Regional anesthesia for management of acute pain in the intensive care unit

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ABSTRACT

Pain is a major problem for Intensive Care Unit (ICU) patients. Despite numerous improvements it is estimated that as many as 70% of the patients experience moderate-to-severe postoperative pain during their stay in the ICU. Effective pain management means not only decreasing pain intensity, but also reducing the opioids’ side effects. Minimizing nausea, vomiting, urinary retention, and sedation may indeed facilitate patient recovery and it is likely to shorten the ICU and hospital stay. Adequate postoperative and post-trauma pain management is also crucial for the achievement of effective rehabilitation. Furthermore, recent studies suggest that effective acute pain management may be helpful in reducing the development of chronic pain. When used appropriately, and in combination with other treatment modalities, regional analgesia techniques (neuraxial and peripheral nerve blocks) have the potential to reduce or eliminate the physiological stress response to surgery and trauma, decreasing the possibility of surgical complications and improving the outcomes. Also they may reduce the total amount of opioid analgesics necessary to achieve adequate pain control and the development of potentially dangerous side effects.

Key Words: Pain, regional anesthesia, intensive care unit

INTRODUCTION

The aim of this review is to describe the most commonly used regional analgesia techniques for the management of acute pain in ICU patients, and how a pain management strategy that includes the correct use of regional analgesia techniques (appropriate indication and timing of the intervention) can be effectively implemented in the overall treatment plan.

Pain is a major problem for Intensive Care Unit (ICU) patients. Despite numerous improvements it is estimated that as many as 70% of the patients experience moderate-to-severe postoperative pain during their stay in the ICU.[1-4]

Pain is frequently treated inappropriately because of fears of depressing spontaneous ventilation, inducing opioid dependence, and precipitating cardiovascular instability. Moreover, many clinicians do not clearly understand the methods for assessing pain, the techniques for optimally treating it, and the potential long-term benefits of effective pain management. Effective pain management not only means decreasing the pain intensity, but also improving the functionality. Minimizing opioid side effects such as nausea, vomiting, urinary retention, and sedation may indeed facilitate patient recovery and is likely to shorten the ICU and hospital stay.[5-7] Adequate perioperative pain control has also been reported to decrease the recurrence of certain types of cancer.[8,9]

Adequate postoperative and post-trauma pain management is also crucial for the achievement of effective rehabilitation. Furthermore, recent studies suggest that effective acute pain management may be helpful in reducing the development of chronic pain.[10]

When used appropriately, and in combination with other treatment modalities, regional analgesia techniques (neuraxial and peripheral nerve blocks) have the potential to reduce or eliminate the physiological stress response to surgery and trauma, decreasing the possibility of surgical complications and improving the outcomes. Also they may reduce the total amount of opioid analgesics necessary to achieve adequate pain control and the development of potentially dangerous side effects.
The use of the regional anesthesia technique in the ICU, however, can, in part, be limited by the presence of hemodynamic instability, bleeding diathesis, and by the fear of the performing procedures potentially associated with significant side effects in heavily sedated patients.

Whether or not it is safe to perform the regional anesthesia / analgesia techniques in heavily sedated patients continues to be a matter of debate. However, in an article published in 2008,[11] Bernard et al. state that based on the evidence available, an appropriate local anesthetic solution test dose, containing a marker of intravascular injection (e.g., epinephrine, isoproterenol), properly applied and monitored for an objective cardiovascular response, is a reliable method to detect or prevent intravascular injections that may lead to systemic toxicity, minimizing the importance of the patient’s report of symptoms to detect an intravascular injection.

The concern associated with the potential placement of an epidural catheter in the intrathecal space always requires a high level of suspicion. The introduction of new laboratory techniques (beta 2 transferrin test)[22] can be very helpful in detecting the inadvertent placement of an epidural catheter in the subarachnoid space.

