Perioperative pain control after total knee arthroplasty: An evidence based review of the role of peripheral nerve blocks

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Abstract

Over the last decades, the number of total knee arthroplasty procedures performed in the United States has been increasing dramatically. This very successful intervention, however, is associated with significant postoperative pain, and adequate postoperative analgesia is mandatory in order to allow for successful rehabilitation and recovery. The use of regional anesthesia and peripheral nerve blocks has facilitated and improved this goal. Many different approaches and techniques for peripheral nerve blockades, either landmark or, more recently, ultrasound guided have been described over the last decades. This includes but is not restricted to techniques discussed in this review. The introduction of ultrasound has improved many approaches to peripheral nerves either in success rate and/or time to block. Moreover, ultrasound has enhanced the safety of peripheral nerve blocks due to immediate needle visualization and as consequence needle guidance during the block. In contrast to patient controlled analgesia using opioids, patients with a regional anesthetic technique suffer from fewer adverse events and show higher patient satisfaction; this is important as hospital rankings and advertisement have become more common worldwide and many patients use these factors in order to choose a certain institution for a specific procedure. This review provides a short overview of currently used regional anesthetic and analgesic techniques focusing on related implications, considerations and outcomes.

INTRODUCTION

Over the last decades, major orthopedic procedures have been increasingly performed throughout the United
States. Specifically, total knee arthroplasties (TKA) have risen in volume by 154% between 1993 and 2011[9]. Projections suggest that the same trend will continue over the next decades, resulting in a demand of 3.48 million TKAs in 2030[10]. In order to appropriately meet this demand and provide comprehensive patient care, physicians performing TKA need to keep in mind that this procedure is associated with severe postoperative pain and effective postoperative analgesic care is therefore mandatory. Regional anesthesia, and specifically the application of peripheral nerve blocks, has undergone significant developments over the last decade while proving its effectiveness and superiority over other traditional techniques. In this context, it must be mentioned that the use of peripheral nerve blocks for TKAs remains underutilized[11], thus pointing to a significant potential for growth and expansion. Most recently, the use of ultrasound guidance has become more popular, resulting in the refinement of many nerve block techniques and more expansive utilization. Numerous publications have documented advances in respect to increases in safety, the use of decreased volumes of local anesthetics as well as improved onset times, prolonged duration of the blockade and/or a reduced length of stay[12-15]. Moreover, imaging technique and other necessary resources such as needles, catheters or infusion pumps have been improved in regard of their design as well as the material used[9-11].

Despite this progress, there is an ongoing discussion in the literature which type of block (or combinations thereof) is best for preventing postoperative pain, while facilitating rehabilitation and postoperative mobilization, reducing time to hospital discharge, enhancing cost-effectiveness, and reducing the risk for complications (e.g., inpatient falls) in TKA patients[12-14,16-18]. Various approaches to the performance of peripheral nerve blocks for postoperative pain control in patients undergoing TKA have been described in the literature; this includes the lumbar plexus block, the femoral nerve block, with or without a concomitant sciatic nerve block and the saphenous nerve block[12,15-19]. In addition, there is still a conflicting discussion in the regional anesthesia community whether a peripheral nerve block should be performed as a single-shot or as a continuous peripheral nerve block using a catheter.

This review aims to give an overview of peripheral nerve blocks currently used for postoperative analgesia in patients undergoing TKA, while assessing their impact on various outcomes. While some variations of the blocks discussed in this article exist, this review will focus on the most commonly used block techniques. Furthermore, we may summarize benefits and drawbacks for different approaches (e.g., single shot vs continuous approach) in regard of side effects, complications and economic factors, such as cost effectiveness. In order to provide a focused discussion on the topic, the article, will only focus on peripheral blocks and not engage the field of neuraxial anesthesia and analgesia, which is also considered a regional anesthetic approach, but is more commonly although not exclusively used for effective intraoperative anesthesia.

PERIPHERAL NERVE BLOCKS USED FOR TKA

Lumbar plexus block

In the early 1970s, Winnie and colleagues introduced 2 different approaches to the lumbar plexus[18,19]. While the anterior approach failed to provide blockade of the obturator or lateral cutaneous femoral nerve, the posterior approach provided sufficient analgesia of the lumbar plexus[19]. The latter approach has been modified using various lumbar levels as a landmark for needle insertion as well as different distances from the spinous process[20]. Moreover, the use of ultrasound for regional anesthesia has become more widely available, thus providing and alternative to the traditional landmark guided approach towards the lumbar plexus block[21].

