral block [Purcell-Jones et al., 1989]. The authors have also experienced and reported the unintended placement of a catheter in the epidural space during TPVC placement [Lucas et al., 2011, Epub ahead of print]. Considerable controversy exists regarding the relative safety of paravertebral blocks vs. epidurals in the face of anticoagulation and coagulopathy, which will be discussed later in the chapter. Frequently, bilateral rib fractures or other injuries, such as an exploratory laparotomy incision, require bilateral blockade. Although studies on the use of TPVC are still quite undeveloped, findings by Richardson et al, in a literature review on bilateral paravertebral blocks, found a favorable side effect profile. The high local anesthetic load associated with bilateral TPVC is a worthwhile consideration for analgesia in thoracic trauma patients [Richardson et al., 2011].

The clinician is faced with a number of questions about how to proceed with regional analgesia techniques for blunt thoracic trauma. Does the patient need a catheter or not? The literature supports using either TEA or TPVC for more than three rib fractures, and in the elderly. The timing of catheter placement should be as early as *practicable*, although sometimes a short delay may be prudent to allow the anticoagulant effects to dissipate. Patients with very severe injuries may not benefit from early catheter placement, as the improvement in analgesia from RA may not likely alter the length of ventilator management. However, continuous and close monitoring in close consultation with Trauma Surgery and Critical Care Medicine can be used to determine when a patient will benefit from TPVC. Should TEA or bilateral TPVC be used? Extensive bilateral pathology is considered an indication for using thoracic epidural catheters over thoracic paravertebral catheters because of the extensive amount of local anesthetic required for multiple bilateral TPVC; however, there is scant literature to address this question. Another area of practical practice management in question is in regard to the number of catheters to place. Studies have shown loss of pinprick sensation in one to 13 dermatomes after a single-shot paravertebral block [Cheema et al., 1995; Saito et al., 2001]**.** Richardson et al measured somatosensory evoked potentials of the intercostal nerves and reliably ablated one, but only occasionally two or three nerve potentials [Richardson et al., 1998]. Most patients appear to reliably experience analgesia in approximately five dermatomes; therefore we recommend placing a second unilateral catheter for greater than four fractured ribs. This will provide some margin for error. As the process of adequately positioning and sedating these types of patients can be quite challenging, this seems to be a prudent approach. Figure 1 provides a simplified algorithm for managing these patients.

A number of different techniques have been reported for TPVC. When advancing a predetermined, fixed distance (1.0-1.5 cm) beyond the transverse process, loss of resistance, peripheral nerve stimulation(PNS), and various ultrasound-guided techniques have been described [Ben-Ari et al., 2009; Eason & Wyatt, 1979; Luyet et al., 2009; Naja et al., 2006]. Although any of these techniques can be used in different situations, it should be noted that ultrasound guidance and peripheral nerve stimulation can be technically limited in these patients, as they often have subcutaneous emphysema and hematomas. Measuring the depth of the transverse process and the parietal pleura on CT scan provides definitive information that can be used to guide the depth of needle insertion, thereby improving the safety margin and significantly expediting catheter placement. A CT scan also helps to determine the most severely injured ribs and flail segments.

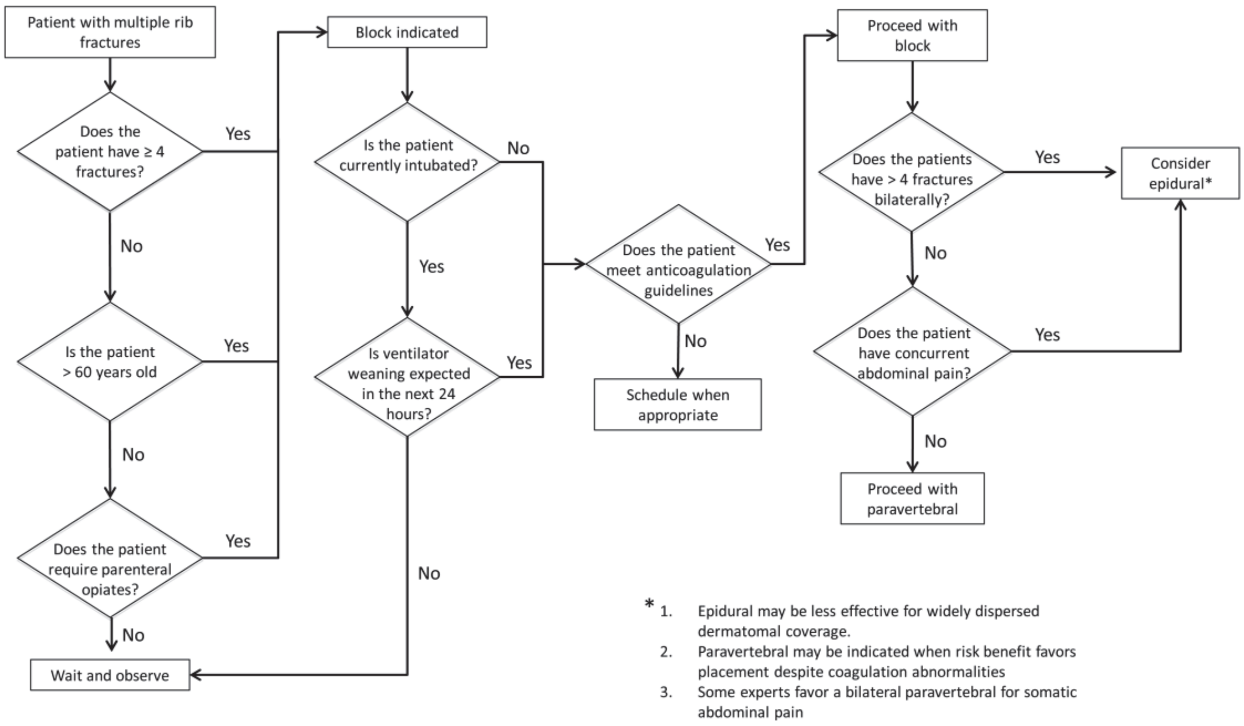


Fig. 1. Algorithm for managing analgesia in patients with multiple rib fractures.

2.2 Long bone fractures

Long bones are composed of a diaphysis, or hollow shaft, connected to the physis, or growth plate, at each end via the metaphysis. Long bones in the body include the humerus, radius, ulna, femur, tibia, fibula, and phalanges. Long bone fractures can result in significant pain, especially prior to stabilization, due to the significant number of nerve endings located in the periosteum and mineralized bone [Mach et al., 2002]. While sclerotome maps have been created to assist in the understanding of innervation to the bones, little evidence exists to confirm their accuracy. Classic studies, including those by Inman and Saunders in 1944 [Inman & Saunders, 1944], provide some evidence for the skeletal innervation [Ivanusic, 2007]. We will review anatomical considerations of the most common fractures and suggest strategies for analgesic management (Table 1).

Fracture	Innervation	Recommended Nerve Block for Analgesia	Considerations
Proximal femur	Femoral nerve Sciatic nerve Obturator nerve	-Single injection or continuous -Femoral nerve block, fascia iliaca block, or lumbar plexus block -Obturator nerve block	For surgical anesthesia, neuraxial anesthesia may decrease incidence of postoperative confusion

Midshaft and distal femur	Femoral nerve Sciatic nerve	-Single injection or continuous -Femoral nerve block -Sciatic nerve block	Greater predominance of sciatic nerve innervation
Proximal and midhumerus	-Brachial plexus, predominantly C5-C6 roots	-Single injection or continuous -Interscalene block, cervical paravertebral block, or supraclavicular block	Radial nerve injury may occur with midshaft humeral fractures
Distal humerus	-Brachial plexus, predominantly C6-C7-roots	-Single injection vs continuous -Interscalene block, cervical paravertebral, supraclavicular, or infraclavicular block	
Clavicle (distal)	Brachial plexus, predominantly C5-C6 roots	-Single injection vs continuous -Interscalene or cervical paravertebral	Possibility of brachial plexus injury due to surgical fixation
Clavicle (proximal)	Brachial plexus, predominantly C4, C5, C6 roots	-Single injection -Cervical paravertebral or deep cervical plexus	Skin overlying clavicle is innervated by supraclavicular nerves, which may be injured during surgery
Radius/Ulna	Brachial plexus, C5-T1	-Single injection -Supraclavicular block, infraclavicular block, or axillary block	
Tibia/Fibula	Sciatic nerve predominantly Possibly femoral nerve in proximal fractures such as tibial plateau	-Single injection or continuous -Sciatic nerve block (Labat or subgluteal or popliteal) -Femoral nerve block for more proximal fractures or to provide for skin sensation to medial lower extremity below knee	Compartment syndrome may occur, especially with young males in high-velocity accidents

Table 1. Regional Anesthesia Considerations for Common Long Bone Fractures

2.2.1 Femur fractures

Femur fractures represent a majority of the patients who suffer from long bone fractures, with one-third of these eventually undergoing surgical stabilization. Regional anesthesia for lower extremity fractures, including femur and hip fractures, has been extensively studied in the literature. Meta-analyses suggest that regional anesthesia, specifically neuraxial anesthesia, decreases the incidence of DVT and pulmonary embolism as well as the incidence of postoperative confusion, in addition to reducing the risk of postoperative pneumonia in patients who require surgical stabilization. Whether regional anesthesia affects mortality in the patient with a femur fracture has yet to be determined [Luger et al., 2010; Parker et al., 2004]. Evidence does suggest that analgesia is improved, and systemic analgesics are spared, when regional anesthesia techniques, such as perineural nerve blocks, are used to help manage pain in patients with hip fractures [Parker, 2002]. Femoral nerve blocks have also been shown to optimize patient positioning for performance of a neuraxial block [Sia et al., 2004; Yun, 2009].