Concern about the risk of nerve injury is also one of the reasons often cited for not performing peripheral nerve blocks in heavily sedated patients. In the same article the authors recommend that blocks should not be performed in heavily sedated patients as a routine. However, it may be reasonable, after careful consideration of the risk-to-benefit ratio, to place regional analgesia blocks if the clinical situation warrants it.[11]

The recent introduction of ultrasound-guided (USG) techniques allows an easier and more reliable identification of neural structures, the safe administration of lower doses of local anesthetic,[13] and the insertion of nerve catheters, even in heavily sedated ICU patients. High success rates with reduced onset time until complete analgesia have been reported.[14,15] Effective identification of the needle allows for the reduction of the amount of administered drug volumes, which might be of importance in critically ill patients, who may need more than one block, especially those who have undergone multi-site surgery, or sustained multi-trauma.[16]

Other important factors, such as the presence of an infectious process and / or the patient’s coagulation status must be considered when planning the use of regional analgesia techniques in ICU patients. Careful consideration of the risk-to-benefit ratio, correct indication and timing of the intervention, and a strict adherence to the American Society of Regional Anesthesia and Pain Medicine Guidelines, published in 2006 (regarding infectious complications in Regional Anesthesia)[17-20] and 2010 (anticoagulation and Regional Anesthesia)[21] will always guide the practitioner and are strongly recommended.

It is our opinion that performing regional analgesia intervention at the appropriate time is of utmost importance. For example placement of a thoracic epidural in a patient mechanically ventilated with chest wall trauma and rib fractures when he / she may not be ready to be weaned from the ventilator is inappropriate and can expose the patient to unnecessary risks. Furthermore, it is imperative to fully assess the full impact of the potential side effects associated with the use of regional anesthesia techniques on the patients’ clinical condition; the reduction of the sympathetic tone associated with most neuraxial and peripheral nerve blocks can cause a deterioration of the patient’s clinical status, which could negatively affect a potentially favorable outcome.[22] However, it is also extremely important to consider the positive impact that epidural analgesia may have in reducing the risks of unnecessary intubation and prolonged ventilation in patients with chest wall trauma. Furthermore the positive cardioprotective effects of thoracic epidural analgesia,[23,24] and the reduction in the incidence of deep vein thrombosis, reported in patients in whom a regional anesthesia / analgesia technique has been utilized, cannot be emphasized enough.[25]

Regional Analgesia for Thoracic and Abdominal Trauma and Surgery
Blunt chest wall trauma is frequently associated with rib fractures and lung injury. Pain associated with chest wall trauma is very intense and may lead to ineffective coughing and shallow breathing, and the consequent development of atelectasis, pneumonia, and consolidation and respiratory failure.[26] Mechanical ventilation may be necessary and can potentially be associated with increased morbidity and mortality. Providing adequate analgesia can help these patients with respiratory care, improving pulmonary mechanics, and respiratory parameters, especially in older patients (> 65 years of age) and in patients with more than three rib fractures.[27]

Thoracic epidural analgesia is associated with better pain scores and side effect profile, in patients with blunt thoracic trauma, and after thoracic surgery, when compared to systemic analgesia.[28,29] However, the impact of epidural analgesia on mortality, duration of mechanical ventilation, and length of ICU and hospital stay is controversial. Although a recent meta-analysis[22] has not found a statistically significant difference, another one including more than 5,000 surgical patients[30] has shown that postoperative epidural analgesia reduces the time to extubation, length of ICU stay, incidence of renal failure, morphine consumption during the first 24 hours, maximal glucose, and cortisol blood concentrations,
and improves forced vital capacity. Many of these benefits may be relevant to ICU patients and have been demonstrated to be beneficial in cardiac surgery,\textsuperscript{[31]} as well as in patients with severe acute pancreatitis.\textsuperscript{[32]}

**Thoracic paravertebral blocks** have been found to be as effective as thoracic epidurals in providing adequate analgesia in patients with chest wall trauma and unilateral rib fractures,\textsuperscript{[33]} after a thoracotomy,\textsuperscript{[34]} and in patients in whom epidural anesthesia may be contraindicated. Technically they are less challenging to perform\textsuperscript{[35]} and are associated with minimal hypotension, making them appealing to patients with hemodynamic instability. Other side effects (urinary retention and pruritus) are also less frequent. A small risk of pneumothorax, the inadvertent administration of the drug in the epidural and intrathecal space, and a more rapid absorption of local anesthetic must always be considered when performing paravertebral blocks.\textsuperscript{[36]}

**Intercostal nerve blocks** are associated with risk of pneumothorax and systemic local anesthetic toxicity. As with all regional analgesia techniques, the patient’s coagulation status must always be checked, to prevent the risk of bleeding and hematoma formation, subsequent to the laceration of an intercostal vessel.

