Hasegawa M, Singh D, Urits I, et al. Review on Nerve Blocks Utilized for Perioperative Total Knee Arthroplasty Analgesia. *Orthopedic Reviews*. 2022;14(3). doi:10.52965/001c.37405

General

Review on Nerve Blocks Utilized for Perioperative Total Knee Arthroplasty Analgesia

Morgan Hasegawa[1a], Dylan Singh[2], Ivan Urits[3], Michael Pi[4], Cass Nakasone[5], Omar Viswanath[6], Alan D. Kaye[7]

[1] Surgery- Division of Orthopaedics, University of Hawai'i Department of Sugery-Division of Orthopaedics, [2] John A. Burns School of Medicine, University of Hawai'i- John A . Burns School of Medicine, [3] SouthCoast Health, [4] University of Hawai'i, Department of Surgery; Pediatric Anesthesia Division Lead, Department of Anesthesiology; American Society of Anesthesiology; Pediatric Anesthesia Division Lead, Pacific Anesthesia Corporation, Inc, [5] The Bone and Joint Center at Straub, Straub Clinic and Hospital, Honolulu, Hawaii; University of Hawai'i, John A. Burns School of Medicine, Honolulu, Hawaii, [6] Department of Anesthesiology, Louisiana State University Health Shreveport, Department of Anesthesiology; Valley Pain Consultants e Envision Physician Services; University of Arizona College of Medicine-Phoenix, Department of Anesthesiology; Creighton University School of Medicine, Department of Anesthesiology, [7] Department of Anesthesia, Louisiana State University Health Shreveport

Keywords: Knee, Nerve Block, Arthoplasty

https://doi.org/10.52965/001c.37405

Orthopedic Reviews

Vol. 14, Issue 3, 2022

Total Knee Arthroplasty (TKA) is an increasingly common procedure performed for advanced osteoarthritis. Optimal perioperative pain management strategies are critical for early mobilization and shorter hospital stays in TKA. Peripheral nerve blocks commonly used in TKA perioperative analgesia including individual and combined femoral, obturator, sciatic, lumbar plexus, and adductor canal nerve blocks. Overall, the safety profile varies depending on which block is utilized, but the current evidence suggests when optimally chosen and delivered, peripheral nerve blocks may provide a safe, effective option for perioperative analgesia. Determining optimal analgesic regimens for total knee arthroplasty is critical to improve postoperative pain, patient satisfaction, decreasing opioid usage, recovery times and functional outcomes, and as such, peripheral nerve blocks may represent a viable option to supplement analgesic requirements in the perioperative period.

INTRODUCTION

Total Knee Arthroplasty (TKA), frequently performed for advanced osteoarthritis, has become increasingly common with annual operative rates expected to rise. As such, many providers have sought to determine optimal pain management in the perioperative period. Adequate analgesia has been shown to decrease post-operative morbidity and mortality by improving post-operative mobilization, and shorter hospital stays.[1-8] Traditional methods of pain control, including intravenous and oral pain medications have been associated with unreliable pain control and adverse effects such as hypotension, sedation, urinary retention, and nausea.[9,10] As such, contemporary strategy for pain control following total knee arthroplasty is utilizing a multi-modal approach, frequently including nerve blockade. Nerve blocks have been shown to be a valuable modality in perioperative Total Knee Arthroplasty analgesia. Various nerves have been targeted through solo or combination blockade, and single injection or continuous infusion. In this review, we aim to summarize current literature on common peripheral nerve blocks used in practice, and the literature surrounding their efficacy and safety profile.

FEMORAL NERVE BLOCK

The first femoral nerve block (FNB) was described in 1952 by Moore.[11,12] Its use has been implicated in pain control concerning pathology of the anterior thigh, and lower medial leg. Some of which include hip fractures, femoral shaft fractures, and operations involving the knee.[13,14] Since its introduction, its use has allowed for decreased narcotic use, earlier mobilization, improved pain scores, knee flexion, and decreased duration of hospitalization.[15-22] It can be given as a single injection, or continuously with an indwelling catheter.[23] When given as a single injection, current literature reports the analgesic effects typically lasts 12-24 hours, though some studies have suggest residual ef-

a **Corresponding author:**
Morgan Hasegawa
1301 Punchbowl St.
Honolulu, Hawaii 96813
morganha@hawaii.edu
808-439-3842

fects may linger up to 48 hours.[24-26] Femoral nerve block was first administered in single shot femoral nerve block (SSFB), with recent progression to continuous infusion femoral nerve block (CFNB), through an indwelling catheter, which can be administered continuously and used in concurrence with other forms of nerve blockade.

As with other peripheral nerve blocks, femoral nerve blockade has been associated with earlier mobilization, decreased narcotic use, and improved side effects associated with other forms of analgesia. Ilfeld et al. found that continuous femoral never blockade (CFNB) decreased time to discharge in patients undergoing TKA.[21] Likewise, a study by Szczuzukowski Jr. et al, found a significant decrease in morphine consumption, sedation and pain scores in a patient group who received single injection of bupivacaine with epinephrine as compared to a group who did not receive a FNB.[26] These findings were also shown in a meta-analysis by Paul et al., including 23 studies totaling 1,016 patients, showing significant decrease in opioid consumption at 24 and 48 hours, less pain at rest at 24 hours post-op, and less pain with activity at 24 and 48 hours with FNB use.[17] Numerous studies have continued to reiterate these findings, reporting FNB provides superior pain control, improves time to functional recovery and decreases hospital length of stay, with an improved side effect profile compared to epidural or IV PCA.[27,28] Of note, it appears these beneficial effects are present with all forms of femoral nerve blocks, including the single shot form, continuous blockade, and studies that included concurrent sciatic nerve blockade or PCA.[17]