Analgesia for proximal femur fractures may be obtained by blocking the femoral nerve, whether via a single injection or continuous block technique. Although the femur has innervations from multiple nerves, proximally, the femur is predominantly innervated by the femoral nerve, with contributions from the sciatic nerve and an articular branch of the obturator nerve [Locher et al., 2008].

There are a variety of methods available for performance of femoral nerve blocks. The femoral nerve can be anesthetized using stimulation, ultrasound [Beaudoin et al., 2010; Marhofer et al., 1998], or a fascial-pop technique [Candal-Couto et al., 2005; Dalens et al., 1989; Haddad et al., 1995]

Nerve stimulation approaches to the femoral nerve block are common but may cause significant discomfort in a patient with a fracture. The use of ultrasound has been popularized in the past decade for its various benefits. The femoral nerve can be easily visualized at the inguinal crease lateral to the femoral artery, below the fascia lata and iliaca, on the anteromedial aspect of the iliopsoas muscle as it attaches to the proximal femur. The needle can be readily identified since the femoral nerve is typically superficial in nature, and local anesthetic spread is obvious on ultrasound as it encircles the nerve.

In the absence of available ultrasound machines or nerve stimulators, the fascia iliaca compartment block can be easily performed using a simple blunt needle and local anesthetic. This technique has been successfully used in the emergency department setting [Foss et al., 2007; Monzon et al., 2007; Wathen et al., 2007]. The proceduralist draws a line connecting the pubic bone to the anterior superior iliac spine, and divides this line into thirds. At the marking between the distal third (near the anterior superior iliac spine) and middle third, a blunt needle is advanced one centimeter below this point until two pops are felt, the first as the needle punctures the fascia lata and the second as the needle punctures the fascia iliaca. Local anesthetic volumes similar to those used for stimulation-based approaches (20 mL) have been used successfully with the fascia iliaca block with good efficacy [Lopez et al., 2003]; however, weight-based dosing (0.3 mL/kg) [Monzon et al., 2007; Mouzopoulos et al., 2009] and higher doses may be considered to improve local anesthetic delivery [Candal-Couto et al., 2005]. As with any block performed with high volume, confirmation that no intravascular injection has occurred is necessary.

Sciatic nerve blocksbecome more important in more distal femur fractures and fractures of the leg and ankle. Various approaches to the sciatic nerve are utilized. For femur fractures, more proximal approaches, such as the classic Labat technique or the subgluteal approach [Di Benedetto et al, 2002; Franco et al., 2006], are appropriate. For leg and ankle fractures, a more distal approach, such as a popliteal catheter, may be more suitable, as sparing of the hamstring musculature is important for ambulation.

The subgluteal approach can be achieved with stimulation or ultrasound. Using the stimulation technique, the proceduralist elicits appropriate motor twitches, such as plantar/dorsiflexion and gastrocnemius twitches. When employing ultrasound [Danelli et al., 2009; Karmaker et al., 2007], a low frequency ultrasound probe allows visualization of the proximal femur and ischial tuberosity, as well as the sciatic nerve between these two bones. Confirmation of the nerve location on ultrasound can be done by tracing the nerve distally to the popliteal crease as the nerve divides into its two terminal branches: the common perineal and posterior tibial nerve [Bruhn et al., 2008].

2.2.2 Humerus and clavicle fractures

Proximal humerus fractures are the third, most common fracture in the elderly patient (4-5% of all fractures) after femur fractures and radial fractures [Court-Brown et al., 2001]. The most common mechanism of proximal humeral fractures in the elderly are falls [Chu et al., 2004]. Midhumeral fractures occur in 1-2% of patients, with the mechanism of this injury usually resulting from a direct blow to the arm or application of a bending force to the humeral shaft. This type of fracture typically occurs in the young, physically active patient [Ogawa et al., 1998]. Documentation of any radial nerve injury is important prior to proceeding with a regional anesthetic technique, especially with midhumeral shaft fractures in which the radial nerve may be injured from the trauma as it courses posteriorly alongside the humerus in the spiral groove [Ekholm et al., 2006]. Clavicle fractures also occur in the younger population and are usually related to direct or indirect trauma to the clavicle, commonly due to traffic accidents or a sports-related injury [Pecci et al., 2008; Postacchini et al., 2002; Robinson et al., 1998].

The humerus receives its innervation from the brachial plexus. Like the femur, multiple nerves are involved in providing sensation to the bone. Derivations of the C5 and C6 nerve root predominantly innervate the humerus. As the fracture becomes more distal, the innervation emanates from derivations of the C7 nerve root, and a regional anesthetic technique should be targeted accordingly.

Single injections may be performed using a cervical paravertebral, interscalene, or supraclavicular block. However, fractures of the humerus are painful, even after surgical stabilization, and a continuous approach is recommended for prolonged analgesia. Both stimulation and ultrasound-guided approaches have been utilized successfully. If using stimulation, biceps and deltoids are elicited as endpoints for a proximal humerus fracture and triceps stimulation for distal humeral fractures. As with femur fractures, use of stimulation may result in severe pain, and short but intense systemic analgesia may be needed for patient comfort. Ultrasound allows visualization of the brachial plexus from the root all the way to the terminal nerve, and can assist in minimizing needle attempts. By using ultrasound, nerves can be traced to their origin where they exit the intervertebral foramen as they convene in the interscalene groove, and further down as they become situated posterolateral to the subclavian artery in the supraclavicular approach.

The clavicle is innervated from nerve roots that are more cephalad in origin [Choi et al., 2005]. While distal clavicle fractures can be anesthetized with a C5/C6 block, more medial fractures, which are more common, may be anesthetized as well by depositing local anesthetic near the C4 nerve root, which can be blocked and confirmed by ultrasound. The physician should be aware that numbness across the shoulder and upper chest wall may occur from surgical fixation due to injury to the supraclavicular nerve [Wang et al., 2010]. Furthermore, the brachial plexus lies between the first rib and clavicle as it courses to the upper extremity, and may be at risk for injury due to its proximity to a clavicle fracture.

2.2.3 Radial/ulnar fractures

Repair of radial and ulnar fractures are typically carried out in an outpatient setting, and analgesia prior to surgery is usually provided using oral systemic analgesics. Reduction of a dislocated fracture, however, is extremely painful and may be alleviated by either potent and short-acting anesthetics or a regional anesthetic technique [McManus et al., 2008]. Pain from the surgery itself is typically not severe beyond the initial perioperative phase [Chung et al., 2010], and single-injection brachial plexus blocks using a supraclavicular, infraclavicular [Chin et al., 2010], or axillary approach usually results in adequate intraoperative anesthesia and postoperative analgesia. Ultrasound guidance allows for minimal needle passes, sparing of volumes of local anesthetics, and faster onset [Liu et al., 2010; McCartney et al., 2010; Neal et al., 2010]. Because the radius and ulna are innervated by the entire brachial plexus, all branches of the brachial plexus should be considered when providing surgical anesthesia in the operating room; at the trunk level (supraclavicular), this includes the superior, middle and lower trunk, and at the cord level (infraclavicular), the lateral, posterior and medical cord should be covered. At the axillary level, all terminal nerves should be blocked, which includes the median, ulnar, radial, musculocutaneous, and medial cutaneous nerve of the forearm.

2.2.4 Tibia/fibula fractures

Fractures of the tibia and fibula may occur due to indirect (torsional injuries) or direct impact [Johner et al., 2000]. Open tibia and fibula fracture injuries occur due to high-velocity trauma, such as motor vehicle accidents [Ivarsson et al., 2008], while closed injuries occur due to falls or a sports-related injury. Isolated fibula fractures without concurrent tibial fractures are rare and usually require nonoperative treatment.