Technique: The L4 approach was described by Capdevila et al[20] and modified by the New York School of Regional Anesthesia, and includes the following landmarks: the spinous processes serve to define the midline at the level of the iliac crest (intercrystal line, level of L4), the needle is inserted 4 cm lateral to the intersection of the midline and the iliac crest using nerve stimulation. A successful block will be achieved when local anesthetic is injected in the fascial plane of the psoas compartment; switches of the quadriceps muscle using the nerve stimulator indicate the appropriate depth[21]. In 2001, Kirchmair et al[24] published a detailed description of the sonoanatomy of the lumbar plexus. They introduced a paramedian sagittal scan technique to identify the psoas muscle between L3-5. The needle is again inserted approximately 4 cm from the midline. The ultrasound guided technique described above, thus uses a similar approach as the landmark guided technique; it does, however, provide the benefits of ultrasound guidance including visualization of the needle as well as of the local anesthetic spread during injection.

Implications, considerations and outcomes: In regard to the use of a lumbar plexus block for total knee arthroplasty, some drawbacks have to be considered (Table 1). The block represents a clinically advanced technique with the potential for serious complications[22]. The main risk is derived from the close relation of important anatomical structures to the lumbar plexus, i.e., proximity of the epidural space, the retroperitoneum or the kidney. Epidural spread leading to high neuraxial anesthesia, mislead catheters (epidural space) as well as kidney injuries have been reported[21-23]. Moreover, this technique should be avoided in anticoagulated patients to the lumbar plexus’ location within the psoas muscle and risk of hematoma formation and subsequent nerve injury[24,25]. A large volume of local anesthetic is needed to provide sufficient anesthesia and postoperative analgesia; this fact may be one reason for reports of local anesthetic toxicity associated with lumbar plexus blocks[21]. Furthermore, when using ultrasound guidance, the user should have advanced skills as it may be challenging to obtain optimal images according to the
Table 1  Overview of block characteristics

| Block           | Landmarks                                           | Ultrasound guidance                                      | Catheter technique                  | Benefits                                      |
|-----------------|-----------------------------------------------------|-----------------------------------------------------------|-------------------------------------|-----------------------------------------------|
| Lumbar plexus block | Spinal process iliac crest (L4) needle insertion 4 cm from midline | Paramedian sagittal L3-L5 identification of psoas muscle needle insertion 4 cm from midline | Not widely used; not practical | Some evidence for benefit in regard of early recovery and opioid consumption |
| Femoral nerve block | Inguinal ligament inguinal crease femoral artery | Transverse direction femoral crease identification of femoral artery and femoral nerve | Superior to single shot after 24 h | Easy to learn; safe to use                      |
| Saphenous nerve block | United States guidance preferred | Midthigh identifying sartorius muscle anteromedial to femoral artery | FNB catheter necessary | Easy to learn; safe to use                      |
| Sciatic nerve block | Classic approach; greater trochanter posterior superior iliac spine needle insertion 4 cm distal to the mid of the drawn line | Anterior approach; proximal end of medial thigh nerve beneath adductor magnus muscle and femur | FNB catheter necessary | Classic approach; easy to perform; high success rate |

The femoral nerve block (FNB) is currently deemed to be the analgesic of choice when used for postoperative analgesia in patients undergoing TKA. It was first described in the 1920’s by Labat [15]. FNBs are well studied and used in patients undergoing TKA to provide sufficient postoperative analgesia; this may be due to some advantages of this technique. Regardless if a single shot or continuous approach is chosen, a FNB is relatively simple to perform and therefore easy to learn; it has shown to have high success rates and carries a low risk for complications. FNBs can be performed using either nerve stimulator technique or ultrasound guidance; the latter technique has evolved over the last decade and is gaining popularity rapidly.

**Technique:** In contrast to lumbar plexus blocks, there is a well-defined insertion site for the FNB [34]: it is based on 3 landmarks: inguinal ligament, inguinal crease, and femoral artery. Using a nerve stimulator, the needle is inserted at the lateral margin of the artery in a sagittal, slightly cephalad plane; patella twitches, indicating quadriceps muscle stimulation and consequently the correct injection site, must be obtained before administrating the local anesthetic. For placing a nerve catheter, the technique is similar; however, a reduced insertion angle of the needle may facilitate advancement of the catheter. Using ultrasound guidance, it is however not necessary to palpate the femoral pulse as the artery needs to be visualized [35].

The transducer is positioned in a transverse direction, close to the femoral crease. After identifying the femoral artery and the femoral nerve using an in-plane technique, the needle is advanced towards the nerve. As soon as the needle tip is adjacent to the nerve, a small dose is administered to confirm the correct position by visualization of adequate spread. If the spread of local anesthetic is confirmed surrounding the nerve, the complete volume can be injected. A nerve stimulator may be used in addition to ultrasound guidance. Inserting a nerve catheter in the ultrasound guided setting, may be facilitated through a helper, as the catheter position should be visualized during advancement.

**Implications, considerations and outcomes:** An abundant amount of literature is available on the use of FNBs, for both regarding single shot blockade and continuous catheter techniques. Much of the literature suggests that a FNB facilitates recovery, improves early mobilization and reduces morphine consumption during the perioperative period when compared with other approaches [33,34]. It has shown that a single shot FNB can provide sufficient analgesia for pain with activity during the first 24 h, thereafter a continuous catheter technique is of advantage if depth of the plexus and the anatomical structures in the neighboring area.