Continuous intercostal nerve blockade after thoracotomy using an extrapleural catheter results in better pain relief and preservation of pulmonary function than the use of systemic opioids, and appears to be at least as effective as the relief provided by the epidural approach.\textsuperscript{[37]} The ease of the extrapleural approach and the low incidence of complications, suggest that this technique should be used more frequently. The use of a multifaceted approach to post-thoracotomy analgesia, which includes the intercostal nerve blockade, has been shown to be beneficial in the immediate postoperative period and seems to be associated with a reduction in the incidence of chronic pain.\textsuperscript{[38]} Major pulmonary resections, which have been managed with a mini-thoracotomy and intrapleural intercostal nerve blocks have been shown to be associated with reduced postoperative pain and improved outcome.\textsuperscript{[39]}

Although not frequently used, multilevel intercostal nerve blocks can be extremely useful in ICU patients, especially when used as a single injection for painful procedures (e.g., placement of chest tubes), or as an infusion when the patient’s hemodynamic conditions do not allow the use of thoracic epidural analgesia.\textsuperscript{[40]}

**Interpleural blockade** is a technique by which an amount of local anesthetic is injected into the thoracic cage between the parietal and visceral pleura, to produce an ipsilateral somatic block of multiple thoracic dermatomes. Local anesthetic solutions can be administered as single or intermittent boluses, or as continuous infusions via an indwelling catheter.\textsuperscript{[41,42]} It has been shown to provide safe, high quality analgesia after cholecystectomy, thoracotomy, renal surgery, breast surgery, and for some invasive radiological procedures of the renal and hepatobiliary system. It has also been used successfully in the treatment of pain from multiple rib fractures, herpes zoster, Complex Regional Pain Syndromes (CRPS), thoracic and abdominal cancer, and pancreatitis.\textsuperscript{[42]}

There are several methods proposed for the detection of the entry of the needle into the pleural space and all of them involve detection of the ‘negative pressure’ of the intrapleural space.\textsuperscript{[42]} If a posterior approach is not possible, an anterior approach can be used. The catheter also may be positioned in the interpleural space under direct vision, during surgery.

The risk of pneumothorax is 2%\textsuperscript{[42]} and the risk of systemic local anesthetic toxicity is 1.3%. Pleural inflammation increases the risk of toxicity.

It has been suggested that the local anesthetic solution diffuses outward with the interpleural technique, blocking multiple intercostal nerves, the sympathetic chain of the head, neck, and upper extremity, the brachial plexus, splanchic nerves, the phrenic nerve, the celiac plexus, and the ganglia. As the injected local anesthetic diffuses out through both layers of the pleura, direct local effects on the diaphragm, lung, pericardium, and peritoneum may also contribute to some of its analgesic activity.\textsuperscript{[42]} However, given the high and rapid absorption of the local anesthetic, which could be associated with systemic toxicity, the bolus doses and the infusion rates of medication through interpleural catheters must be carefully monitored.