Some studies have shown decreased length of stay, though it appears most current literature suggests FNB provides no benefit in length of stay after TKA.[10,16,23,29] What has been shown in the literature is significantly improved knee range of motion, pain at rest and pain with activity, which greatly contributes to early physiotherapy and mobilization.[16,17,30] These positive findings have spurred investigation into comparisons of single and continuous forms of femoral nerve blockade. In a study of 33 patients undergoing TKA, Hirst et al. compared single injection femoral nerve block with continuous infusion and found the only significant benefit of continuous infusion was reported pain scores in the post-operative recovery room, which did not remain beyond the recovery room.[31] Whereas in a study by Salinas et al., they found cFNB provided significant improvement in narcotic use, pain scores at the 24 and 48 hour mark, with continuation of improved pain scores into post-operative therapy.[23] They did not find any differences between the groups in terms of hospital length of stay, or long term functional recovery, as measured by knee flexion post-operatively.[23] Similarly, a more recent study in 2013 by Chan et al. reported cFNB had statistically significant pain score improvements during movement, as compared to SSFNB at 24 hours. They also reported significant improvements in opioid consumption, nausea and vomiting.[32] However, a 2014 pilot study by Albrecht et al. found no discernible difference in primary or secondary outcomes between SNFB and CFNB, which included length of stay, opioid consumption, pain and functional outcomes.[32,33] These mixed findings suggest further work is needed to determine any superiority between cFNB and SSFNB.

While the safety profile of FNB has been reported as excellent, several adverse effects have been cited. Most notably, quadricep weakness and femoral nerve palsy has been estimated to occur in 2-2.7% of patients who receive FNB, and can lead to deleterious events such as falls or prolonged mobilization.[29,34,35] In their case report, Kandasami et al. reported 5 patients who experienced quadricep weakness, and falls, leading to prolonged hospital stays, periprosthetic fractures and additional operative management.[29] The authors suggested FNB mediated quadricep weakness is likely underreported, and a cause for larger studies reevaluating of its overall safety profile.[29,30] Other side effects reported in the literature include nausea, vomiting, hematoma formation, catheter site infection and blockade failure.[9,26,35-37]

OBTURATOR NERVE BLOCK

A portion of the obturator nerve penetrates the intraarticular space and provides innervation into the knee joint itself.[38] As such, appropriate blockade can prevent referred pain, often to the posterior aspect of the knee.[39,40] FNB does not consistently anesthetize the obturator nerve, which may preclude inadequate analgesia and impaired functional outcomes post-operatively.[41] Due to the inconsistency of obturator nerve blockade with isolated FNB, a variation was developed called the “3-in-1 block”, utilizing the femoral nerve’s proximity and shared facial plane with the obturator and lateral femoral cutaneous nerves, allowing anesthetic injection which provides blockade at all three nerves. The addition of an obturator nerve block diminishes pain conduction through intraarticular nerve segments, originating from the popliteal nerve plexus in the posterior aspect of the knee.[38,42] With the added benefit of obturator nerve blockade, many studies have shown significant decrease in post-operative pain, opioid use, and improved functional measures.[41,43,44] Unfortunately, prior studies have suggested 3-in-1 blockades do not provide adequate obturator blockade.[45] As a result, several authors have examined the effect of isolated obturator nerve blocks or additional peripheral blockade after FNB for post-operative TKA pain.

Prior to increased use of ultrasound technology, obturator nerve blocks showed varying efficacy. In a study by Kardash et al. 60 patients undergoing unilateral TKA, patients were given either a FNB, Obturator nerve block or sham block, with no statistically significant results suggesting obturator nerve block alone provided benefit.[46] Whereas studies by Mcnamee et al and Macalou et al. showed improved post-operative analgesia with the addition of an obturator nerve block.[41,43] These positive effects were also shown in a study by Bergeron et al., where no difference in pain scores, range of motion, and daily function at 6 weeks and 1 year post-operatively were observed between patients receiving a femoral nerve block or obturator nerve block.[47] Recently investigators have incorporated use of ultrasonography, which has improved targeted delivery of analgesia and improved opioid use, vomiting, and nausea.[44,48]

The literature on complications associated with obturator block is limited. In a study by Heywang-Kobrunner et al. they noted that no major complications had been described with obturator nerve blockade, but a theoretical risk of infection, hematoma formation and persistent nerve palsy likely exists.[49] The relative safety of obturator nerve blockade was also shown by Choquet et al. whom reported no minor complications, defined as local bleeding, painful bone contact, groin pain, or major complications, defined as hematoma, paresthesia, or neuropathy.[50] Though, some adverse effects have been reported. In their study comparing obturator versus femoral nerve block after TKA, Kardash et al. reported patients with urinary retention after surgery, pruritus, and numbness of the leg within the first 48 hour post-operative window, though there was no statistically significant difference between the femoral nerve block group.[46] Overall, the literature supports obturator nerve blockade as safe, with theoretical risks that are assumed with all peripheral nerve blocks, such as infection, hematoma, and persistent numbness to affected legs.

SCIATIC NERVE BLOCK

The sciatic nerve originates from the sacral plexus, and exits the greater sciatic foramen to traverse through the posterior portion of the thigh and leg. It ends in the popliteal fossa to bifurcate into the common peroneal nerve and the tibial nerve. Fibers forming from the tibial nerve joining with fibers from the obturator nerve to form the popliteal plexus, which can be responsible for intraarticular nociception in the knee.[38]

Sciatic nerve blockade can be achieved by either blocking the sacral plexus, or, targeting a more distal portion of the sciatic nerve, often with ultrasonography. As with other peripheral nerve blocks, much of the current literature examines sciatic nerve blockade as a supplement to a femoral nerve block.[51] In a review by Abdallah et al. they examined studies comparing sciatic nerve block in addition to FNB with FNB alone, which included four intermediate randomized studies and three observational trials, all of which included 391 patients. Overall, three out of the four studies examining single shot sciatic nerve blockade reported improved pain, and two out of three examining continuous sciatic nerve blockade reported improved analgesia. Their review was limited though, as they could not determine specifically any improvement to posterior knee pain, as well as any effect beyond the initial 24 hour post-operative period.[51] Zuglani et al. reported when added to femoral nerve blocks, sciatic nerve blockade improved quality of post-operative analgesia.[52] However, in studies aiming to compare functional outcomes, such as physical rehabilitation and length of stay, sciatic nerve blockade has not shown to add any benefit when compared to other peripheral nerve blockade.[53-56]