Following TKA, early mobilization and physiotherapy is a crucial part of the recovery process. The downside of this practice still lies in dreaded complications like inpatient falls. Therefore, the goal of regional anesthesia in this context must be a balance between the most effective pain relief and-at the same time—a minimal amount of motor blockade. In terms of postoperative outcomes, only very limited data for lumbar plexus blocks for total knee arthroplasty are available [32,33]. There is at least some evidence that the use of a continuous lumbar plexus blockade may be beneficial for early recovery. Watson et al [34] reported improved early recovery of patients receiving a continuous lumbar plexus block while simultaneously achieving a reduction in morphine consumption when compared with a single shot blockade. Lee et al [35] provided similar results; they compared pain scores over 48 h [continuous lumbar plexus block vs intravenous patient controlled analgesia (IV PCA)]. There were no differences in the first 6 h, whereas significant lower pain scores were found at 24 and 48 h, respectively. Consequently, nausea and sedation occurred more frequently in the IV PCA group. A difference in rescue analgesic consumption was however not observed. Indeed, lumbar plexus block might be used as an approach for regional anesthesia in patients undergoing TKA; there is however a potential for serious complications, moreover, advanced skills to perform the block are necessary. As a consequence, this block is not widely used.

**Femoral nerve block**

The femoral nerve block (FNB) is currently deemed to be the analgesic of choice when used for postoperative analgesia in patients undergoing TKA. It was first described in the 1920’s by Labat [15]. FNBs are well studied and used in patients undergoing TKA to provide sufficient postoperative analgesia; this may be due to some advantages of this technique. Regardless if a single shot or continuous approach is chosen, a FNB is relatively simple to perform and therefore easy to learn; it has shown to have high success rates and carries a low risk
Prolonged analgesia is desired compared to a single shot blockade\[\text{[37]}\]. The use of an indwelling catheter in an inpatient setting after TKA has been well described while it may be challenging to provide continuous FNB catheters in an outpatient setting\[\text{[38,39]}\]. More resources, such as a well-trained acute pain team or on call anesthesiologists are needed. One of the major drawbacks may consist in a belated awareness of complications\[\text{[40]}\]; moreover falls may occur more frequently if the patient is discharged home early. Some institutions, including leading centers for regional anesthesia, do not provide such services on an ambulatory basis due to those limitations. In contrast, the use of FNB catheters in an inpatient setting is well established. However, catheter dislodgment, nerve injury or prolonged motor weakness resulting in falls may also occur during the course of the patient’s recovery\[\text{[2,14,42]}\]. Although exceedingly rare and with limited consequences if treated, an increased infection rate for catheters may be of concern; bacterial contamination is common 48 h after placement\[\text{[43]}\].

In terms of block safety, FNB is associated with a low complication rate and a low incidence of related long-term adverse effects. In general, neurologic complications after peripheral nerve blocks are low with a range reported between 0.3% and 2.07%\[\text{[44-47]}\]. Data on long-term outcomes beyond 6 mo are very limited, mainly due to limitations in study design (i.e., follow up period) and high numbers needed to identify these already rarely occurring adverse effects. Moreover, neurological complications, which are attributable to the peripheral nerve block, are less likely to be resolved within one year after the procedure. Recently, Widmer et al\[\text{[48]}\] reported an incidence of nerve injury of 1.94% in a retrospective analysis, ranging in the upper zone, which was previously described for femoral nerve blocks. The neurological symptoms lasted on average longer (25 mo) than previous studies have suggested. Interestingly, patients receiving a nerve catheter reported significantly fewer neurological adverse events than those receiving a single shot technique (0.93% vs 2.66%, $P = 0.01$). There are, however, some limitations to this study (retrospective, small sample size to determine rare adverse events) and data therefore have to be interpreted with caution. As an additional consequence of a FNB, a reduction in the quadriceps muscle strength of up to 80% can be observed\[\text{[48]}\]. Various attempts to counteract this effect, including a reduction in volume and/or dose of local anesthetic administered, blockade on a more distal level (saphenous nerve, see below) or manipulation of the location of the catheter tip have been performed with variable success\[\text{[46,51]}\]. Ilfeld et al\[\text{[13]}\] re-analyzed and pooled the data of three separate trials, which have – analyzed independently–not shown a significant difference between sham FNB and active FNB in regard to inpatient fall risk, which is viewed as a major complication associated with potential quadriceps weakness. However, in the pooled analysis a significantly higher fall rate for active FNB has been encountered. It remains, however, the subject of current research if a peripheral nerve block in-...
block onset times were reduced by approximately 30% compared to the conventional technique. However, it has to be determined in randomized controlled clinical trials if this would be a feasible approach for postoperative analgesia in TKA patients.