The tibia and fibula are predominantly innervated by the sciatic nerve. More proximally, the bones may receive innervation from the femoral nerve. For proximal tibia and fibula fractures, a combined femoral and sciatic nerve block is needed for more complete analgesia, especially if regional anesthesia is utilized for surgical repair Continuous blockade is the technique typically employed for proximal fractures, as many of these patients continue to have severe pain after surgical stabilization. Continuous blockade will also allow monitoring for severe pain out of proportion to what is deemed an appropriate analgesic regimen, as this may signify a developing compartment syndrome. It is important to be aware that patients with tibial fractures are at a particularly high risk of developing compartment syndrome [Park et al., 2009] (discussed in more detail below). Distal tibia and fibula fractures, if uncomplicated, normally do not require more than a single-injection sciatic nerve block, with or without a saphenous nerve block depending on the medial cutaneous involvement of the injury or location of the surgical incision.

3. Challenges and opportunities

The anesthesiologist who performs RA for trauma patients has several challenges that must be addressed, and, thus, it is imperative to have a solid understanding of the complexities of compartment syndrome and coagulation issues in the trauma patient. Included in this chapter is a discussion on a number of technical challenges that frequently arise in trauma patients will be discussed, along with various solutions to these challenges. There are presently exciting opportunities in the field of RA for the trauma patient, one of which will be elucidated: the provision of RA in the prehospital or early hospital period.

3.1 Compartment syndrome

Compartment syndrome has been defined as a condition in which increased pressure within a closed compartment is compromising the circulation and function of the tissues within that space [Matsen, 1975].

In the setting of patients who have experienced trauma, we are primarily concerned with acute compartment syndrome (ACS). The most common sites of ACS are the forearm or leg, although it can occur in any closed compartment. Over 200,000 patients are diagnosed with ACS in the United States every year [Konstanantakos et al., 2007];fractures and various soft tissue injuries are the most common causes (Table 2) [McQueen et al., 2000] .Men are at a substantially greater risk than women, as are patients <35 years old [McQueen et al., 2000].

Tibial diaphyseal fracture
Soft tissue injury
Distal radius fracture
Crush syndrome
Diaphyseal fracture of the radius or ulna

Table 2. Most Common Causes of Acute Compartment Syndrome

The sine qua non of ACS management is early diagnosis and treatment, with extensive fasciotomy [Kashuk et al., 2009].Classically, the diagnosis of ACS is made by recognition of the 6 P's (Table 3) [Elliott & Johnstone, 2003].Of these, pulselessness and paralysis occur too late to effectively provide an intervention, and palpation abnormalities are difficult to discern in the traumatized patient. The other signs and symptoms all involve the need for the patient to sense the pain or parasthesia. For this reason, the use of RA in patients at risk for developing compartment syndrome is controversial [Davis et al., 2005; Thonse et al., 2004].

Pain out of proportion to injury
Parasthesia
Pain with forced dorsiflexion
Palpation (tense)
Paralysis
Pulselessness

Table 3. The 6 P's: Signs and Symptoms of Acute Compartment Syndrome

There are no randomized controlled trials comparing outcomes in patients at risk for ACS who had local anesthetic-based analgesia versus opioid-based analgesia. Clinical practice and recommendations have been founded on case reports and retrospective case series [Mar et al., 2009]; Clark's recent excellent editorial pointed out the usefulness of these case reports [Clark, 2011]. However, it is imperative that we carefully review these reports and not over-interpret their significance. It would seem an archaic practice to simply allow all patients at risk for ACS to suffer. Alternatives to RA, such as patient-controlled analgesia, have also been implicated as obscuring an ACS diagnosis [Richards et al., 2004].The literature on these topics will be briefly reviewed, and several recommendations for reasonable practices will be offered.

Recommendations against RA in patients at risk for ACS are based on the premise that any degree of sensory blockade will block the ischemic pain the patient is experiencing in a compromised compartment. Little distinction is made between a limb in which a patient has analgesia but still can sense a pinprick exam, and one that is completely insensate. A recent case report by Cometa illustrated a scenario of a patient with an initially good analgesic block who experienced increasing pain as he developed ACS [Cometa et al., 2011].Because of the prompt recognition of this increasing pain by the anesthesiologists involved, the patient underwent a timely and limb-saving fasciotomy. Although no clear-cut evidence exists to support it, most experts suspect that somewhere on a continuum of density of nerve blockade lies the "danger zone" of sensory blockade in which we are at risk of masking the symptoms of ACS. For this reason, prolonged duration of a dense blockade, such as with a long-acting, potent neuraxial block, are to be discouraged. Intraoperatively and immediately postoperatively, these patients will not be able to report the pain of ACS, so RA and general anesthesia (GA) represent a similar risk. If, however, a dense sensory block persists long after the operative period, then the choice of RA may place the patient at increased risk. For that reason, intraoperative RA - whether neuraxial, single shot peripheral nerve block, or dosing of a continuous perineural catheter - should be limited to short-acting local anesthetic regimens. A much more controversial question is whether a continuous regional anesthetic technique, aimed at providing analgesia but avoiding the "danger zone", should be offered to these patients. Epidural infusions have been implicated in delayed diagnosis of lower extremity ACS [Mar et al., 2009].Unfortunately, in this review of 35 cases, the infusion drugs and concentrations were not reported in the majority of the patients. Of those that were reported, some involved infusates that are much more concentrated than current practices. Eighteen of the 35 patients had symptoms of ACS while the epidural infusions were running. Interestingly, there is a paucity of reports of ACS diagnosis delay in peripheral nerve blockade (PNB), in either single-shot or continuous infusions. Upper limb nerve block has not been associated with delayed ACS diagnosis, but lower limb PNB has been reported in two cases, but the validity of that attribution is extremely doubtful [Mar et al., 2009].In one report, a femoral nerve block was cited for masking a lower leg ACS; as discussed previously, it is obvious that the femoral nerve supplies only cutaneous innervation of the medial lower leg via the saphenous nerve and a small portion of the proximal tibia anteriorly. It cannot block ischemic pain coming from lower leg muscles, all of which are innervated by the sciatic nerve. In the other case, an ankle block was presumed to mask an ACS in the foot, but although severe pain was reported, it was ignored.

There are no reported cases of delayed ACS diagnosis attributed to continuous perineural infusions. The absence of reports certainly does not imply that RA poses no risk to these patients, but may represent a number of factors, such as failure to report complications or avoidance of RA in these patients. Conversely, the literature certainly does not support a wholesale abandonment of RA in patients at risk. We would recommend avoiding long-lasting dense blockade, using minimally effective infusions, and promptly addressing insensate limbs by withholding infusions until pinprick sensation returns. Perhaps even more importantly is a high level of vigilance as was exhibited by Cometa et al [Cometa et al., 2011] and close cooperation between the orthopedic surgeons and anesthesiologists involved. Using RA in these patients should only be considered in centers with a willingness to dedicate resources to the close monitoring of these patients and with caregivers who are acutely aware of the risks involved.

Despite all the attention to the subjective symptoms of ACS, they have actually been found to be quite unreliable [Ulmer, 2002]. A reliable objective measure to diagnose ACS would drastically improve care. Most of the attention in the past has been centered on direct, invasive measurement of intracompartmental pressures [Al-Dadah et al., 2008; Harris, et al., 2006].These techniques have, to date, been somewhat limited by technical problems. The most promising use of this approach would appear to be the series reported by McQueen and Court-Brown, who suggest that maintaining a differential pressure between the diastolic blood pressure and an intracompartmental pressure greater than 30 mm Hg is protective [McQueen et al., 1996].Much more exciting is the prospect of a noninvasive modality, such as near-infrared spectroscopy or laser Doppler flowmetry capable of diagnosing ACS [Elliott & Johnstone, 2003]. Evidently, further research is needed in this area.

3.2 Regional anesthesia and anticoagulation

The trauma patient, depending on the injury, may be at risk for bleeding or clotting. Patients with a high volume blood loss and massive resuscitation can end up with a dilutional coagulopathy, while patients with lower extremity fractures, intracranial injuries, and immobility may be at risk for thromboembolic complications necessitating aggressive anticoagulation strategies. An increasing number of patients present with anticoagulants as part of their home medicine regimen (e.g. Plavix for patients with coronary stents). Close vigilance of the patient’s coagulation status, whether hyper- or hypocoagulable, is important prior to initiation of a regional technique.