**Transversus Abdominis Plane Block:**
Incisional pain represents a considerable portion of postoperative pain following abdominal operations.\textsuperscript{[43]}

The abdominal wall consists of three muscle layers; external oblique, internal oblique, transversus abdominis, and their corresponding fascial sheaths. Nerves supplying the skin, muscles, and parietal peritoneum of the anterior abdominal wall are derived from T6 to L1, and pass through the transversus abdominis plane, before supplying to the anterior abdominal wall.\textsuperscript{[44,45]} The anterior primary rami of these nerves exit their respective intervertebral foramina and extend over the vertebral transverse process. Subsequently, they pierce the musculature of the lateral abdominal wall, to travel through a neuro-fascial plane between the internal oblique and transversus abdominis muscles. Deposition of local anesthetic dorsal to the mid-axillary line, blocks both the lateral cutaneous branch and the lateral cutaneous afferents, thus facilitating blockade...
of the entire anterior abdominal wall. The transversus abdominis plane (TAP), thus provides a space into which the local anesthetic can be deposited to achieve a myocutaneous sensory blockade. An approach to this neurofascial plane, through the lumbar triangle of Petit, by using a loss of resistance technique is described in an article published by McDonnell et al., in 2007.\[43\]

This regional analgesia technique has been shown to provide good postoperative analgesia for a variety of procedures involving the abdominal wall.\[44\]-\[48\] Use of a fine-gauge, blunt-tipped, short bevel needle and USG have been proposed, to reduce the incidence of possible complications (intraperitoneal injection with bowel injury / hematoma, liver laceration, transient femoral nerve palsy, accidental intravascular injection, infection, and catheter breakage).\[49\]-\[51\] In addition, with the USG techniques, the upper and lower portions of the abdominal wall can be preferentially blocked.\[52\]

Continuous brachial plexus blocks consistently provide superior analgesia with minimal side effects, while promoting earlier hospital discharge, and possibly improving rehabilitation after a major surgery.\[56,57\]

Peripheral nerve injury is a rare complication of regional anesthesia for the upper extremities. A large study from France has reported 0.04% overall risk of a serious adverse event after peripheral nerve block.\[58\] Several retrospective studies have reported the incidence of peripheral nerve injury to be between 0.5 and 1.0%, while prospective studies published higher incidence rates, between 10 and 15%.\[59,60\]

The current evidence suggests that peripheral nerve blocks should not be routinely performed in most adults during general anesthesia or heavy sedation, especially when the interscalene approach to the brachial plexus is used. However, the risk-to-benefit ratio of performing a peripheral nerve block under these conditions versus utilizing high doses of opioids, to maintain adequate analgesia, should be carefully considered in select ICU patients.\[11\]

Furthermore the advent of ultrasound techniques,\[61\]-\[63\] in combination with injection pressure monitoring, and electric nerve stimulation, might help to significantly minimize possible serious complications in heavily sedated patients, with an increased success rate and potential benefits overall.

**Peripheral Nerve Blocks for the Upper Extremities**

Severe trauma to the shoulders and arms is frequently present in acutely injured ICU patients. These injuries usually augment overall pain, especially during positioning of the patient.\[59\] If the orthopedic injury is associated with a closed head injury, causing alterations of the mental status, which limit the use of opioid-based analgesia regimens, adequate analgesia can be provided with blocks of the brachial plexus.

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CONCLUSIONS

Pain control in critically ill patients is of paramount importance. Achieving adequate levels of analgesia in trauma and surgery patients decreases the stress response and improves morbidity and mortality.

Lack of education, fear of possible side effects, and inappropriate use of medications contribute to the ineffective treatment of pain in critically ill ICU patients. The expertise of pain management specialists and anesthesiologists is often necessary.

Choosing the treatment plan that best fits the patient’s clinical conditions is mandatory. A potentially favorable outcome can be altered if inappropriate pain modalities are chosen and used.

A rational multimodal approach including the use of non-pharmacological, pharmacological, and regional analgesia techniques is desirable, and often needed. The continued use of these techniques extended into the postoperative period may shorten the recovery time and speed up the discharge.

Regional analgesia techniques (neuraxial and peripheral nerve blocks), although proven to be safe and effective, are underused in the management of pain, in critically ill patients. They allow a decrease in the overall use of opioid analgesics and sedatives and reduce the possibility of developing potentially dangerous side effects, associated with the use of these medications. A correct indication as well as an appropriate timing for their use is required in order to increase their beneficial effects.