Implications, considerations and outcomes: The SNB itself, especially the posterior approach, is relatively simple to perform. Moreover, it has shown a high success rate (Table 1). In terms of a continuous blockade, the SNB in addition to a FNB nerve catheter can be challenging for patients. First, managing two different pumps may be logistically difficult; second, the needle insertion site, especially within the classic approach for the SNB, is not well suited for a nerve catheter, and third, the anterior approach to the sciatic nerve is an advanced technique and is therefore not widely available. However, Morin et al[67] reported reduced opioid consumption with a combined FNB and SNB catheter technique compared to a continuous FNB alone. The authors used the anterior approach for the SNB resulting in a relatively high failure rate, which may be in part attributable to the lack of ultrasound guidance as well as to the approach chosen in general. Of even higher concern may have been the fact that physiotherapists reported “…active exercise was more difficult to perform and walking were more insecure with patients who had the combined FEM/SCI catheter because of more pronounced motor weakness...”\(^\text{[51]}\). There was no measurement for motor strength of the quadriceps muscle; therefore one can only hypothesize on the impact on recovery. A systematic review article by Abdallah et al\(^\text{[12]}\) found no evidence for a beneficial analgesic effect of a SNB beyond 24 h. This was also true when a continuous nerve catheter was used. They concluded that the area innervated by the sciatic nerve might be of minor importance in contributing to postoperative pain following TKA. Of note, within 24 h after TKA, a SNB has provided better pain relief and has reduced the opioid consumption within the majority of the trials that have been included into the systematic review. Therefore the question arises if a continuous catheter technique is (still) needed at times when the analgesic duration achieved with a single shot of local anesthetics tends to be prolonged, either through the choice of long acting anesthetic or the addition of additives.

Patient satisfaction and cost effectiveness
Peripheral nerve blocks in general have contributed to improving patient satisfaction, shortening length of stay in the recovery unit and while remaining cost effective.

Patient satisfaction: Hospital rankings and advertisement have become more common worldwide; especially in the United States many patients use these factors in order to choose a certain institution for a specific procedure. A similar trend has started and is expected to continue in many other countries over the next years as well. However, these rankings seem to always include some measure of patient satisfaction. High levels in pa-

Sciatic nerve block
The sciatic nerve block (SNB) has undergone a controversial debate in the literature in regard of its usefulness for patients undergoing TKA. It is most commonly considered to treat posterior knee pain after TKA. The posterior approach to the sciatic nerve was first described by Labat\(^\text{[18]}\). Since then, it has been modified multiple times, however, the clinical impact of those modifications remains uncertain\(^\text{[60,63]}\). Nonetheless, the classic posterior approach remains to be used most commonly and will be referred to for the purposes of the review.

Technique: The landmark guided approach for the classic SNB includes the greater trochanter and the posterior superior iliac spine.\(^\text{[58]}\) The needle insertion point may be found approximately 4 cm distal to the mid of a line drawn between the two anatomic landmarks. The needle is inserted perpendicular to the skin and advanced slowly. Twitches of the gluteal muscle are observed first; as soon as a response to the sciatic nerve (hamstring, calf, foot or toes) is obtained, the current is decreased. After negative aspiration, the local anesthetic may be injected slowly. Similar to most other nerve blocks, the posterior approach to the sciatic nerve may also be performed using ultrasound guidance.\(^\text{[60]}\) Alternatively, the anterior approach using ultrasound guidance can be used.\(^\text{[63]}\) This technique may be advantageous when the patient cannot be positioned in the lateral position. The ultrasound probe is positioned on the proximal end of the medial thigh. The sciatic nerve can be visualized as a hyperechoic structure beneath the adductor magnus muscle medially to the femur. Nerve stimulation can be used to further confirm the needle position. A different approach of blocking the sciatic nerve would be a high popliteal sciatic block. Perlas\(^\text{[66]}\) recently showed that an ultrasound-guided block through the paraneural sheath at the site of the bifurcation of the sciatic nerve is a simple and safe alternative compared to 2 single injections; moreover block onset times were reduced by approximately 30%
tient satisfaction might resemble an institution’s ability to meet the patient’s needs and meet or even exceed the patient’s expectations. This is important, as with a change in the reimbursement policy, the Centers for Medicare and Medicaid will account for patient satisfaction rating when reimbursing hospitals for their expenses\textsuperscript{[9]}. In this context it is important to note that regional anesthesia and peripheral nerve blocks have shown the potential to significantly contribute to a higher overall level of patient satisfaction\textsuperscript{[8]}. In the successful multimodal analgesic model, regional anesthesia plays one of the most important roles. Therefore, it seems prudent that when medically indicated peripheral nerve blocks should be considered whenever possible in TKA patients.

Cost effectiveness: Cost-effectiveness has become a major factor in most health care systems around the world when providing medical care. In this regard, it has been shown that peripheral nerve blocks are associated with cost savings when used for postoperative pain management after TKA. In a retrospective analysis, Ilfeld et al\textsuperscript{[9]} demonstrated a 34% reduction in hospital cost for patients receiving continuous FNB after conventional TKA. Regarding the use of ultrasound guidance, it has been shown to be a cost-effective alternative compared to a nerve stimulator technique for a continuous sciatic nerve block despite initially high acquisition costs\textsuperscript{[10]}. A limitation for this and all other studies evaluating the costs for ultrasound usage are overhead costs which are not reflected within these trials. This includes the cost for education and training for users. Moreover, most trials do not take multiple clinical applications of ultrasound machines into account which may have a cost sparing effect as well.