3.2.1 Venous thromboembolism risk in the trauma patient

Venous thromboembolism can lead to pulmonary embolism, the most common preventable cause of hospital death. In patients with major trauma who are not receiving thromboprophylaxis, rates of DVT can range anywhere between 40 and 80% [Geerts et al., 2008], with rates of pulmonary embolism between 1 and 2% depending on severity of the injury [Schuerer et al., 2005]. Pulmonary embolism is the 3rd leading cause of death for patients who survive beyond the first day [Geerts et al., 2008]. Independent predictors of DVT include spinal cord injury, lower extremity or pelvic fracture, surgery, increasing age, prolonged immobility, and delay in institution of thromboprophylaxis [Geerts et al., 2008].

The American College of Chest Physicians published their updated guidelines on antithrombotic and thrombolytic therapy in 2008 [Geerts et al., 2008]. Low-dose unfractionated heparin alone appears to be insufficient as thromboprophylaxis in trauma patients. The recommendation for patients with major trauma is the use of low molecular weight heparin (LMWH) thromboprophylaxis in the absence of major contraindications. If active bleeding or high risk for clinically significant bleeding is a contraindication for LMWH, mechanical thromboprophylaxis is appropriate. In the patient with hip fracture awaiting surgery, the recommendations include routine use of thromboprophylaxis with fondaparinux, LMWH, adjusted dose of a vitamin K antagonist, or low-dose unfractionated heparin if not at high risk for bleeding. Based on evidence and expert opinion, all these recommendations were grade 1 recommendations, indicating that the benefits of thromboprophylaxis outweigh the risks, burden, and costs of implementation. The panel did recognize that, for patients undergoing neuraxial procedures and deep peripheral blocks, the physician should exercise caution when selecting anticoagulant thromboprophylaxis [Geerts et al., 2008].

The EAST Practice Parameter Workgroup for DVT Prophylaxis also published guidelines on anticoagulation focusing on the trauma patient [Simon et al., EAST Practice Management Guidelines Work Group, 2005]. This group states that, while there is inadequate class I evidence for the general use of LMWH in venous thromboembolism prophylaxis, they do recommend that LMWH be standard for thromboprophylaxis in patients with complex pelvic, lower extremity, and spinal cord injuries who are not at risk for significant bleeding. These authors acknowledge that appropriate selection of the subset of patients to administer LMWH without increasing the risk of significant bleeding may be challenging.

3.2.2 American Society of Regional Anesthesia and Pain Medicine (ASRA) guidelines

The American Society of Regional Anesthesia and Pain Medicine (ASRA) convened a 3rd Consensus Conference on anticoagulation and published the guidelines in 2010 [Horlocker et al., 2010] .Recommendations were made with regard to optimal timing and placement of regional anesthetic techniques when patients have received anticoagulants. The guidelines focus on the appropriate timing of needle placement and catheter manipulation until the patient achieves a reasonable state of coagulation in order to avoid significant bleeding complications associated with needle and catheter placement (spinal hematomas, retroperitoneal hemorrhage). These recommendations were made for patients in the inpatient and outpatient setting, including patients in the intensive care unit who are to receive neuraxial, plexus, or deep peripheral blockade. Little mention is made of the trauma or ICU patient, and much of the literature presented was focused on the patient receiving a regional anesthetic technique in the perioperative setting.

The authors of the ASRA guidelines did acknowledge that fewer recommendations were being presented to allow for “flexibility and individuality in patient management”, but stressed proper vigilance when managing a patient with a regional anesthetic and anticoagulation [Horlocker et al., 2010]. The guidelines represent a conservative but safe way to practice regional anesthesia in the anticoagulated patient, and are based on the pharmacologic activity of anticoagulants and large case series reported over a 20-year period. Recently, Chelly et al [Chelly & Schilling, 2008] described a series of orthopedic patients undergoing lumbar paravertebral and perineural blocks placed prior to the administration of thromboprophylaxis. The catheters were maintained during routine use of prophylactic dosing and withdrawn regardless of timing of the anticoagulant. The authors noted no significant hematomas.In another study, Buckenmeier described no bleeding complications in a series of 187 patients receiving continuous nerve blocks and LMWH [Buckenmaier et al., 2006]. These series might suggest that, with a high amount of vigilance and a great deal of technical skill, the ASRA guidelines (Table 4) [Horlocker et al., 2010] may represent too conservative an approach to the use of peripheral nerve blocks. However, neither series was powered to detect serious bleeding complications, and, thus, judgment about safety is not warranted.

Anticoagulant	Recommendations prior to block placement or catheter removal	Time from block placement to resuming anticoagulant	Time from catheter removal to resume anticoagulant
Subcutaneous unfractionated heparin (5000 U twice daily)	-Check platelet count for heparin-induced thrombocytopenia if patient on UFH for more than 4 days -No contraindication, may reduce bleeding by delaying dose until after block	No contraindication	No contraindication
Subcutaneous unfractionated heparin (>5000 U twice daily)	-Check platelet count for heparin-induced thrombocytopenia if patient on UFH for more than 4 days -No current recommendations	-Consider enhanced neurologic monitoring or -Consider switching to twice daily dosing	
Prophylactic LMWH	-12 hours -Anti-Xa level not predictive of bleeding	-If bloody catheter placement, consider postponement of dose for 24 hours -If not difficult placement, 6-8 hours	-2 hours
Therapeutic LMWH	-24 hours	Regardless of technique, postponement of LMWH for 24 hours -Contraindicated while catheter in situ	-2 hours

Warfarin	-Discontinue 4-5 d prior to procedure -INR < 1.5 Consider reversal agent to normalize INR	-INR < 1.5 ideal -Caution in INR 1.5-3 -Contraindicated INR >3	-INR < 1.5
Nonsteroidal antiinflammatory agents	No contraindication	No contraindication	No contraindication
Antiplatelet agents Plavix Ticlpidine	-7 days -if 5-7 days (for high risk patients) documentation of normalization of platelet function recommended -14 days	-Likely Contraindicated while continuous catheter in situ	No recommendation
Thrombolytic therapy	-No recommendation on length of time -Neuraxial techniques should be avoided if possible	Contraindicated	Avoidance for 10days after puncture of noncompressible vessels
Platelet GPIIb/IIIa inhibitors	-Abciximab 24-48 hours -Eptifibatide and tirofiban 4-8 hours -Document normal platelet function	Contraindicated	No recommendation
Fondiparinux (Arixtra)	Recommendations are to follow strict conditions in 2 studies	Contraindicated while continuous catheter in situ	-Follow strict conditions in 2 studies --or -Consider switching to alternative anticoagulant
Thrombin inhibitors	Contraindication	Contraindication	Contraindication
Herbals	No contraindication	No contraindication	No contraindication

*Note these recommendations are for single drug therapy and may not apply if patient receives concomitant anticoagulation with other agents

Table 4. ASRA guidelines for common anticoagulant management in the patient receiving a neuraxial, plexus or deep peripheral nerve block[Horlocker et al., 2010].*

3.2.3 Risks versus benefits

In the trauma patient, the risks of bleeding must be weighed against the benefits of regional anesthesia - for instance, the risk of bleeding from TPVC or thoracic epidural catheterization in a patient on LMWH versus the benefit of improved pulmonary function due to improved analgesia with minimal sedative effects, resulting in decreased incidence of hospital-acquired pneumonia [Bulger et al., 2004; Flagel et al., 2005; Karmakor et al, 2003].

When comparing a central neuraxial technique to a more peripheral technique (TEA versus TPVC or lumbar plexus block versus a lumbar epidural), one must always consider the closed nature of the spinal column. With a central neuraxial technique, compression of the epidural space may lead to devastating neurologic injury, including paraplegia, compared to a more peripheral technique in which bleeding into the paravertebral space may lead to extensive blood loss or compression neuropraxia but not paraplegia. The choice of a paravertebral block may be more appropriate in a patient on thromboprophylaxis therapy. Perineural blocks are usually performed at the terminal branches of the nerve (e.g. sciatic nerve block, popliteal nerve block, femoral nerve block, saphenous nerve block, axillary nerve block), and, while bleeding may result in neuropraxia and hematoma formation, the severity of the complications is less than that involving neuraxial or deep plexus blocks.

The decision to proceed should be based on a careful review of the patient's medical record. Informed consent for the patient and/or their family should include a review of the risks and benefits of the procedure, and their input into medical decision-making should be sought. While normal coagulation status would be preferable prior to the placement of a continuous catheter, this may not be possible or desirable. This decision requires astute clinical judgment on the part of the physician and a careful consideration of the risks versus benefits.

Even if the physician and patient both agree to maintain continuous epidural or paravertebral block with thromboprophylactic doses of anticoagulants, waiting until after the peak effect of a potent anticoagulant is prudent in order to avoid further bleeding complications in the already injured patient. Once a neuraxial technique or deep paraneuraxial or perineural technique is performed, maintenance on a prophylactic dose of a potent anticoagulant is reasonable to allow the patient to not only have improved analgesic but effective deep vein thrombosis prophylaxis as well. However, extreme vigilance is required, particularly during the high risk period that occurs when the catheter is removed.