Some recent studies have examined more regional anesthetic techniques, such as local infiltration analgesia (LIA) incorporating posterior pain receptors and compared them with normal FNB and SNB. Gi et al. reported improved pain scores with periarticular infiltration analgesia, but was not able to show significant functional outcome differences between groups.[54,55,57,58] Li et al. demonstrated LIA may provide quicker onset anesthesia, but found no benefits with active knee flexion, LOS, opioid use, and falls compared with combined sciatic and femoral nerve blockade.[59] Though in a review article and meta-analyses by Zhang et al. who examined three randomized controlled trials, 2 non-randomized controlled trials, all of which included 240 patients, they concluded SNB in combination with FNB provided greater pain control in the first 24-48 hours, decreased opioid consumption in the first 24 hours, along with associated decrease in nausea and vomiting when compared with LIA.[60]

As with other peripheral nerve blocks, the risks associated with sciatic nerve block center around possible hematoma formation, infection, and persistent analgesia. A study by Wiegel et al. examined the complications associated with continuous peripheral nerve blocks in orthopaedic patients, and found that less than 1% of patients who underwent sciatic nerve block suffered local inflammation or catheter breakage, while 6% and 36% encountered transient neurologic deficit and vascular puncture respectively.[61] Zaric et al reported only technical complications, with no physiologic or toxic complications.[62] The overall side effect profile of sciatic nerve blockade is favorable, when compared to other forms of PNB and epidural analgesia.[62]

LUMBAR PLEXUS NERVE BLOCK

A lumbar plexus nerve block is accomplished by administering anesthetic to the Psoas compartment, the area between the Psoas muscle and the quadratus lumborum muscle. Anesthetic affects nerves which passes through this region, including the rami of the lumbar plexus and sacral plexus including genitofemoral nerve, femoral nerve, and obturator nerve, along with portions of the sciatic nerve.[63] As such, a lumbar plexus nerve block, or also called a Psoas compartment block, can achieve vast analgesia of the lower extremity, and has been used for both total knee and hip arthroplasty.

In studies comparing effects compared to patient controlled analgesia (PCA), Watson et al and Raimer et al reported a continuous form of Psoas compartment block (PCB) resulted in lower pain scores and fewer incidences of sides effects including nausea and sedation.[64,65] In a paper by Lee et al., similar pain scores were recorded in comparison to patients with intravenous patient controlled analgesia, after a total knee arthroplasty until after 6 hours post-operatively.[66] Though the PCB group reporting statistically significant improvements on pain, nausea, and sedation after 6 hours post operatively.[66] The authors postulated this difference in time was due to the anesthetics need to fully infiltrate the compartment before achieving full and optimal effect. These findings were also highlighted by Touray et al. in their review and metanalysis which found PCB when paired with a sciatic nerve block is superior than patient-controlled opiate administration. Of note, the authors did not find any difference in length of hospital stay, satisfaction, or rescue emetic use.[66] These favorable outcomes have similarly been shown when compared to other regional blocks. In a study by Kaloul et al. comparing lumbar plexus block with a three-in-one FNB, they found similar reductions in 48 hour opioid consumption, similar pain scores at six and 24 hours post operatively, but a greater sensory and motor blockade of the obturator nerve in the lumbar plexus group.[67] Similar improvements in post-operative analgesia were reported in studies by Ozalp et al and Ganigagli et al who found when PCB was combined with sciatic nerve blockade, it provides superior analgesia than FNB alone.[68,69] Though most studies comparing isolated PCB block to FNB have not shown a difference in analgesic effect.[56,67-69] When comparing single versus continuous form, Watson et al showed continuous postoperative lumbar plexus anesthesia improved recovery and reduced morphine requirement, compared to a single-injection lumbar plexus blockade.[65]

When compared to neuraxial techniques (i.e. epidural), PCB may provide similar analgesia, without some common neuraxial analgesia side effects. This was highlighted in a study by Campbell et al whom reported similar functional measures and pain scores post-operatively between PCB and an epidural, but with a decrease in required bladder catheterization in the PCB group.[70] PCB, in combination with SNB, has been shown to be equivalent if not superior in post-operative pain control when compared to neuraxial techniques.[64,71,72] In a meta-analyses by Touray et al. comparing PCB to other local analgesic techniques, the authors determined PBC to be at least equivalent to neuraxial blocks and peripheral nerve blocks, though they conclude evidence to support PCB as an alternative to other peripheral nerve blocks and neuraxial anesthesia for a TKA is conflicting.[72]

As of now, evidence to support PCB as an alternative to other peripheral nerve blocks and neuraxial anesthesia for a TKA is conflicting.[72] Its relative efficacy has been shown to be equivalent, if not superior, to many commonly employed peripheral or neuraxial nerve blockade techniques.[70,72,73] It is likely the hesitance to incorporate Psoas compartment blocks is due to its safety profile, which includes reports of life-threatening adverse effects, including seizures and cardiac arrest, and less lethal side effects such as retroperitoneal hematoma.[72,74,75]

ADDUCTOR CANAL NERVE BLOCK

The adductor canal is an aponeurotic tunnel in the middle third of the thigh, spanning the distance from the apex of the femoral triangle to the adductor hiatus of the adductor mangus. Traditionally, it was believed to serve as a tunnel for the saphenous nerve, but recent anatomic studies have suggested the adductor canal may also include the vastus medialis nerve, medial femoral cutaneous nerve, medial retinacular nerve, and articular branches from the obturator nerve.[76-78] Thus, blockade in the adductor canal may potentially affect greater sensory distributions beyond that of just the saphenous nerve, and cover portions of the anterior and medial knee, as well as the area between the superior pole of the patella down to the proximal tibia.[79]