CONCLUSION

Regional anesthesia, in specific the use of peripheral nerve blocks, has significantly improved the perioperative (pain) management of patients undergoing TKA. Early mobilization and rehabilitation, improved patient satisfaction and a reduced length of stay have been accomplished by using regional anesthesia and therefore peripheral nerve blocks are becoming ever more popular. The providers’ skill as well as the institution’s resources might however influence the specific choice of the peripheral nerve block used. It must be stressed, that health care providers utilizing peripheral nerve blocks need to be knowledgeable regarding possible complications such as risk nerve damage, bleeding, infection and inpatient falls, and take precautions to reduce such risk.

REFERENCES

1 Agency for Healthcare Research and Quality: HCUPnet, Healthcare Cost and Utilization Project. Rockville, MD: United States Department of Health & Human Services. Cited 2013-05-21. Available from: URL: http://hcupnet.ahrq.gov

2 Kurtz S, Ong K, Lau E, Mowaf M, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007; 89: 789-795 [PMID: 17403080 DOI: 10.2106/JBJS.F.00822]

3 Memtsoudis SG, Stundner O, Rasul R, Sun X, Chiu YL, Fleischut P, Danninger T, Mazumdar M. Sleep apnea and total joint arthroplasty under various types of anesthesia: a population-based study of perioperative outcomes. Reg Anesth Pain Med 2013; 38: 274-281 [PMID: 23558371 DOI: 10.1097/AAP.0b013e31828d0173]

4 Marhofer P, Harrop-Griffiths W, Kettner SC, Kirchmair L. Fifteen years of ultrasound guidance in regional anesthesia: part 1. Br J Anaesth 2010; 104: 538-546 [PMID: 20854022 DOI: 10.1093/bja/aep069]

5 Marhofer P, Harrop-Griffiths W, Willshcke H, Kirchmair L. Fifteen years of ultrasound guidance in regional anaesthesia: Part 2-recent developments in block techniques. Br J Anaesth 2010; 104: 673-683 [PMID: 20418267 DOI: 10.1093/bja/aep086]

6 Wang H, Doctor B, Verner J. The effect of single-injection femoral nerve block on rehabilitation and length of hospital stay after total knee replacement. Reg Anesth Pain Med 2002; 27: 139-144 [PMID: 11915059]

7 Koscielnik-Nielsen JZ, Dahl JB. Ultrasound-guided peripheral nerve blockade of the upper extremity. Curr Opin Anaesthesiol 2012; 25: 253-259 [PMID: 22246462 DOI: 10.1097/ACO.0b013e3283569e2]

8 Barrington MJ, Kluger R. Ultrasound guidance reduces the risk of local anesthetic systemic toxicity following peripheral nerve blockade. Reg Anesth Pain Med 2013; 38: 289-297 [PMID: 23788067 DOI: 10.1097/AAP.0b013e318292669b]

9 Hocking G, Mitchell CH. Optimizing the safety and practice of ultrasound-guided regional anesthesia: the role of echogenic technology. Curr Opin Anaesthesiol 2012; 25: 603-609 [PMID: 22825047 DOI: 10.1097/ACO.0b013e3283568835]

10 Munirama S, Joy J, Esima K, Corner G, Cochran S, McLeod G. Images in anesthesiology: shear wave elastography: novel technology for ultrasound-guided regional anesthesia. Anesthesiology 2013; 119: 698 [PMID: 24137868]

11 Choquet O, Abbål B, Capdevila X. The new technologici trends in ultrasound-guided regional anesthesia. Curr Opin Anaesthesiol 2013 Aug 13; Epub ahead of print [PMID: 23945198 DOI: 10.1016/j.coa.2013.05.012]

12 Abdallah FW, Bruil R. Is sciatic nerve block advantageous when combined with femoral nerve block for postoperative analgesia following total knee arthroplasty? A systematic review. Reg Anesth Pain Med 2011; 36: 493-498 [PMID: 21857266 DOI: 10.1097/AAP.0b013e318228d5d4]

13 Ilfeld BM, Duke KB, Donohue MC. The association between lower extremity continuous peripheral nerve blocks and patient falls after knee and hip arthroplasty. Anesth Analg 2010; 111: 1552-1554 [PMID: 20889937 DOI: 10.1213/ANE.0b013e31819507]

14 Johnson RL, Kopp SL, Hebl JR, Erwin PJ, Mantilla CB. Falls and major orthopaedic surgery with peripheral nerve blockade: a systematic review and meta-analysis. Br J Anaesth 2013; 110: 518-528 [PMID: 23440367 DOI: 10.1093/bja/aet013]