4. Technical considerations

Anatomy can be distorted due to the patient's injuries. Swelling and subcutaneous emphysema may result in a difference in the standard sensations felt as the needle is advanced. If a loss of resistance approach is utilized, this may result in an indistinct or false sensation of loss. Even the use of ultrasound may not be helpful in the patient with subcutaneous emphysema, as the image is altered by the air underneath the skin. The use of CT scans to gauge the depth of the epidural space and paravertebral space is very important in allowing the physician to have an intelligent "guesstimate" of the depth of the targeted space.

Stimulating catheters may be utilized to guide catheters based on the motor response elicited via the catheter. While this provides an extra endpoint for confirmation of catheter placement, motor stimulation may result in further worsening of the patient's pain by stimulating muscle movement around a fractured bone. This, in turn, may produce increased analgesic requirements for block placement and an increase in time needed to thread a stimulating catheter.

In the patient placed in the lateral decubitus position on an ICU bed with an inflatable mattress, the spinal curvature may be altered and dependent on the patient's body habitus. Rotation of the spine or lateral displacement of the spine may lead to inaccurate placement of continuous blocks and difficulties in determining midline.

4.1 Confirmation of analgesic effects of the continuous block

In the nonobtunded and nonintubated patient, the efficacy of a continuous regional analgesic technique is simple to assess. Unfortunately, this is not the case in the intubated patient receiving sedatives. While there are many reasons for altered mental status and agitation in the intensive care unit, it is important to rule out severe pain as the cause.

In the patient who received an epidural catheter, accurate placement may be confirmed with a sympathectomy, which can be pronounced, and routinely requires management with fluids or pressors. While the sympathectomy confirms placement in the epidural space, it does not confirm which nerve roots are affected by the local anesthetic spreads, and analgesia may still be inadequate if the nerve roots to the fractured or injured site are spared.

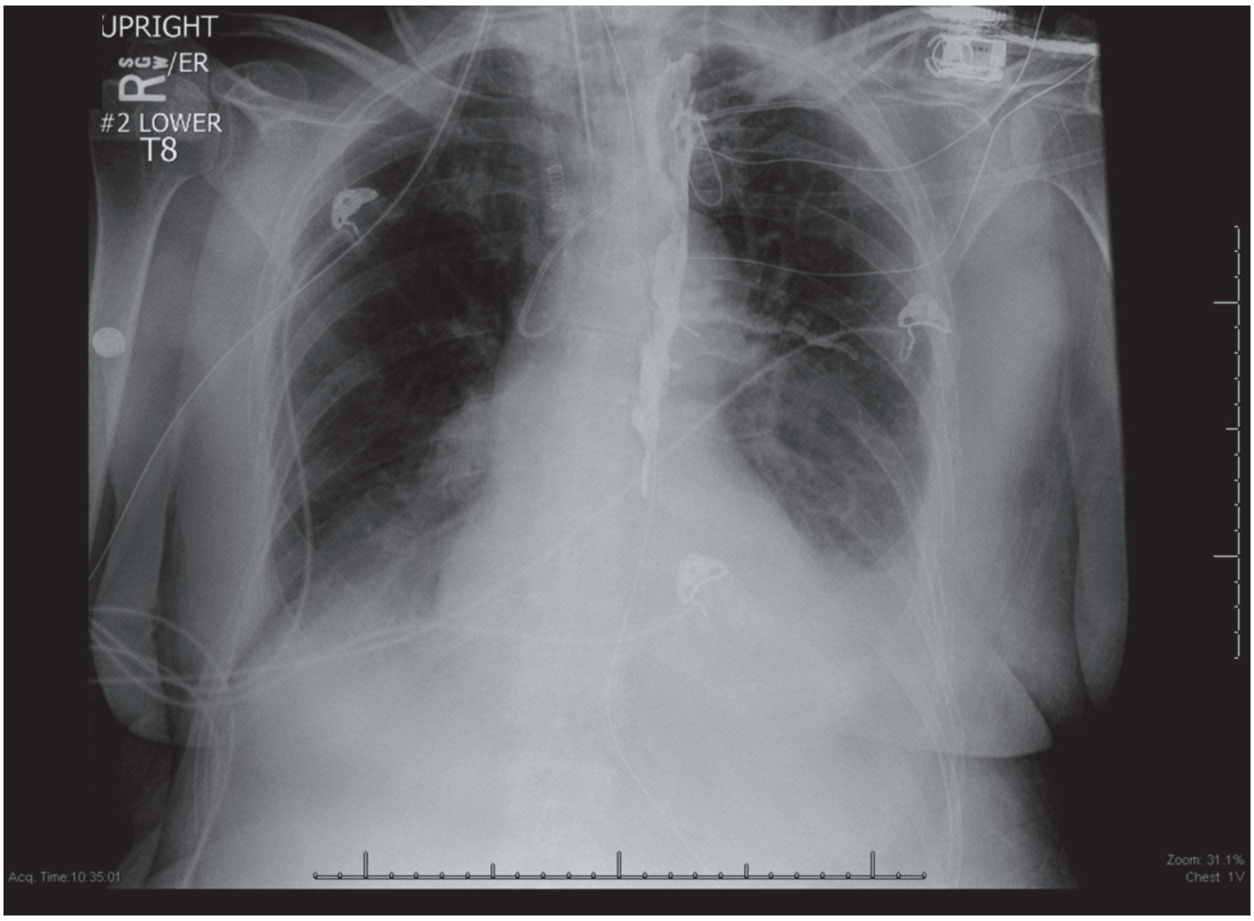


Fig. 2. Dye injection through paravertebral catheter and confirmation of spread of solution.

In the patient with perineural catheters, spread of local anesthetic, while not resulting in hemodynamic effects, can be visualized using ultrasound guidance, as these structures are superficial and can be visualized readily with this mode. In patients with paravertebral continuous blocks, the spread of local anesthetic is difficult to assess and may be inconsistent in its distribution. Therefore, dye injection through the catheter and visualization under fluoroscopy can be used as an alternative gauge of local anesthetic spread, assuming that the patient has no contraindications to contrast dye (Figure 2).

Nursing staff spend the most amount of time with these patients, and can provide important information concerning their perception of whether the patient demonstrates signs of improved or adequate comfort.

4.2 Early management with regional anesthesia

As previously noted, trauma patients often suffer moderate to severe pain in the Emergency Department [Berben et al., 2008]. In Europe, emergency response teams are frequently physician-based. Regional anesthesia performed in the field, prior to hospital admission, has been described for patients with femoral fractures [Lopez et al., 2003; Schiferer et al., 2007]. A simple fascia iliaca block and a nerve stimulator-guided femoral nerve block have been described. Both studies showed reasonably high success rates, with Schiferer reporting a 90% success rate in the RA group [Schiferer et al., 2007].Pain and anxiety scores were much lower in the RA group, as was heart rate. A mean treatment time of seven minutes in the RA group did delay transport time, which is of concern in this setting. While this paradigm will probably not take hold in the rest of the world, including the United States, it surely represents a call to action, to set up processes to provide earlier RA in the hospital setting.

5. Conclusion

Trauma patients represent a significant proportion of current surgical volume and of patients being cared for ICUs. Estimates suggest that this proportion will increase [Lopez et al., 2006]. These patients present many challenges and require extreme vigilance on the part of the health care team. An in-depth understanding of anatomy, physiology, and pharmacology is important when dealing with the trauma patient. Flexibility on the part of the physician to respond to the myriad challenges by adapting to different approaches and modalities is key. Clearly, RA can safely decrease suffering and improve outcomes in these patients when applied judiciously.

6. References

Al-Dadah, O.Q., Darrah, C., Cooper, A., Donell, S.T. & Patel, A.D. (2008). Continuous compartment pressure monitoring vs. clinical monitoring in tibial diaphysial fractures. *Injury* Oct; Vol. 39(No. 10): 1204-1209.

Beaudoin, F.L., Nagdev, A., Merchant, R.C. & Becker, B.M. (2010). Ultrasound-guided femoral nerve block in elderly patients with hip fractures. *American Journal of Emergency Medicine* Jan; Vol. 28(No. 1): 76-81.

Ben-Ari, A., Moreno, M., Chelly, J.E. & Bigeleisen, P.E. (2009). Ultrasound-guided paravertebral block using an intercostal approach. *Anesthesia & Analgesia* Nov; Vol. 109(No. 5): 1691-1694.

Berben, S.A., Meijs, T.H., van Dongen, R.T., van Vugt, A.B., Vloet, L.C., Mintjes-de Groot, J.J. & van Achterberg, T. (2008). Pain prevalence and pain relief in trauma patients in the Accident & Emergency department. *Injury* May; Vol. 39(No. 5): 578-85.