A benefit of the adductor canal block (ACB), as summarized by Jæger et al., comes with the primarily sensory blockade without affecting quadricep motor function.[80] This was highlighted by Jæger et al. which demonstrated in patients receiving FNB there was a 49% decrease in quadricep strength from baseline, as compared to an 8% decrease in strength after an ACB.[81] This trend of preserved quadricep appears to remain post operatively, as shown by Grevstad et al. who found statistically significant increase in quadricep muscle strength post-operatively in patients who received an ACB compared to patients who received FNB.[82] Of note, the authors did not find a statistical difference between the two groups in terms of adductor muscle strength, pain, or mobility.[82] ACB has also been associated with improved ambulation and early functional recovery, including staircase competency and straight leg tests, as compared with FNB after a TKA.[83,84] ACB also appears to provide adequate analgesia. In a study by Patterson et al. they highlighted no significant differences in pain scores and opioid requirements in first 24 hours after TKA, between ACB or FNB groups.[85] Consistently, it has been shown in various studies and metanalysis, that when compared to FNB, ACB appears to provide equivalent analgesia, while preserving quadriceps function, which has shown to improve hospital length of stays and patient satisfaction scores.[86,87] ACB utilization has also been suggested to decrease post-operative opiate use, highlighted in studies by Jenstrup and Jaeger et al, whom showed whether given as a solo agent or in combination with other PNB, ACB use was associated with improved pain scores and opiate consumption.[88,89]

The benefits of ACB appear to be in at least equivalent analgesia to other popular PNB for TKA, while avoiding muscular weakness. There are theoretical benefits, such as decreased falls, which to date have not been shown to be better in patients receiving ACB.[90] It is likely the full therapeutic benefits of ACB will require larger, more robust randomized controlled trials to truly elucidate the validity of other purported theoretical benefits.[91,92]

CONCLUSION

In conclusion, the current evidence is mixed regarding optimal analgesic regimens for total knee arthroplasty. Currently, multimodal analgesia is recommended, and options including femoral, sciatic, lumbar and adductor nerve blocks are being used. Establishing optimal analgesic regimens for total knee arthroplasty is critical to improve post-operative pain, patient satisfaction, recovery times and functional outcomes.

AUTHOR CONTRIBUTIONS

All authors – Dylan Singh, Morgan Hasegawa, Ivan Uritis, Cass Nakasone, Micheal Pi, Omar Viswanath, Alan D Kaye

- contributed to review of articles, manuscript preparation and revisions.

DISCLOSURES

None.

IRB

Does not apply.

FUNDING

No sources of funding. Not presented at any meeting.

ACKNOWLEDGEMENTS

None.

REFERENCES

1. Summers S, Mohile N, McNamara C, Osman B, Gebhard R, Hernandez VH. Analgesia in Total Knee Arthroplasty. *J Bone Jt Surg*. 2020;102(8):719-727. doi:10.2106/jbjs.19.01035

2. Li J wen, Ye-shuo M, Liang-kun X. Postoperative Pain Management in Total Knee Arthroplasty. *Orthop Surg*. 2019;11(5):755-761. doi:10.1111/os.12535

3. Kremers HM, Larson DR, Crowson CS, et al. Prevalence of total hip and knee replacement in the United States. *J Bone Jt Surg - Am Vol*. 2015;97(17):1386-1397. doi:10.2106/jbjs.n.01141

4. Inacio MCS, Paxton EW, Graves SE, Namba RS, Nemes S. Projected increase in total knee arthroplasty in the United States – an alternative projection model. *Osteoarthr Cartil*. 2017;25(11):1797-1803. doi:10.1016/j.joca.2017.07.022

5. Webb CA, Mariano ER. Best multimodal analgesic protocol for total knee arthroplasty. *Pain Manag*. 2015;5(3):185-196. doi:10.2217/pmt.15.8

6. Anastase DM, Cionac Florescu S, Munteanu AM, Ursu T, Stoica CI. Analgesic techniques in hip and knee arthroplasty: From the daily practice to evidence-based medicine. *Anesthesiol Res Pract*. 2014;2014:1-8. doi:10.1155/2014/569319

7. Canata G, Casale V, Chiey A. Pain management in total knee arthroplasty: Efficacy of a multimodal opiate-free protocol. *Joints*. 2016;04(04):222-227. doi:10.11138/jts/2016.4.4.222

8. Hu S, Zhang ZY, Hua YQ, Li J, Cai ZD. A comparison of regional and general anaesthesia for total replacement of the hip or knee: A meta-analysis. *J Bone Jt Surg - Ser B*. 2009;91-B(7):935-942. doi:10.1302/0301-620x.91b7.21538

9. Toftdahl K, Nikolajsen L, Haraldsted V, Madsen F, Tønnesen EK, Søballe K. Comparison of peri- and intraarticular analgesia with femoral nerve block after total knee arthroplasty: A randomized clinical trial. *Acta Orthop*. 2007;78(2):172-179. doi:10.1080/17453670710013645

10. Sharma S, Iorio R, Specht LM, Davies-Lepie S, Healy WL. Complications of Femoral Nerve Block for Total Knee Arthroplasty. *Clin Orthop Relat Res*. 2010;468(1):135-140. doi:10.1007/s11999-009-1025-1

11. Moore DC. SCIATIC AND FEMORAL NERVE BLOCK. *J Am Med Assoc*. 1952;150(6):550-554. doi:10.1001/jama.1952.03680060022007

12. Wanderer JP, Rathmell JP. A Brief History of Femoral Nerve Blocks. *Anesthesiol J Am Soc Anesthesiol*. 2014;121(2):A21-A21. doi:10.1097/01.anes.0000451814.86649.1d