15 Labat G. Regional Anesthesia in its Technique and Clinical Application. 2nd ed. Philadelphia: WB Saunders, 1924

16 Mannion S, O’Callaghan S, Walsh M, Murphy DB, Shorten GD. In the new; with the out; with the old? Comparison of two approaches for psoas compartment block. Anesth Analg 2005; 101: 259-264, table of contents [PMID: 15976242 DOI: 10.1213/01.ANE.0000153866.38440.43]

17 Moore DM, O’Gara A, Duggan M. Continuous saphenous nerve block for total knee arthroplasty: when and how? Reg Anesth Pain Med 2013; 38: 570-571 [PMID: 23788073 DOI: 10.1097/AAP.0b013e318294fe4b]

18 Parkinson SK, Mueller JB, Little WL, Bailey SL. Extent of

REFERENCES
blockade with various approaches to the lumbar plexus. *Anesth Analg* 1989; 68: 243-248 [PMID: 2919761]

19 Paul JE, Araya A, Hurlburt L, Cheng J, Thabane L, Tidy A, Murthy Y. Femoral nerve block improves analgesia outcomes after total knee arthroplasty: a meta-analysis of randomized controlled trials. *Anesth Analg* 2010; 113: 1144-1162 [PMID: 20966667 DOI: 10.1097/ALN.0b013e31814b18]

20 Winnie AP, Ramamurthy S, Durrani Z. The inguinal paravascular technic of lumbar plexus anesthesia: the “3-in-1 block”. *Anesth Analg* 1973; 52: 989-996 [PMID: 4796576]

21 Winnie A, Ramamurthy S, Durrani Z, Radjonic R. Plexus blocks for lower extremity surgery. *Anesthesiol Rev* 1974; 1: 1-6

22 Awad IT, Duggan EM. Posterior lumbar plexus block: anatomy, approaches, and techniques. *Reg Anesth Pain Med* 2005; 30: 143-149 [PMID: 15765457]

23 Kirchmair L, Entner T, Kapral S, Mitterschiffthaler G. Ultra-sound guidance for the psoas compartment block: an imaging study. *Anesth Analg* 2002; 94: 706-710; table of contents [PMID: 11867402]

24 Capdevila X, Macaire P, Dadure C, Choquet O, Bibeoulet P, Ryckwaert Y, D’Athis F. Continuous psoas compartment block for postoperative analgesia after total hip arthroplasty: new landmarks, technical guidelines, and clinical evaluation. *Anesth Analg* 2002; 94: 1606-1613; table of contents [PMID: 12052037]

25 Robards C, Hadzic A. Lumbar Plexus Block. In: Hadzic A. *Textbook of Regional Anesthesia and Acute Pain Management*. 1st ed. New York: McGraw Hill Medical, 2006

26 Touray ST, de Leeuw MA, Zuurmond WW, Perez RS. Psoas compartment block for lower extremity surgery: a meta-analysis. *Br J Anaesth* 2008; 101: 750-760 [PMID: 18945717 DOI: 10.1093/bja/aen298]

27 Mannion S. Epidural spread depends on the approach used for posterior lumbar plexus block. *Can J Anaesth* 2004; 51: 516-517; author reply 517 [PMID: 15128643 DOI: 10.1007/BF03018320]

28 Pousman RM, Mansoor Z, Sciard D. Total spinal anesthesia after continuous posterior lumbar plexus block. *Anesthesiology* 2003; 98: 1281-1282 [PMID: 12717153]

29 Daun M, Faria S, Celdionio L, Tarantino U, Fabbri E, Sabato AF. Retropertitoneal haematoma in a patient with continuous psoas compartment block and enoxaparin administration for total knee replacement. *Br J Anaesth* 2009; 103: 309-310 [PMID: 19596765 DOI: 10.1093/bja/aep189]

30 Weller RS, Gheranner JC, Crewe J, Wadde KL. Extensive retroperitoneal haematoma without neurologic deficit in two patients who underwent lumbar plexus block and were later anticoagulated. *Anesthesiology* 2003; 98: 581-585 [PMID: 12552223]

31 Breslin DS, Martin G, Macleod DB, D’ercole F, Grant SA. Central nervous system toxicity following the administration of levobupivacaine for lumbar plexus block: A report of two cases. *Reg Anesth Pain Med* 2003; 28: 144-147 [PMID: 12677626 DOI: 10.1016/rapm.2003.07.012]

32 Watson MW, Mitra D, McIntosh TC, Grant SA. Continuous versus single-injection lumbar plexus blocks: comparison of the effects on morphine use and early recovery after total knee arthroplasty. *Reg Anesth Pain Med* 2005; 30: 541-547 [PMID: 16326339 DOI: 10.1016/j.rapm.2005.06.006]

33 Lee JJ, Choi SS, Lee MK, Lim BG, Hur W. Effect of continuous psoas compartment block and intravenous patient controlled analgesia on postoperative pain control after total knee arthroplasty. *Korean J Anesthesiol* 2012; 62: 47-51 [PMID: 22323954 DOI: 10.4097/kjae.2012.62.1.47]