Bjurholm A., Kreicbergs, A., Brodin, E. & Schultzberg, M. (1988). Substance P – and CGRP-immunoreactive nerves in bone. *Peptides* Jan-Feb; Vol. 9(No. 1): 165-171.

Bruhn, J., Van Geffen, G.J., Gielen, M.J. & Scheffer, G.J. (2008). Visualization of the course of the sciatic nerve in adult volunteers by ultrasonography. *Acta Anaesthesiologica Scandinavica* Oct; Vol. 52(No. 9): 1298-1302.

Buckenmaier, C.C. 3rd, Shields, C.H., Auton, A.A., Evans, S.L., Croll, S.M., Bleckner, L.L., Brown, D.S. & Stojadinovic, A. (2006). Continuous peripheral nerve block in combat casualties receiving low-molecular weight heparin. *British Journal of Anaesthesia* Dec; Vol. 97(No. 6): 874-877.

Bulger, E.M., Arneson, M.A., Mock, C.N. & Jurkovich, G.J. (2000). Rib fractures in the elderly. *J Trauma* Feb; Vol. 48(No. 2): 1040-1046.

Bulger, E.M., Edwards, T., Klotz, P. & Jurkovich, G.J. (2004). Epidural analgesia improves outcome after multiple rib fractures. *Surgery* Aug; Vol. 136(No. 2): 426-430.

Candal-Couto, J.J., McVie, J.L., Haslam, N., Innes, A.R. & Rushmer, J. (2005). Pre-operative analgesia for patients with femoral neck fractures using a modified fascia iliaca block technique. *Injury* Apr; Vol. 36(No. 4): 505-510.

Carrier, F.M., Turgeon, A.F., Nicole, P.C., Trepanier, C.A., Fergusson, D.A., Thauvette, D. & Lessard, M.R. (2009). Effect of epidural analgesia in patients with traumatic rib fractures: a systematic review and meta-analysis of randomized controlled trials. *Can J Anesth* Mar; Vol. 56(No. 3): 230-242.

Centers for Disease Control and Prevention. (Last updated February 24, 2011). *Web-based injury statistics query and reporting system,* Accessed July 11, 2011, Available from:www.cdc.gov/injury/wisqars/index.html.

Cheema, S.P., Ilsley, D., Richardson, J. & Sabanathan, S. (1995). A thermographic study of paravertebral analgesia. *Anaesthesia* Feb; Vol. 50(No. 2): 118-1121.

Chelly, J.E. & Schilling, D. (2008). Thromboprophylaxis and peripheral nerve blocks in patients undergoing joint arthroplasty. *Journal of Arthroplasty* Apr; Vol. 23(No. 3): 350-354.

Chin, K.J., Singh, M., Velayutham, V. & Chee, V. (2010). Infraclavicular brachial plexus block for regional anaesthesia of the lower arm. *Cochrane Database of Systematic Reviews* Feb 17; (2): CD 005487.

Chu, S.P., Kelsey, J.L., Keegan, T.H., Sternfeld, B., Prill M., Quesenberry, C.P. & Sidney, S. Risk factors for proximal humerus fracture. (2004). *American Journal of Epidemiology* Aug; Vol. 160(No. 4): 360-367.

Chung, M.S., Roh, Y.H., Baek, G.H., Lee, Y.H., Rhee, S.H. & Gong, H.S. (2010). Evaluation of early postoperative pain and the effectiveness of perifracture site injections following volar plating for distal radius fractures. *Journal of Hand Surgery Am* Nov; Vol. 35(No. 11): 1787-1794.

Clark, L.L. (2011). The value of the case report in the age of evidence–based medicine. *Pain Med* May; Vol. 12(No. 5): 692-694.

Cometa, M.A., Esch, A.T. & Boezaart, A.P. (2011). Did continuous femoral and sciatic nerve block obscure the diagnosis or delay the treatment of acute lower leg compartment syndrome? A case report. *Pain Medicine* Vol. 12(No. 5): 823-828.

Court-Brown, C.M., Garg, A. & McQueen, M.M. (2001). The epidemiology of proximal humeral fractures. *Acta Orthopaedica Scandinavica* Aug; Vol. 72(No. 4): 365-371.

Choi DS, Atchabahian A, Brown AR. (2005). *Anesthesia and Analgesia* May; Vol. 100(No. 5): 1542-1543.

Dalens, B., Vanneuville, G. & Tanquy, A. (1989). Comparison of the fascia iliaca compartment block with the 3-in-1 block in children. *Anesthesia and Analgesia* Dec; Vol. 69(No. 6): 705-713.

Danelli, G., Ghisi, D., Fanelli, A., Ortu, A., Moschini, E., Berti, M., Ziegler, S. & Fanelli, G. (2009). The effects of ultrasound guidance and neurostimulation on the minimum effective anesthetic volume of mepivacaine 1.5% required to block the sciatic nerve using the subgluteal approach. *Anesthesia and Analgesia* Nov; Vol. 109(No. 5): 1674-1678.

Davies, R.G., Myles, P.S. & Graham, J.M. (2006). A comparison of the analgesic efficacy and side-effects of paravertebral vs. epidural blockade for thoracotomy - a systematic review and met-analysis of randomized controlled trials. *Br J Anaesth* Apr; Vol. 96(No. 4):418-426.

Davis, ET, Harris, A, Keene, D, Porter, K, Manji, M. (2005). The use of regional anaesthesia in patients at risk of acute compartment syndrome. Injury 2006; Vol. 37(No. 3): 128-133.

Di Benedetto, P., Casati, A., Bertini, L. & Fanelli, G. (2002). Posterior subgluteal approach to block the sciatic nerve: description of the technique and initial clinical experiences. *European Journal of Anaesthesiology* Sep; Vol. 19(No. 9): 682-686.

Eason, M.J. & Wyatt, R. (1979). Paravertebral thoracic block - a reappraisal. *Anaesthesia* Jul; Vol. 34(No. 7): 638-642.

Ekholm, R., Adami, J., Tidermark, J., Hansson, K., Tornkvis, H. & Ponzer, S. (2006). Fractures of the shaft of the humerus. An epidemiological study of 401 fractures. *Journal of Bone and Joint Surgery British* Nov; Vol. 88(No. 11): 1469-1473.

Elliott, K.G. & Johnstone, A.J. (2003). Diagnosing acute compartment syndrome. *Journal of Bone and Joint Surgery Britis*h Jul; Vol. 85(No. 5): 625-632.

Flagel, B.T., Luchette, F.A., Reed, L., Esposito, T.J., Davis, K.A., Santaniello, J.M. & Gamelli, R.L. (2005). Half-a-dozen ribs: the breakpoint for mortality. *Surgery* Oct; Vol. 138(No. 4): 717-725.]

Foss, N.B., Kristensen, B.B., Bundgaard, M., Bak, M., Heiring, C., Virkelyst, C., Hougaard, S. & Kehlet, H. (2007). *Anesthesiology* Apr; Vol. 106(No. 4): 773-778.

Franco, C.D., Choksi, N., Rahman, A., Voronov, G. & Almachnouk, M.H. (2006). A subgluteal approach to the sciatic nerve in adults at 10 cm from the midline. *Regional Anesthesia and Pain Medicine* May-Jun; Vol. 31(No. 3): 215-220.

Geerts, W.H., Bergqvist, D., Pineo, G.F., Heit, J.A., Samama, C.M., Lassen, M.R. & Colwell, C.W.; American College of Chest Physicians. (2008). Prevention of venous thromboembolism: American College of Chest Physicians Evidence-Based Clinical Practice Guidelines (8th Edition). *Chest* Jun; Vol. 133(6 Suppl); 381S-453S.

Haddad, F.S. & Williams, R.L. (1995). Femoral nerve block in extracapsular femoral neck fractures. *Journal of Bone and Joint SurgeryBr* Nov; Vol. 77(No. 6): 922-923.

Harris, I.A., Kadir, A. & Donald, G. (2006). Continuous compartment pressure monitoring for tibia fractures: does it influence outcomes? *Journal of Trauma* Jun; Vol. 60(No. 6): 1330-1335.

Horlocker, T.T., Wedel, D.J., Rowlingson, J.C., Enneking, F.K., Kopp, S.L., Benzon, H.T., Brown, D.L., Heit, J.A., Mulroy, M.F., Rosenquist, R.W., Tryba, M., & Yuan, C.S. (2010). Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American Society of Regional Anesthesia and Pain Medicine Evidence-Based Guidelines (Third Edition). *Regional Anesthesia and Pain Medicine* Jan; Vol. 35(No. 1): 64-101.

Inman, V. & Saunders, J. Referred pain from skeletal structures. *Journal of Nervous and Mental Disease* 1944; 99: 660-667.