13. Tondare AS, Nadkarni AV. Femoral nerve block for fractured shaft of femur. *Can Anaesth Soc J*. 1982;29(3):270-271. doi:10.1007/bf03007129

14. Beaudoin FL, Nagdev A, Merchant RC, Becker BM. Ultrasound-guided femoral nerve blocks in elderly patients with hip fractures. *Am J Emerg Med*. 2010;28(1):76-81. doi:10.1016/j.ajem.2008.09.015

15. Widmer B, Lustig S, Scholes CJ, et al. Incidence and severity of complications due to femoral nerve blocks performed for knee surgery. *Knee*. 2013;20(3):181-185. doi:10.1016/j.knee.2012.11.002

16. Wang H, Boctor 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(2):139-144. doi:10.1053/rapm.2002.29253

17. Paul JE, Arya A, Hurlburt L, et al. Femoral Nerve Block Improves Analgesia Outcomes after Total Knee Arthroplasty: A Meta-analysis of Randomized Controlled Trials. *Anesthesiol J Am Soc Anesthesiol*. 2010;113(5):1144-1162. doi:10.1097/aln.0b013e3181f4b18

18. Ben-David B, Chelly JE. Continuous peripheral neural blockade for postoperative analgesia: Practical advantages. *Anesth Analg*. 2003;96(5):1537. doi:10.1213/01.ane.0000063170.15467.f2

19. Heo BH, Lee HJ, Lee HG, et al. Femoral nerve block for patient undergoing total knee arthroplasty. *Medicine*. 2016;95(36):e4771. doi:10.1097/md.0000000000004771

20. Parvataneni HK, Shah VP, Howard H, Cole N, Ranawat AS, Ranawat CS. Controlling Pain After Total Hip and Knee Arthroplasty Using a Multimodal Protocol With Local Periarticular Injections. A Prospective Randomized Study. *J Arthroplasty*. 2007;22(6):33-38. doi:10.1016/j.arth.2007.03.034

21. Ilfeld BM. Ambulatory Continuous Femoral Nerve Blocks Decrease time to discharge readiness after tricompartmental TKA. 2012;100(2):130-134. doi:10.1097/ALN.0b013e318167af46.Ambulatory

22. Kadic L, Boonstra MC, De Waal Malefijt MC, Lako SJ, Van Egmond J, Driessen JJ. Continuous femoral nerve block after total knee arthroplasty? *Acta Anaesthesiol Scand*. 2009;53(7):914-920. doi:10.1111/j.1399-6576.2009.01965.x

23. Salinas FV, Liu SS, Mulroy MF. The Effect of Single-Injection Femoral Nerve Block Versus Continuous Femoral Nerve Block After Total Knee Arthroplasty on Hospital Length of Stay and Long-Term Functional Recovery Within an Established Clinical Pathway. *Anesth Analg*. 2006;102(4):1234-1239. doi:10.1213/01.ane.0000198675.20279.81

24. Allen HW, Liu SS, Ware PD, Nairn CS, Owens BD. Peripheral Nerve Blocks Improve Analgesia After Total Knee Replacement Surgery. *Anesth Analg*. 1998;87(1):93-97. doi:10.1213/00000539-199807000-00020

25. Ping H, Cheong KF, Lim A, Lim J, Puhaindran ME. Intraoperative single-shot "3-in-1" femoral nerve block with ropivacaine 0.25%, ropivacaine 0.5% or bupivacaine 0.25% provides comparable 48-hr analgesia after unilateral total knee replacement. *Can J Anesth*. 2001;48(11):1102-1108. doi:10.1007/bf03020376

26. Szczukowski MJ Jr, Hines JA, Snell JA, Sisca TS. Femoral nerve block for total knee arthroplasty patients: A method to control postoperative pain. *J Arthroplasty*. 2004;19(6):720-725. doi:10.1016/j.arth.2004.02.043

27. HEBL JR, KOPP SL, ALI MH, et al. a Comprehensive Anesthesia Protocol That Emphasizes Peripheral Nerve Blockade for Total Knee and Total Hip Arthroplasty. *J Bone Jt Surgery-American Vol*. 2005;87(Table I):63-70. doi:10.2106/00004623-200511002-00008

28. YaDeau JT, Cahill JB, Zawadsky MW, et al. The effects of femoral nerve blockade in conjunction with epidural analgesia after total knee arthroplasty. *Anesth Analg*. 2005;101(3):891-895. doi:10.1213/01.ane.0000159150.79908.21

29. Kandasami M, Kinninmonth AW, Sarungi M, Baines J, Scott NB. Femoral nerve block for total knee replacement — A word of caution. *Knee*. 2009;16(2):98-100. doi:10.1016/j.knee.2008.10.007

30. Sakai N, Inoue T, Kunugiza Y, Tomita T, Mashimo T. Continuous Femoral Versus Epidural Block for Attainment Of 120° Knee Flexion After Total Knee Arthroplasty: A Randomized Controlled Trial. *J Arthroplasty*. 2013;28(5):807-814. doi:10.1016/j.arth.2012.09.013

31. Hirst GC, Lang SA, Dust WN, Cassidy DJ, Yip RW. Femoral Nerve Block: Single Injection versus Continuous Infusion for Total Knee Arthroplasty. *Reg Anesth J Neural Blockade Obstet Surgery, & Pain Control*. 1996;21(4):292 LP - 297. doi:10.1136/rapm-00115550-199621040-00004

32. Chan EY, Fransen M, Sathappan S, Chua NHL, Chan YH, Chua N. Comparing the Analgesia Effects of Single-injection and Continuous Femoral Nerve Blocks with Patient Controlled Analgesia after Total Knee Arthroplasty. *J Arthroplasty*. 2013;28(4):608-613. doi:10.1016/j.arth.2012.06.039