34 Singelyn FJ. Femoral Nerve Block. In: Hadzic A. *Textbook of Regional Anesthesia and Acute Pain Management*. 1st ed. New York: McGraw Hill Medical, 2006

35 New York School of Regional Anesthesia. *Ultrasound-Guided Femoral Nerve Block*. New York: New York School of Regional Anesthesia. Cited 2013-12-07. Available from: URL: http://www.nysora.com/techniques/3120-ultrasound-guided-femoral-nerve-block.html

36 Capdevila X, Barthelet Y, Bibeoulet P, Ryckwaert Y, Rubenovitch J, d’Athis F: Effects of perioperative analgesic technique on the surgical outcome and duration of rehabilitation after major knee surgery. *Anesthesiology* 1999; 91: 8-15 [PMID: 10422923]

37 Fischer HB, Simanski CJ, Sharp C, Bonnet F, Camu F, Neugebauer EA, Rawal N, Joshi GP, Schug SA, Kehlet H. A procedure-specific systematic review and consensus recommendations for postoperative analgesia following total knee arthroplasty. *Anaesthesia* 2008; 63: 1105-1123 [PMID: 18627367 DOI: 10.1111/j.1365-2044.2008.05565.x]

38 Ilfeld BM, Le LT, Meyer RS, Mariano ER, Vandenburg K, Duncan PW, Sessler DI, Enneking FK, Shuster JJ, Theriaque DW, Berry LF, Spadoni EH, Gearen PF. Ambulatory continuous femoral nerve blocks decrease time to discharge readiness after tricompartmental knee arthroplasty: a randomized, triple-masked, placebo-controlled study. *Anesthesiology* 2008; 108: 703-713 [PMID: 18562660 DOI: 10.1097/ALN.0b013e318167af46]

39 Ilfeld BM, Mariano ER, Girard PJ, Loland VJ, Meyer RS, Donovan JF, Pugh GA, Le LT, Sessler DI, Shuster JJ, Theriaque DW, Ball ST. A multicenter, randomized, triple-masked, placebo-controlled trial of the effect of ambulatory continuous femoral nerve blocks on discharge-readiness following total knee arthroplasty in patients on general orthopaedic wards. *Pain* 2010; 150: 477-484 [PMID: 20573448 DOI: 10.1016/j.j.pain.2010.05.029]

40 Mantilla CB, Horlocker TT, Schroeder DR, Berry JJ, Brown DL. Frequency of myocardial infarction, pulmonary embolism, deep venous thrombosis, and death following primary hip or knee arthroplasty. *Anesthesiology* 2002; 96: 1140-1146 [PMID: 11981154]

41 Widmer B, Lustig S, Scholes CJ, Molloy A, Leo SP, Coolican MR, Parker DA. Incidence and severity of complications due to femoral nerve blocks performed for knee surgery. *Knee* 2013; 20: 181-185 [PMID: 23276419 DOI: 10.1016/j.knee.2012.11.002]

42 Ng FY, Chiu KY, Yan CH, Ng KF. Continuous femoral nerve block versus patient-controlled analgesia following total knee arthroplasty. *J Orthop Surg (Hong Kong)* 2012; 20: 23-26 [PMID: 22558666]

43 Cuivillon P, Ripart J, Lalourcey L, Veyrat E, L’Hermite J, Boesson C, Thouabtia E, Elekdjam J. The continuous femoral nerve block catheter for postoperative analgesia: bacterial colonization, infectious rate and adverse effects. *Anesth Analg* 2001; 93: 1045-1049 [PMID: 11574381]

44 Fanelli G, Casati A, Garancini P, Torri G. Nerve stimulator and multiple injection technique for upper and lower limb blockade: failure rate, patient acceptance, and neurologic complications. *Study Group on Regional Anesthesia. Anaesthesia* 1999; 54: 847-852 [PMID: 10195536]

45 Watts SA, Sharma DJ. Long-term neurological complications associated with surgery and peripheral nerve blockade: outcomes after 1065 consecutive blocks. *Anaesth Intensive Care* 2007; 35: 24-31 [PMID: 17323662]

46 Fredrickson MJ, Kilfoyle DH. Neurological complication analysis of 1000 ultrasound guided peripheral nerve blocks for elective orthopaedic surgery: a prospective study. *Anaesthesia* 2009; 64: 834-844 [PMID: 19604186 DOI: 10.1111/j.1365-2044.2009.05938.x]

47 Brull R, McCartney CJ, Chan VW, El-Beheyri H. Neurological complications after regional anesthesia: contemporary estimates of risk. *Anesth Analg* 2007; 104: 965-974 [PMID: 17577115 DOI: 10.1213/01.ane.0000258740.17193.ee]