Ivanusic, J. The evidence for the spinal segmental innervation of bone. *Clinical Anatomy* 2007; Nov; Vol. 20(No. 8): 956-960.

Ivanusic, JJ. (2007). The evidence for the spinal segmental innervation of bone. *Clinical Anatomy* Nov; Vol. 20(No. 8): 956-960.

Ivarsson, B.J., Manaswi, A., Genovese, D., Crandall, J.R., Hurwitz, S.R., Burke, C. & Fakhry, S. (2008). Site, type, and local mechanism of tibial shaft fracture in drivers in frontal automobile crashes. *Forensic Science International* Mar; Vol. 175(No. 2-3): 186-192.

Johner, R., Staubli, H.U., Gunst, M. & Cordey, J. (2000). The point of view of the clinician: a prospective study of the mechanism of accidents and the morphology of tibial and fibular shaft structures. *Injury* Sep; Vol. 31 (Suppl 3): C45-49.

Karmakar, M.J., Critchley, L.A., Ho, A.M., Gin, T., Lee, T.W. & Yim, A.P. (2003). Continuous thoracic paravertebral infusion of bupivacaine for pain management in patients with multiple fractured ribs. *Chest* Feb; Vol. 123(No. 2): 424-431.

Karmakar, M.K., Kwok, W.H., Ho, A.M., Tsang, K., Chui, P.T. & Gin, T. (2007). Ultrasound-guided sciatic nerve block: description of a new approach at the subgluteal space. *British Journal of Anaesthesia* Mar; Vol. 98(No. 3): 390-395.

Kashuk, JL, Moore, EE, Pinski, S, Johnson, JL, Moore, JB, Morgan, S, Cothren, CC, Smith, W. (2009). Lower extremity compartment syndrome in the acute care surgery paradigm: safety lessons learned. Patient Safety in Surgery 2009; Vol. 3(No. 1): 11.

Konstantakos, E.K., Dalstrom, D.J., Nelles, M.E., Laughlin, R.T. & Prayson, M.J. (2007). Diagnosis and management of extremity compartment syndrome: an orthopedic perspective. *American Surgeon* Dec; Vol. 73(No. 12): 1199-1209.

Liu, S.S., Ngeow, J. & John, R.S.. (2010). Evidence basis for ultrasound-guided block characteristics: onset, quality, and duration. *Regional Anesthesia and Pain Medicine* Mar-Apr; Vol. 35(2 Suppl): S26-35.

Locher, S., Burmeister, H., Bohlen, T., Eichenberger, U., Stoupis, C., Moriggl, B., Siebenrock, K. & Curatolo, M. (2008). Radiological anatomy of the obturator nerve and its articular branches: basis to develop a method of radiofrequency denervation for hip joint pain. *Pain Medicine* Apr; Vol. 9(No. 3): 291-298.

Lopez, S., Gros, T., Bernard, N., Plasse, C. & Capdevila, X. (2003). Fascia iliaca compartment block for femoral bone fractures in prehospital care. *Regional Anesthesia and Pain Medicine* May-Jun; Vol. 28(No. 3): 203-207.

Lopez, A.D., Mathers, C.D., Ezzati, M., Jamison, D.T. & Murray, C.J.L. (Eds.). (2006). *Global Burden of Disease and Risk Factors.* Oxford University Press and the World Bank, New York, NY.

Lucas, S.D., Higdon, T.A. & Boezaart, A.P. (2011). Unintended epidural placement of a thoracic paravertebral catheter in a patient with severe chest trauma. *Pain Medicine* Jun 30; doi: 10.1111/j.1526-4637.2011.01180.x. [Epub ahead of print]

Luchette, F.A., Radafshar, S.M., Kaiser, R., Flynn, W. & Hassett, J.M. (1994). Prospective evaluation of epidural versus intrapleural catheters for analgesia in chest wall trauma. *Journal of Trauma* Jun; Vol. 36(No. 6): 865-869.

Luger, T.J., Kammerlander, C., Gosch, M., Luger, M.F., Kammerlander-Knauer, U., Roth, T. & Kreutziger, J. (2010). Neuroaxial versus general anaesthesia in geriatric patients for hip fracture surgery: does it matter? *Osteoporos International* Dec; Vol. 21(No. 4): S555-572.

Luyet, C., Eichenberger, U., Greif, R., Vogt, A., Szucs Farkas, Z. & Moriggl, B. (2009). Ultrasound-guided paravertebral puncture and placement of catheters in human cadavers: an imaging study. *British Journal of Anaesthesia* Apr; Vol. 102(No. 4): 534-539.

Mach, D.B., Rogers, S.D., Sabino, M.C., Luger, N.M., Schwei, M.J., Pomonis, J.D., Keyser, C.P., Clohisy, D.R., Adams, D.J., O'Leary, P. & Mantyh, P.W. (2002). Origins of skeletal pain: sensory and sympathetic innervation of the mouse femur. *Neuroscience* Vol. 113(No. 1): 155-156.

Mackenzie, E.J., Rivara, F.P., Jurkovich, G.J., Nathens, A.B., Frey, K.P., Egleston, B.L., Salkever, D.S., Weir, S. & Scharfstein, D.O. (2007). The National Study on Costs and Outcomes of Trauma. *J Trauma* Dec; Vol. 63(6 Suppl): S54-67.

Mar, G.J., Barrington, M.J. & McGuirk, B.R. (2009). Acute compartment syndrome of the lower limb and the effect of postoperative analgesia on diagnosis. *British Journal of Anaesthesia* Jan; Vol. 102(No. 1): 3-11.

Marhofer, P., Schrogendorfer, K., Wallner, T., Konig, H., Mayer, N. & Kapral, S. (1998). Ultrasonographic guidance reduces the amount of local anesthetic for 3-in-1 blocks. *Regional Anesthesia and Pain Medicine* Nov-Dec; Vol. 23(No. 6): 584-588.

Matsen, F.A. 3rd. (1975). Compartment syndrome. A unified concept. *Clinical Orthopaedics and Related Research* Nov-Dec; Vol. 113: 8-14.

McCartney, C.J., Lin, L. & Shastri, U. (2010). Evidence basis for the use of ultrasound for upper-extremity blocks. *Regional Anesthesia and Pain Medicine* Mar-Apr; Vol. 35(2 Suppl): S10-15.

McQueen, M.M. & Court-Brown, C.M. (1996). Compartment monitoring in tibial fractures. The pressure threshold for decompression. *Journal of Bone and Joint Surgery British* Jan; Vol. 78(No. 1): 99-104.

McQueen, M.M., Gaston, P. & Court-Brown, C.M. (2000). Acute compartment syndrome. Who is at risk? *Journal of Bone and Joint Surgery British* Mar; Vol. 82(No. 2): 200-203.

McManus, J.G., Morton, M.J., Crystal, C.S., McArthur, T.J., Helphenstine, J.S., Masneri, D.A., Young, S.E. & Miller, M.A. (2008). Use of ultrasound to assess acute fracture reduction in emergency care settings. *American Journal of Disaster Medicine* Jul-Aug; Vol. 3(No. 4): 241-247.

Mohta, M., Verma, P., Saxena, A.K., Sethi, A.K., Tyagi, A. & Girotra, G. (2009). Prospective, randomized comparison of continuous thoracic epidural and thoracic paravertebral infusion in patients with unilateral multiple fractured ribs-a pilot study. *Journal of Trauma* Apr; Vol. 66(No. 4): 1096-1101.

Monzon, D.G., Iserson, K.V. & Vazquez, J.A. (2007). Single fascia iliaca compartment block for post-hip fracture pain relief. *Journal of Emergency Medicine* Apr; Vol. 32(No. 3): 257-262.

Moon, M.R., Luchette, F.A., Gibson, S.W., Crews, J., Sudarshan, G., Hurst, J.M., Davis, K. Jr, Johannigman, J.A., Frame, S.B. & Fischer, J.E. (1999). Prospective, randomized comparison of epidural versus parenteral opioid analgesia in thoracic trauma. *Annals of Surgery* May; Vol. 229(No. 5): 684-691.

Mouzopoulos, G., Vasiliadis, G., Lasanianos, N., Nikolaras, G., Morakis, E. & Kaminaris, M. (2009). Fascia iliaca block prophylaxis for hip fracture patients at risk for delirium: a randomized placebo-controlled study. *Journal of Orthopaedics and Traumatology* Sep; Vol. 10(No. 3): 127-133.

Naja, Z.M., El-Rajab, M., Al-Tannir, M.A., Ziade, F.M., Tayara, K., Younes, F. & Lonnqvist, P.A. (2006). Thoracic paravertebral block: influence of the number of injections. *Regional Anesthesia and Pain Medicine* May-Jun; Vol. 31(No. 3): 196-201.