33. Albrecht E, Morfey D, Chan V, et al. Single-injection or Continuous Femoral Nerve Block for Total Knee Arthroplasty? *Clin Orthop Relat Res*. 2014;472(5):1384-1393. doi:10.1007/s11999-013-3192-3

34. Beaulieu P, Babin D, Hemmerling T. The Pharmacodynamics of Ropivacaine and Bupivacaine in Combined Sciatic and Femoral Nerve Blocks for Total Knee Arthroplasty. *Anesth Analg*. 2006;103(3):768-774. doi:10.1213/01.ane.0000229652.70488.32

35. Pelt CE, Anderson AW, Anderson MB, Van Dine C, Peters CL. Postoperative Falls After Total Knee Arthroplasty in Patients With a Femoral Nerve Catheter: Can We Reduce the Incidence? *J Arthroplasty*. 2014;29(6):1154-1157. doi:10.1016/j.arth.2014.01.006

36. Feibel RJ, Dervin GF, Kim PR, Beaulé PE. Major Complications Associated with Femoral Nerve Catheters for Knee Arthroplasty: A Word of Caution. *J Arthroplasty*. 2009;24(6):132-137. doi:10.1016/j.arth.2009.04.008

37. Cuvillon P, Ripart J, Lalourcey L, et al. The Continuous Femoral Nerve Block Catheter for Postoperative Analgesia: Bacterial Colonization, Infectious Rate and Adverse Effects. *Anesth Analg*. 2001;93(4):1045-1049. doi:10.1097/00000539-200110000-00050

38. Bendtsen TF, Moriggl B, Chan V, Børglum J. The Optimal Analgesic Block for Total Knee Arthroplasty. *Reg Anesth Pain Med*. 2016;41(6):711-719. doi:10.1097/aap.0000000000000485

39. Hirasawa Y, Okajima S, Ohta M, Tokioka T. Nerve distribution to the human knee joint: anatomical and immunohistochemical study. *Int Orthop*. 2000;24(1):1-4. doi:10.1007/s002640050001

40. Kennedy JC, Alexander IJ, Hayes KC. Nerve supply of the human knee and its functional importance. *Am J Sports Med*. 1982;10(6):329-335. doi:10.1177/036354658201000601

41. Macalou D, Trueck S, Meuret P, et al. Postoperative Analgesia After Total Knee Replacement: The Effect of an Obturator Nerve Block Added to the Femoral 3-in-1 Nerve Block. *Anesth Analg*. 2004;99(1):251-254. doi:10.1213/01.ane.0000121350.09915.84

42. Kumka MD, PhD M. Critical sites of entrapment of the posterior division of the obturator nerve: anatomical considerations. *J Can Chiropr Assoc*. 2010;54(1):33-42.

43. McNamee DA, Parks L, Milligan KR. Post-operative analgesia following total knee replacement: an evaluation of the addition of an obturator nerve block to combined femoral and sciatic nerve block. *Acta Anaesthesiol Scand*. 2002;46(1):95-99. doi:10.1034/j.1399-6576.2002.460117.x

44. Runge C, Børglum J, Jensen JM, et al. The Analgesic Effect of Obturator Nerve Block Added to a Femoral Triangle Block After Total Knee Arthroplasty: A Randomized Controlled Trial *Reg Anesth & Pain Med*. 2016;41(4):445-451. doi:10.1097/aap.0000000000000406

45. Lang SA, Yip RW, Chang PC, Gerard MA. The femoral 3-in-1 block revisited. *J Clin Anesth*. 1993;5(4):292-296. doi:10.1016/0952-8180(93)90121-t

46. Kardash K, Hickey D, Tessler MJ, Payne S, Zukor D, Velly AM. Obturator Versus Femoral Nerve Block for Analgesia After Total Knee Arthroplasty. *Anesth Analg*. 2007;105(3):853-858. doi:10.1213/01.ane.0000278158.36843.f7

47. Bergeron SG, Kardash KJ, Huk OL, Zukor DJ, Antoniou J. Functional Outcome of Femoral versus Obturator Nerve Block after Total Knee Arthroplasty. *Clin Orthop Relat Res*. 2009;467(6):1458-1462. doi:10.1007/s11999-009-0732-y

48. Sato K, Sai S, Shirai N, Adachi T. Ultrasound Guided Obturator versus Sciatic Nerve Block in Addition to Continuous Femoral Nerve Block for Analgesia after Total Knee Arthroplasty. *Japanese Clin Med*. 2011;2:JCM.S7399. doi:10.4137/jcm.s7399

49. Heywang-Köbrunner SH, Amaya B, Okoniewski M, Pickuth D, Spielmann RP. CT-guided obturator nerve block for diagnosis and treatment of painful conditions of the hip. *Eur Radiol*. 2001;11(6):1047-1053. doi:10.1007/s003300000682

50. Choquet O, Capdevila X, Bennourine K, Feugeas JL, Bringuier-Branchereau S, Manelli JC. A New Inguinal Approach for the Obturator Nerve Block: Anatomical and Randomized Clinical Studies. *Anesthesiology*. 2005;103(6):1238-1245. doi:10.1097/00000542-200512000-00020

51. Abdallah FW, Brull 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(5):493-498. doi:10.1097/aap.0b013e318228d5d4

52. Zugliani AH, Verçosa N, Amaral JLG do, Barrucand L, Salgado C, Karam MBH. Controle da dor pós-operatória da artroplastia total do joelho: é necessário associar o bloqueio do nervo isquiático ao bloqueio do nervo femoral? *Rev Bras Anestesiol*. 2007;57(5):514-524. doi:10.1590/s0034-70942007000500006

53. Wegener JT, van Ooij B, van Dijk CN, et al. Long-Term Pain and Functional Disability After Total Knee Arthroplasty With and Without Single-Injection or Continuous Sciatic Nerve Block in Addition to Continuous Femoral Nerve Block: <em>A Prospective, 1-Year Follow-Up of a Randomized Controlled . *Reg Anesth & Pain Med*. 2013;38(1):58-63. doi:10.1097/aap.0b013e318272523c