48 Charous MT, Madison SJ, Suresh PJ, Sandhu NS, Loland VJ, Mariano ER, Donohue MC, Dutton PH, Ferguson EJ, Ilfeld BM. Continuous femoral nerve blocks: varying local
anesthetic delivery method (bolus versus basal) to minimize quadriceps motor block while maintaining sensory block. *Anesthesiology* 2011; 115: 774-781 [PMID: 21394001 DOI: 10.1097/ALN.0b013e31821d9c6e]

49 Ilfeld BM, Moellor LK, Mariano ER, Loland VJ, F. Prasad A, Jorgensen HB, Jørgensen L and Turlington M. Single- versus double-injection techniques for sciatic nerve block: a comparison of motor and sensory blockade. *Pain Med* 2012; 13: 265-266 [PMID: 22855632 DOI: 10.1093/bja/aes259]

50 Jäger P, Zoric D, Fomsgaard JS, Hillest KL, Bjerggaard J, Pye J, Mathiesen O, Larsen TK, Dahl JB. Adductor canal block versus femoral nerve block for analgesia after total knee arthroplasty: a randomized, double-blind study. *Reg Anesth Pain Med* 2013; 38: 526-532 [PMID: 24121608 DOI: 10.1097/AAP.0b013e318261f326]

51 Memtsoudis SG, Dannienger T, Rasul R, Poeran J, Gerner J, Beall C, Kirkpatrick J, Siefring C, McQuillan PM. The saphenous nerve and its relationship to the nerve to the vas.

52 Benzon HT, Sharma S, Calimaran A. Comparison of the different approaches to saphenous nerve block. *Anesthesiology* 2005; 102: 633-638 [PMID: 15731603]

53 Dunaway DJ, Steensens RN, Wiand W, Dopiak RM. The sartorial branch of the saphenous nerve: its anatomy at the joint line of the knee. *Arthroscopy* 2005; 21: 547-351 [PMID: 15891719 DOII: 10.1016/j.arthro.2005.02.019]

54 Mansour NY. Sub-sartorial saphenous nerve block with the aid of nerve stimulator. *Reg Anesth* 1993; 18: 266-268 [PMID: 8398966]

55 New York School of Regional Anesthesia. Ultrasound-Guided Saphenous Nerve Block. New York: New York School of Regional Anesthesia. Cited 2013-12-07. Available from: URL: http://www.nysora.com/techniques/nerve-stimulator-and-surface-based-ra-techniques/lower-extremity/3265-transgluteal-anterior-approach.html

56 New York School of Regional Anesthesia. Sciatic Nerve Block: Anterior/Transgluteal/Subgluteal Approach. New York: New York School of Regional Anesthesia. Cited 2013-12-07. Available from: URL: http://www.nysora.com/techniques/ultrasound-guided-techniques/lower-extremity/3482-sciatic-nerve-block-anterior-transgluteal-subgluteal-approach.html

57 Perlas A, Wong P, Abdallah F, Hazrati NN, Tse C, Chan V. Ultrasound-guided popliteal block through a common paraneural sheath versus conventional injection: a prospective, randomized, double-blind study. *Reg Anesth Pain Med* 2013; 38: 216-225 [PMID: 23558372 DOI: 10.1097/AAP.0b013e31828db12f]

58 Morin AM, Kratz CD, Eberhart LH, Dinges G, Heider E, Schwarz N, Eisenhardt G, Geldner G, Wulf H. Postoperative analgesia and functional recovery after total-knee replacement: comparison of a continuous posterior lumbar plexus (psosas compartment) block, a continuous femoral nerve block, and the combination of a continuous femoral and sciatic nerve block. *Reg Anesth Pain Med* 2005; 30: 434-445 [PMID: 16135347 DOI: 10.1016/j.rapm.2005.05.006]

59 Hospital Inpatient Value-Based Purchasing Program: Centers for Medicare & Medicaid Services web site. Cited 2013-12-01. Available from: URL: http://www.hipaa.gov/indiv-law/privacy/patient-notice/2000-patientnotice-2003-patientnotice.html

60 Ironfield CM, Harrington MJ, Kluger R, Sites B. Are patients satisfied after peripheral nerve blockade? Results from an International Registry of Regional Anesthesia. *Reg Anesth Pain Med* 2014; 39: 48-55 [PMID: 24310051 DOI: 10.1097/AAP.000000000000038]

61 Ilfeld BM, Mariano ER, Williams BA, Woodward JJ, Macario A. Hospitalization costs of total knee arthroplasty with a continuous femoral nerve block provided only in the hospital versus on an ambulatory basis: a retrospective, case-control, cost-minimization analysis. *Reg Anesth Pain Med* 2007; 32: 46-54 [PMID: 17194922 DOI: 10.1016/j.rapm.2006.10.010]

62 Ehlers L, Jensen J, Bendtsen TF. Cost-effectiveness of ultrasound vs nerve stimulation guidance for continuous sciatic nerve block. *Br J Anaesth* 2012; 109: 804-808 [PMID: 22855632 DOI: 10.1093/bja/aes259]