Neal, J.M., Brull, R., Chan, V.W., Grant, S.A., Horn, J.L., Liu, S.S., McCartney, C.J., Narouze, S.N., Perlas, A., Salinas, F.V., Sites, B.D. & Tsui, B.C. (2010). *Regional Anesthesia and Pain Medicine* Mar-Apr; Vol. 35(2 Suppl): S1-9.

Ogawa, K. & Yoshida, A. (1998). Throwing fracture of the humeral shaft. An analysis of 90 patients. *American Journal of Sports Medicine* Mar-Apr; Vol. 26(No. 2): 242-246.

Osinowo, O.A., Zahrani, M. & Softah, A. (2004). Effect of intercostal nerve block with 0.5% bupivacaine on peak expiratory flow rate and arterial oxygen saturation in rib fractures. *Journal of Trauma* ;Feb; Vol. 56(No. 2): 345-347.

Powell, E.S., Cook, D., Pearce, A.C., Davies, P., Bowler, G.M., Naidu, B. & Gao, F.; UKPOS Investigators. (2011). A prospective, multicentre, observational cohort study of analgesia and outcome after pneumonectomy. *Br J Anaesth* Mar; Vol. 106(No. 3): 364-370.

Park, S., Ahn, J., Gee, A.O., Kuntz, A.F. & Esterhai, J.L. (2009). Compartment syndrome in tibial fractures. *Journal of Orthopaedic Trauma* Aug; Vol. 23(No. 7): 514-518.

Parker, M.J., Griffiths, R. & Appadu, B.N. (2002). Nerve blocks (subcostal, lateral cutaneous, femoral, triple, psoas) for hip fractures. *Cochrane Database of Systematic Reviews* (1):CD001159.

Parker, M.J., Handoll, H.H. & Griffiths, R. (2004). Anaesthesia for hip fracture surgery in adults. *Cochrane Database of Systematic Reviews* Oct 18;(4):CD000521.

Pecci, M. & Kreher, J.B. Clavicle fractures. (2008). Clavicle fractures. *American Family Physician* Jan; Vol. 77(No. 1): 65-70.

Pintaric, T.S., Potocnik, I., Hadzic, A., Stupnik, T., Pintaric, M. & Jankovic, V.N. (2011). Comparison of continuous thoracic epidural with paravertebral block on perioperative analgesia and hemodynamic stability in patients having open lung surgery. *Regional Anesthesia and Pain Medicine* May-Jun; Vol. 36(No. 3): 256-260.

Postacchini, F., Gumina, S., De Santis, P. & Albo, F. (2002). Epidemiology of clavicle fractures. *Journal of Shoulder and Elbow Surgery* Oct; Vol. 11(No. 5): 452-456.

Purcell-Jones, G., Pither, C.E. & Justins, D.M. (1989). Paravertebral somatic nerve block: a clinical, radiographic and computed tomographic study in chronic pain patients. *Anesthesia and Analgesia* Jan; Vol. 68(No. 1): 32-39.

Richards, H., Langston, A., Kulkarni, R. & Downes, E.M. (2004). Does patient controlled analgesia delay the diagnosis of compartment syndrome following intramedullary nailing of the tibia? *Injury* Mar; Vol. 35(No. 3): 296-298.

Richardson, J., Jones, J. & Atkinson, R.. (1998). The effect of thoracic paravertebral blockade on intercostal somatosensory evoked potentials. *Anesthesia and Analgesia* Aug; Vol. 87(No. 2): 373-376.

Richardson, J., Lonnqvist, P.A. & Naja, Z. (2011). Bilateral thoracic paravertebral block: potential and practice. *British Journal of Anaesthesia* Feb; Vol. 106(No.2): 164-171.

Robinson, C.M. Fractures of the clavicle in the adult. (1998). Epidemiology and classification. *Journal of Bone and Joint Surgery British* May; Vol. 80(No. 3): 476-484.

Rogers, F.B., Cipolle, M.D., Velmahos, G .& Rozycki, G. Practice management guidelines for the management of venous thromboembolism in trauma patients, Accessed July 12, 2011, Available from: http://www.east.org/tpg/dvt.pdf.]

Saito, T., Den, S., Cheema, P.S., Tanuma, K., Carney, E., Carlsson, C. & Richardson, J. (2001). A single injection, multi-segmental paravertebral block- extension of somatosensory and sympathetic block in volunteers. *Acta Anaesthesiologica Scandinavica* Jan; Vol. 45(No. 1): 30-33.

Schiferer, A., Gore, C., Gorove, L., Lang, T., Steinlechner, B., Zimpfer, M. & Kober, A. (2007). A randomized controlled trial of femoral nerve blockade administered preclinically for pain relief in femoral trauma. *Anesthesia and Analgesia* Dec; Vol. 105(No. 6): 1852-1854.

Schuerer, D.J.E., Whinney, R.R., Freeman, B.D., Nash, J., Prasad, S., Krem, M.M., Mazuski, H.E. & Buchman, T.G. (2005). Evaluation of the applicability, efficacy, and safety of a thromboembolic event prophylaxis guideline designed for quality improvement of the traumatically injured patient. *Journal of Trauma* Apr; Vol. 58(No. 4): 731-739.

Shorr, R.M., Rodriguez, A., Indeck, M.C., Crittenden, M.D., Hartunian, S. & Cowley, R.A. (1989). Blunt chest trauma in the elderly. *Journal of Trauma* Feb; Vol. 29(No. 2): 234-237.]

Sia, S., Pelusio, F., Barbagli, R. & Rivituso, C. (2004). 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. *Anesthesia and Analgesia* Oct; Vol. 99(No. 4): 1221-1224.

Simon, B.J., Cushman, J., Barraco, R., Lane, V. & Luchette, F.A., Miglietta, M., Roccaforte, D.J., Spector, R., EAST Practice Management Guidelines Work Group. (2005). Pain management guidelines for blunt thoracic trauma. *Journal of Trauma* Nov; Vol. 59(No. 5): 1256-1267.

Thonse, R, Ashford, RU, Williams, TI, Harrington, P. (2004). Differences in attitudes to analgesia in post-operative limb surgery put patients at risk of compartment syndrome. Injury 2004; Vol. 35 (No.3): 290-295.

Thurston, T.J. (1982). Distribution of nerves in long bones as shown by silver impregnation. *Journal of Anatomy* Jun; Vol. 134(Pt 4): 719-728.]

Trunkey, D.D., Lewis, F.R. (1980). Chest trauma. *Surgical Clinics of North America* Dec; Vol. 60(No.6): 1541-1549.

Ulmer, T. The clinical diagnosis of compartment syndrome of the lower leg: are clinical findings predictive of the disorder? Journal of Orthopaedic Trauma 2002; Vol. 16 (No. 8): 572-577.

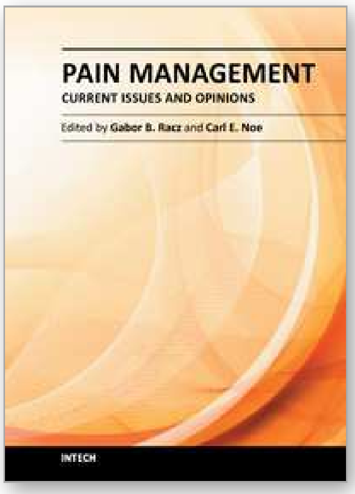
Wang, K., Dowrick, A., Choi, J., Rahim, R. & Edwards, E. (2010). Post-operative numbness and patient satisfaction following plate fixation of clavicular fractures. *Injury* Oct; Vol. 41(No. 10): 1002-1005.

Wathen, J.E., Gao, D., Merritt, G., Georgopoulos, G. & Battan, F.K. (2007). A randomized controlled trial comparing a fascia iliaca compartment nerve block to a traditional systemic analgesic for femur fractures in a pediatric emergency department. *Annals of Emergency Medicine* Aug; Vol. 50(No. 2): 162-171.

Wisner, D.H. (1990). A stepwise logistic regression analysis of factors affecting morbidity and mortality after thoracic trauma: effect of epidural analgesia. *Journal of Trauma* Jul; Vol. 7(No. 7): 799-804.

World Health Organization. (2004). *Global Burden of Disease (GBD)*, Accessed July 11, 2011, Available from: www.who.int/healthinfo/global_burden_of_disease/en/.

Yun M.J., Kim, Y.H., Han, M.K., Kim, J.H., Hwang, J.W. & Do, S.H. (2009). Analgesia before a spinal block for femoral neck fracture: fascia iliaca compartment block. *Acta Anesthesiologica Scandinavica* Nov; Vol. 53(No. 10): 1282-1287.



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