The availability of new technologies (e.g., ultrasonography) improves the quality and safety of the neuraxial, upper, and lower extremity peripheral nerve blocks, even in heavily sedated ICU patients.

REFERENCES

1. Gelinas C, Johnston C. Pain assessment in the critically ill ventilated adult: Validation of the Critical Care Pain Observation Tool and physiologic indicators. Clin J Pain 2007;23:497-505.
2. Dolin SJ, Cashman JN, Bland JM. Effectiveness of acute postoperative pain management: I. Evidence from published data. Br J Anaesth 2002;89:409-23.
3. Apfelbaum JL, Chen C, Mehta SS, Gan TJ. Postoperative pain experience: Results from a national survey suggest postoperative pain continues to be undermanaged. Anesth Analg 2003;97:534-40.
4. Puntillo KA, White C, Morris AB, Perdue ST, Stanik-Hutt J, Thompson CL, et al. Patients’ perceptions and responses to procedural pain: Results from ‘Thunder Project II. Am J Crit Care 2001;10:238-51.
5. Bonnet F, Marret E. Postoperative pain management and outcome after surgery. Best Pract Res Clin Anaesthesiol 2007;21:99-107.
6. Basse L, Hjort Jakobsen D, Billesbolle P, Werner M, Kehlet H. A clinical pathway to accelerate recovery after colonic resection. Ann Surg 2000;232:51-7.
7. Kehlet H, Wilmore DW. Multimodal strategies to improve surgical outcome. Am J Surg 2002;183:630-41.
8. Biki B, Mascha E, Moriarty DC, Fitzpatrick JM, Sessler DI, Buggy DJ. Anesthetic technique for radical prostatectomy surgery affects cancer recurrence: A retrospective analysis. Anesthesiology 2008;109:180-7.
9. Exadaktylos AK, Buggy DJ, Moriarty DC, Macha E, Sessler DI. Can anesthetic technique for primary breast cancer surgery affect recurrence or metastasis? Anesthesiology 2006;105:660-4.
10. Kehlet H, Jensen TS, Woolf CJ. Persistent postsurgical pain: Risk factors and prevention. Lancet 2006;367:1618-25.
11. Bernards CM, Hadzic, A, Suresh S, Neal J. Regional anesthesia in anesthetized or heavily sedated patients. Reg Anesth Pain Med 2008;33:449-60.
12. Wornecke A, Averbeck T, Wurster U, Harmening M, Lenarz T, Stover T. Diagnostic relevance of beta 2 transferrin for the detection of cerebrospinal fluid fistulas. Arch Otolaryngol Head Neck Surg 2004;130:1178-84.
13. Cassigneau A, Bacarello M, Di Cianii S, Danelli D, De Marco G, Leone S, et al. Effects of ultrasound guidance on the minimum effective anesthetic volume required to block the femoral nerve. Br J Anaesth 2007;98:823-7.
14. Gray AT, Schafhalter-Zoppoth I. Ultrasound guidance for ulnar nerve block in the forearm. Reg Anesth Pain Med 2003;28:335-9.
15. Williams SR, Chouinard P, Arcand G, Harris P, Ruel M, Boudreau D, et al. Ultrasound guidance speeds execution and improves the quality of supraclavicular block. Anesth Analg 2003;97:1518-23.
16. Wiebalk A, Grau T. Ultrasound imaging techniques for regional blocks in intensive care patients. Crit Care Med 2007;35(5 Suppl):S268-74.
17. Hebl JR, Neal J. Infectious complications: A new practice advisory. Reg Anesth Pain Med 2006;31:289-90.
18. Hebl JR. The importance and implications of aseptic techniques during regional anesthesia. Reg Anesth Pain Med 2006;31:311-23.
19. Wedel DJ, Horlocker TT. Regional anesthesia in the febrile or infected patient. Reg Anesth Pain Med 2006;31:324-33.
20. Horlocker TT, Wedel DJ. Regional anesthesia in the immunocompromised patient. Reg Anesth Pain Med 2006;31:334-45.