54. Tanikawa H, Sato T, Nagafuchi M, Takeda K, Oshida J, Okuma K. Comparison of Local Infiltration of Analgesia and Sciatic Nerve Block in Addition to Femoral Nerve Block for Total Knee Arthroplasty. *J Arthroplasty*. 2014;29(12):2462-2467. doi:10.1016/j.arth.2014.04.011

55. Safa B, Gollish J, Haslam L, McCartney CJL. Comparing the Effects of Single Shot Sciatic Nerve Block Versus Posterior Capsule Local Anesthetic Infiltration on Analgesia and Functional Outcome After Total Knee Arthroplasty: A Prospective, Randomized, Double-Blinded, Controlled Trial. *J Arthroplasty*. 2014;29(6):1149-1153. doi:10.1016/j.arth.2013.11.020

56. Morin A, Kratz C, Eberhart L, et al. Postoperative Analgesia and Functional Recovery After Total-Knee Replacement: Comparison of a Continuous Posterior Lumbar Plexus (Psoas Compartment) Block, a Continuous Femoral Nerve Block, and the Combination of a Continuous Femoral and Sciatic Nerve Block. *Reg Anesth & Pain Med*. 2005;30(5):434-445. doi:10.1016/j.rapm.2005.05.006

57. Gi E, Yamauchi M, Yamakage M, et al. Effects of local infiltration analgesia for posterior knee pain after total knee arthroplasty: comparison with sciatic nerve block. *J Anesth*. 2014;28(5):696-701. doi:10.1007/s00540-014-1793-y

58. Kurosaka K, Tsukada S, Seino D, Morooka T, Nakayama H, Yoshiya S. Local Infiltration Analgesia Versus Continuous Femoral Nerve Block in Pain Relief After Total Knee Arthroplasty: A Randomized Controlled Trial. *J Arthroplasty*. 2016;31(4):913-917. doi:10.1016/j.arth.2015.10.030

59. Li J, Deng X, Jiang T. Combined femoral and sciatic nerve block versus femoral and local infiltration anesthesia for pain control after total knee arthroplasty: a meta-analysis of randomized controlled trials. *J Orthop Surg Res*. 2016;11(1):158. doi:10.1186/s13018-016-0495-6

60. Zhang Z, Yang Q, Xin W, Zhang Y. Comparison of local infiltration analgesia and sciatic nerve block as an adjunct to femoral nerve block for pain control after total knee arthroplasty: A systematic review and meta-analysis. *Medicine*. 2017;96(19):e6829. doi:10.1097/md.0000000000006829

61. Wiegel M, Gottschaldt U, Hennebach R, Hirschberg T, Reske A. Complications and Adverse Effects Associated with Continuous Peripheral Nerve Blocks in Orthopedic Patients. *Anesth Analg*. 2007;104(6):1578-1582. doi:10.1213/01.ane.0000261260.69083.f3

62. Zaric D, Boysen K, Christiansen C, Christiansen J, Stephensen S, Christensen B. A Comparison of Epidural Analgesia With Combined Continuous Femoral-Sciatic Nerve Blocks After Total Knee Replacement. *Anesth Analg*. 2006;102(4):1240-1246. doi:10.1213/01.ane.0000198561.03742.50

63. Hogan MV, Grant RE, Lee L. Analgesia for total hip and knee arthroplasty: a review of lumbar plexus, femoral, and sciatic nerve blocks. *Am J Orthop (Belle Mead NJ)*. 2009;38(8):E129-33.

64. Raimer C, Priem K, Wiese AA, et al. Continuous psoas and sciatic block after knee arthroplasty: good effects compared to epidural analgesia or i.v. opioid analgesia: A prospective study of 63 patients. *Acta Orthop*. 2007;78(2):193-200. doi:10.1080/17453670710013672

65. Watson MW, Mitra D, McLintock 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(6):541-547. doi:10.1016/j.rapm.2005.06.006

66. 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(1):47-51. doi:10.4097/kjae.2012.62.1.47

67. Kaloul I, Guay J, Côté C, Fallaha M. The posterior lumbar plexus (psoas compartment) block and the three-in-one femoral nerve block provide similar postoperative analgesia after total knee replacement. *Can J Anesth*. 2004;51(1):45-51. doi:10.1007/bf03018546

68. Özalp G, Kaya M, Tuncel G, et al. The analgesic efficacy of two different approaches to the lumbar plexus for patient-controlled analgesia after total knee replacement. *J Anesth*. 2007;21(3):409-412. doi:10.1007/s00540-007-0515-0

69. Gani ̇ dağli S, Cengiz M, Baysal Z, Baktiroğlu L, Sarban S. The comparison of two lower extremity block techniques combined with sciatic block: 3-in-1 femoral block vs. psoas compartment block. *Int J Clin Pract*. 2005;59(7):771-776. doi:10.1111/j.1368-5031.2005.00414.x

70. Campbell A, McCormick M, McKinlay K, Scott NB. Epidural vs. lumbar plexus infusions following total knee arthroplasty: randomized controlled trial. *Eur J Anaesthesiol*. 2008;25(6):502-507. doi:10.1017/s0265021508003724

71. Aldahish, MM, Zeidan, AZ, Moussa S. Regional anaesthesia and postoperative analgesia for major knee surgery: Comparison between epidural and combined lumbar plexus and sciatic nerve block. *Egypt J Anaesth*. 2004;20(4):411-415.