21. Horlocker TT, Wedel DJ, Rowlands JC, Enneking FK, Kopp SL, Benzon HT, et al. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy. American Society of Regional Anesthesia and Pain Medicine Evidence-Based Guidelines (3rd ed.). Reg Anesth Pain Med 2010;35:64-101.
22. Carrier FM, Turgeon AF, Nicole PC, Trepanier CA, Fergusson DA, Thuavette D, et al. Effect of epidural analgesia in patients with traumatic rib fractures: A systematic review and meta-analysis of randomized controlled trials. Can J Anaesth 2009;56:230-42.
23. Caputo M, Alwar H, Rogers CA, Pike K, Cohen A, Monk C, et al. Thoracic epidural anesthesia improves outcome in patients in patients undergoing off-pump coronary artery by-pass surgery: A prospective, randomized, controlled trial. Anesthesiology 2011;114:380-90.
24. Bignami E, Landoni G, Biondi-Zoccai GG, Boroli F, Messina M, Dedalo E, et al. Epidural analgesia improves outcome in cardiac surgery: A meta-analysis of randomized controlled trials. J Cardiothorac Vasc Anesth 2010;24:586-97.
25. Kohrs R, Hoenemann CW, Feirer N, Durieux ME. Bupivacaine inhibits spinal fluis fistulas. Arch Otolaryngol Head Neck Surg 2004;130:1178-84.
26. Wasielewski M, Hebl JR. The importance and implications of aseptic techniques during regional anesthesia. Reg Anesth Pain Med 2006;31:334-5.
27. Wornecke A, Grau T. Ultrasound imaging techniques for regional blocks in intensive care patients. Crit Care Med 2007;35(5 Suppl):S268-74.
28. Hebl JR, Neal J. Infectious complications: A new practice advisory. Reg Anesth Pain Med 2006;31:289-90.
29. Hebl JR. The importance and implications of aseptic techniques during regional anesthesia. Reg Anesth Pain Med 2006;31:311-23.
30. Wedel DJ, Horlocker TT. Regional anesthesia in the febrile or infected patient. Reg Anesth Pain Med 2006;31:324-33.
31. Horlocker TT, Wedel DJ. Regional anesthesia in the immunocompromised patient. Reg Anesth Pain Med 2006;31:334-45.
32. Horlocker TT, Wedel DJ, Rowlingson JC, Enneking FK, Kopp SL, Benzon HT, et al. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy. American Society of Regional Anesthesia and Pain Medicine Evidence-Based Guidelines (3rd ed.). Reg Anesth Pain Med 2010;35:64-101.
33. Carrier FM, Turgeon AF, Nicole PC, Trepanier CA, Fergusson DA, Thuavette D, et al. Effect of epidural analgesia in patients with traumatic rib fractures: A systematic review and meta-analysis of randomized controlled trials. Can J Anaesth 2009;56:230-42.
34. Kirby L, Schreiber M. Management of the crushed chest. Crit Care Med 2010;38(9 Suppl):S469-77.
35. Ho AMH, Karmak MK, Critchley LAH. Acute pain management of patients with multiple fractured ribs: A focus on regional techniques. Curr Opin Crit Care 2011;17:323-7.
36. Bulger EM, Edwards WT, Klotz PT, Jurkovich GJ. Epidural analgesia improves outcome after multiple rib fractures. Surgery 2004;136:426-30.
37. Behera BK, Puri GD, Gai B. Patient controlled epidural analgesia with fentanyl and bupivacaine provides better analgesia than intravenous patient controlled analgesia for early thoracotomy pain. J Postgrad Med 2008;54:86-90.
38. Guay J. The benefits of adding epidural analgesia to general anesthesia: A metaanalysis. J Anesth 2006;20:335-40.
39. Liu SS, Block BM, Wu CL. Effects of perioperative central neuraxial analgesia on outcome after coronary artery bypass surgery: A meta-analysis. Anesthesiology 2004;101:153-61.
40. Bernhardt A, Kortgen A, Niesel H, Goertt A. Using epidural anesthesia in patients with acute pancreatitis-prospective study of 121 patients. Anaesthesiol Reanim 2002;27:16-22.
33. Mohta M, Verma P, Saxena AK, Sethi AK, Tyagi A, Girotra G. Prospective randomized comparison of continuous thoracic epidural and thoracic paravertebral infusion in patients with unilateral multiple fractured ribs: A pilot study. J Trauma 2009;66:1096-101.
34. Casati A, Alessandrini P, Nuzzo M, Tosi M, Iotti E, Ampollini L, et al. A prospective, randomized, blinded comparison between continuous thoracic paravertebral and epidural infusion of 0.2% ropivacaine after lung resection surgery. Eur J Anaesthesiol 2006;23:999-1004.
35. Kamarkar MK, Ho AM. Thoracic and lumbar paravertebral block. In Hadzic A, editor. The New York School of Regional Anesthesia textbook of regional anesthesia nad acute pain management. New York: McGraw-Hill; 2007.p. 583-97.
36. Schnabel A, Reich SU, Kranke P, Pogatzi-Zahn EM, Zahn PK. Efficacy and safety of paravertebral block in breast surgery: a meta-analysis of randomized controlled trials. Br J Anaesth 2010;105:842-52.
37. Luketic JD, Land SR, Sullivan EA, Alvelo-Rivera M, Ward J, Nuebaventura PO, et al. Thoracic epidural vs intercostal nerve catheter patient controlled analgesia: A randomized study. Ann Thorac Surg 2005;79:1845-9.
38. Deterbeck EC. Efficacy of methods of intercostal nerve blockade for pain relief after thoracotomy. Ann Thorac Surg 2005;80:1550-9.
39. D'Andrilli A, Ibrahim M, Ciccone AM, Venuta F, De Giacomo T, Massullo D, et al. Intrapleural intercostal nerve block associated with mini-thoracotomy improves pain control after major lung resection. Eur J Cardiothorac Surg 2006;29:790-4.
40. De Pinto M, Edwards WT. Management of pain in the critically ill patient. In Irwin-Rippe's Intensive Care Medicine. 6th ed. Philadelphia, PA USA: Lippincott, Williams & Wilkins; 2006. p. 212-23.
41. Dravid RM, Paul RE. Interpleural block - part 1. Anaesthesia 2007;62:1039-49.
42. Dravid RM, Paul RE. Interpleural block - part 2. Anaesthesia 2007;62:1143-53.
43. McDonnell JG, O'Donnell B, Curley G, Heffernan A, Power C, Laffey JG. The analgesic efficacy of transversus abdominis plane block after abdominal surgery: A prospective randomized controlled trial. Anaest Analg 2007;104:193-7.
44. McDonnell JG, O'Donnell BD, Farrell T, Gough N, Tuite D, Powe C, et al. Transversus abdominis plane block: a cadaveric and radiological evaluation. Reg Anesth Pain Med 2007;32:399-404.
45. Rozen WM, Tran TM, Ashton MW, Burrington MJ, Ivanusic JJ, Taylor GI. Refining the course of the thoraco-lumbar nerves: A new understanding of the innervation of the anterior abdominal wall. Clin Anat 2008;21:325-33.
46. Carney J, McDonnell JG, Ochana A, Blinder B, Laffey JG. The transversus abdominis plane block provides effective postoperative analgesia in patients undergoing total abdominal hysterectomy. Anaest Analg 2008;107:2056-60.
47. McDonnell JG, Curley G, Carney J, Benton A, Costello J, Maharaj CH, et al. The analgesic efficacy of transversus abdominis plane block after cesarean delivery: A randomized controlled trial. Anaest Analg 2008;106:866-91.
48. Belavy D, Cowshaw PJ, Howes M, Phillips F. Ultrasound-guided transversus abdominis plane block for analgesia after Caesarean delivery. Br J Anaesth 2009;103:726-30.