72. Touray ST, de Leeuw MA, Zuurmond WWA, Perez RSGM. Psoas compartment block for lower extremity surgery: a meta-analysis. *Br J Anaesth*. 2008;101(6):750-760. doi:10.1093/bja/aen298

73. Mannion S. Psoas compartment block. *Contin Educ Anaesthesia, Crit Care Pain*. 2007;7(5):162-166. doi:10.1093/bjaceaccp/mkm029

74. Dauri M, Faria S, Celidonio L, Tarantino U, Fabbi E, Sabato AF. Retroperitoneal haematoma in a patient with continuous psoas compartment block and enoxaparin administration for total knee replacement. *Br J Anaesth*. 2009;103(2):309-310. doi:10.1093/bja/aep189

75. Auroy Y, Benhamou D, Bargues L, et al. Major Complications of Regional Anesthesia in France: The SOS Regional Anesthesia Hotline Service. *Anesthesiol J Am Soc Anesthesiol*. 2002;97(5):1274-1280. doi:10.1097/00000542-200211000-00034

76. Manickam B, Perlas A, Duggan E, Brull R, Chan VWS, Ramlogan R. Feasibility and Efficacy of Ultrasound-Guided Block of the Saphenous Nerve in the Adductor Canal. *Reg Anesth & Pain Med*. 2009;34(6):578-580. doi:10.1097/aap.0b013e3181bfbf84

77. Akkaya T, Ersan O, Ozkan D, et al. Saphenous nerve block is an effective regional technique for post-menisectomy pain. *Knee Surgery, Sport Traumatol Arthrosc*. 2008;16(9):855-858. doi:10.1007/s00167-008-0572-4

78. Horn JL, Pitsch T, Salinas F, Benninger B. Anatomic Basis to the Ultrasound-Guided Approach for Saphenous Nerve Blockade. *Reg Anesth & Pain Med*. 2009;34(5):486-489. doi:10.1097/aap.0b013e3181ae11af

79. Krombach J, Gray AT. Sonography for saphenous nerve block near the adductor canal. *Reg Anesth Pain Med*. 2007;32(4):369-370. doi:10.1016/j.rapm.2007.04.006

80. Jæger P, Zaric D, Fomsgaard JS, et al. Adductor canal block versus femoral nerve block for analgesia after total knee arthroplasty a randomized, double-blind study. *Reg Anesth Pain Med*. 2013;38(6):526-532. doi:10.1097/aap.0000000000000015

81. Jæger P, Nielsen ZJK, Henningsen MH, Hilsted KL, Mathiesen O, Dahl JB. Adductor Canal Block versus Femoral Nerve Block and Quadriceps Strength: A Randomized, Double-blind, Placebo-controlled, Crossover Study in Healthy Volunteers. *Anesthesiol J Am Soc Anesthesiol*. 2013;118(2):409-415. doi:10.1097/aln.0b013e318279fa0b

82. Grevstad U, Mathiesen O, Valentiner LS, Jaeger P, Hilsted KL, Dahl JB. Effect of Adductor Canal Block Versus Femoral Nerve Block on Quadriceps Strength, Mobilization, and Pain After Total Knee Arthroplasty: A Randomized, Blinded Study *Reg Anesth & Pain Med*. 2015;40(1):3-10. doi:10.1097/aap.0000000000000169

83. Shah NA, Jain NP. Is Continuous Adductor Canal Block Better Than Continuous Femoral Nerve Block After Total Knee Arthroplasty? Effect on Ambulation Ability, Early Functional Recovery and Pain Control: A Randomized Controlled Trial. *J Arthroplasty*. 2014;29(11):2224-2229. doi:10.1016/j.arth.2014.06.010

84. Karkhur Y, Mahajan R, Kakralia A, Pandey AP, Kapoor MC. A comparative analysis of femoral nerve block with adductor canal block following total knee arthroplasty: A systematic literature review. *J Anaesthesiol Clin Pharmacol*. 2018;34(4):433-438. doi:10.4103/joacp.joacp_198_18

85. Patterson ME, Bland KS, Thomas LC, et al. The adductor canal block provides effective analgesia similar to a femoral nerve block in patients undergoing total knee arthroplasty—a retrospective study. *J Clin Anesth*. 2015;27(1):39-44. doi:10.1016/j.jclinane.2014.08.005

86. O'Donnell R, Dolan J. Anaesthesia and analgesia for knee joint arthroplasty. *BJA Educ*. 2018;18(1):8-15. doi:10.1016/j.bjae.2017.11.003

87. Abdallah FW, Whelan DB, Chan VW, et al. Adductor canal block provides noninferior analgesia and superior quadriceps strength compared with femoral nerve block in anterior cruciate ligament reconstruction. *Anesthesiology*. 2016;124(5):1053-1064. doi:10.1097/aln.0000000000001045

88. JENSTRUP MT, JÆGER P, LUND J, et al. Effects of Adductor-Canal-Blockade on pain and ambulation after total knee arthroplasty: a randomized study. *Acta Anaesthesiol Scand*. 2012;56(3):357-364. doi:10.1111/j.1399-6576.2011.02621.x

89. Hanson NA, Allen CJ, Hostetter LS, et al. Continuous ultrasound-guided adductor canal block for total knee arthroplasty: A randomized, double-blind trial. *Anesth Analg*. 2014;118(6):1370-1377. doi:10.1213/ane.0000000000000197

90. Elkassabany NM, Antosh S, Ahmed M, et al. The Risk of Falls After Total Knee Arthroplasty with the Use of a Femoral Nerve Block Versus an Adductor Canal Block: A Double-Blinded Randomized Controlled Study. *Anesth Analg*. 2016;122(5):1696-1703. doi:10.1213/ane.0000000000001237

91. Wang D, Yang Y, Li Q, et al. Adductor canal block versus femoral nerve block for total knee arthroplasty: A meta-Analysis of randomized controlled trials. *Sci Rep*. 2017;7(1):1-13. doi:10.1038/srep40721

92. Rasouli MR, Viscusi ER. Adductor canal block for knee surgeries: An emerging analgesic technique. *Arch Bone Jt Surg*. 2017;5(3):131-132. doi:10.22038/abjs.2017.8433