49. Hebbard P, Fujimura Y, Shibata Y, Royle C. Ultrasonoguided transversus abdominis plane (TAP) block. Anaesth Intensive Care 2007;35:616-7.
50. Tran TM, Ivanusic JJ, Hebbard P, Barrington MJ. Determination of spread of injectate after ultrasonoguided transversus abdominis plane block: A cadaveric study. Br J Anaesth 2009;102:123-7.
51. Walter EJ, Smith P, Albertyn R, Uncles DR. Ultrasound imaging for transversus abdominis blocks. Anaesthesia 2008;63:211.
52. Hebbard P. Subcostal transversus abdominis plane block under ultrasound guidance. Anaesth Analg 2008;106:674-5; author reply 5.
53. De Oliveira GS Jr, Fitzgerald PC, Marcus RJ, Ahmad S, McCarthy RJ. A dose-ranging study of the effect of transversus abdominis block on postoperative quality of recovery and analgesia after outpatient laparoscopy. Anaesth Analg 2011;113:1218-25.
54. Heil JW, Ilfeld BM, Loland VJ, NarkParkash SS, Mariano ER. Ultrasound-guided transversus abdominis plane catheters and ambulatory perineural infusions for outpatient inguinal hernia repair. Reg Anesth Pain Med 2010;35:556-8.
55. Schulz-Stübner S, Boezaart A, Hata JS. Regional analgesia in the critically ill. Crit Care Med 2005;33:1400-7.
56. Neal JM, Geranther JC, Hebl JR, Ilfeld BM, McCartyen CJ, Franco CD, et al. Upper extremity regional anaesthesia: Essentials of our current understanding. 2008. Reg Anesth Pain Med 2009;34:134-70.
57. Capdevila X, Ponrouch M, Choquet O. Continuous peripheral nerve blocks in clinical practice. Curr Opin Anaesthesiol 2008;21:619-23.
58. Auroy Y, Benhamou D, Bargues L, Enecoff C, Falissard B, Mercier FJ, et al. Major complications of regional anesthesia in France: The SOS Regional Anesthesia Hotline Service. Anesthesiology 2002;97:1274-80.
59. Liguori GA. Complications of regional anaesthesia: Nerve injury and peripheral neural blockade. J Neurosurg Anesthesiol 2004;16:84-6.
60. Sorenson EJ. Neurological injuries associated with regional anesthesia. Reg Anesth Pain Med 2008;33:442-8.
61. Marhofer P, Greher M, Kapral S. Ultrasound guidance in regional anaesthesia. Br J Anaesth 2005;94:7-17.
62. Warman P, Nicholls B. Ultrasound-guided nerve blocks: Efficacy and safety. Best Pract Res Clin Anaesthesiol 2009;23:313-36.
63. Grau T. Ultrasoundography in the current practice of regional anaesthesia. Best Pract Res Clin Anaesthesiol 2005;19:175-200.
64. De Ruyter ML, Bruelley KE, Harrison BA, Greengrass RA, Putzke JD, Brodersen MP. A pilot study on continuous femoral perineural catheter for analgesia after total knee arthroplasty: The effect on physical rehabilitation and outcomes. J Arthrop 2006;21:1111-7.
65. Davies AF, Segar EP, Murdoch J, Wright DE, Wilson H. Epidural infusion or combined femoral and sciatic nerve blocks as peripropective analgesia for knee arthroplasty. Br J Anaesth 2004;93:368-74.
66. Chalmouki G, Lekka N, Lappas T, Paraskeua E, Mela A, Kostaki S. Perioperative Pain Management in Femoral Shaft Fractures. Continuous Femoral Nerve Block vs Systemic Pain Therapy. Reg Anesth Pain Med 2008;33:e77.
67. Mutty CE. Femoral nerve block for diaphysial and distal femoral fractures in the emergency department. J Bone Joint Surg Am 2007;89(12):2599-603.
68. Tan TT, Coleman MM. Femoral blockade for fractured neck of femur in the emergency department. Ann Emerg Med 2003;42:596-7; author reply 7.
69. Gray AT, Huczko EL, Schafhalter-Zoppoth I. Lateral popliteal nerve block with ultrasound guidance. Reg Anesth Pain Med 2004;29:307-9.