Journal of Clinical Anesthesia (2016) **35**, 295–303

ELSEVIER

Journal of Clinical Anesthesia

Adductor canal block for knee surgical procedures: review article☆,☆☆,★

Maulin U. Vora MBBS (Resident)[a,*], Thomas A. Nicholas MD (Assistant Professor)[a], Cale A. Kassel MD (Instructor)[a], Stuart A. Grant MB, CHB (Professor)[b]

[a]*Department of Anesthesiology, University of Nebraska Medical Center, Omaha, NE*
[b]*Department of Anesthesiology (SAG), Duke University Medical Center, Durham, NC*

Received 24 March 2016; revised 25 July 2016; accepted 9 August 2016

Keywords:
Adductor canal block;
Regional anesthesia;
Pain management;
Lower extremity block

Abstract Adductor canal block (ACB) has recently emerged as an alternative to femoral nerve block for pain control after various knee procedures especially knee arthroplasty. In this review article, we will review the anatomy of adductor canal, sonoanatomy, and ultrasound-guided approach for ACB as well as review current evidence regarding the indications of the ACB.

1. Introduction

Optimal pain relief postoperatively is a prerequisite for any successful surgery from a humanitarian standpoint as well as for avoiding a stress response and long-term chronic pain complications [1]. Pain management is a critical component to the success of the fast-track surgical programs [2,3]. To optimize pain management, it has been recommended to use a multimodal analgesia pathway including a peripheral nerve block [4].

Femoral nerve block (FNB) has been traditionally used as a part of multimodal analgesia strategy after anterior crucial ligament reconstruction (ACL) and total knee arthroplasty (TKA) [5-7]. However, the FNB is associated with quadriceps weakness delaying mobilization [8-10]. Whether this weakness leads to an increased risk of fall has been debated. The single-shot FNB does not seem to increase risk of fall [11]. Although an argument has been made for an increased risk of fall with continuous FNB [11,12], the risk does not seem to exceed what would be expected after a lower extremity orthopedic surgery [13-15]. Regardless of the block, all patients are still at a risk of fall, and appropriate safety precautions should be taken. Adductor canal block (ACB) allowed better quadriceps strength compared with FNB [16,17], which made us believe that rehabilitation could be faster. This has led to a growing interest in the ACB.

In this review, we will discuss the anatomy of adductor canal, sonoanatomy, and ultrasound-guided approach for ACB as well as review current evidence regarding the indications of the ACB.

☆ Funding: no funding.
☆☆ Conflict of interest: none.
★ The contents have not been published elsewhere, and the paper is not being submitted elsewhere. The manuscript has been read and approved by all coauthors. The article is being submitted under "Review Article" category for publication.
* Corresponding author at: Department of Anesthesiology, University of Nebraska Medical Center, 984150 Nebraska Medical Center, Omaha, NE 68198-4150. Tel.: +1 4025594081; fax: +1 4025597372.
E-mail addresses: maulinvora@gmail.com, maulin.vora@unmc.edu (M.U. Vora).

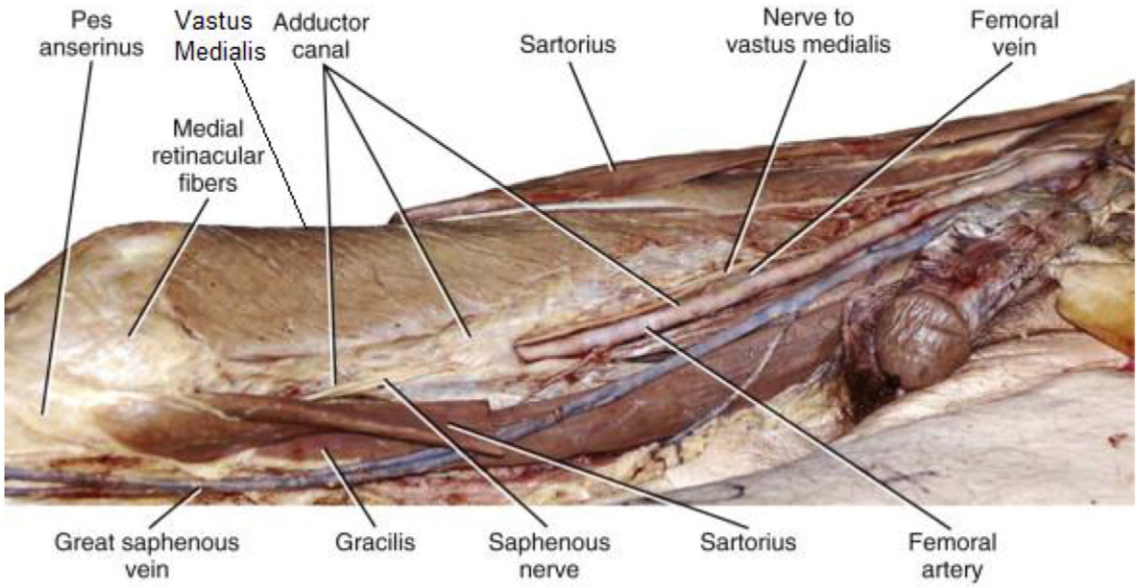
http://dx.doi.org/10.1016/j.jclinane.2016.08.021
0952-8180/

2. Adductor canal

Originally described by John Hunter in the 18th century, the names *adductor canal*, the *hunter's canal*, and the *subsartorial canal* have been used synonymously in the medical literature [18,19]. There has also been some debate as to the exact location to perform an ACB. We believe that both of these factors have contributed to some confusion related to the exact location of needle and local anesthetic placement for the ACB. Review of prior cadaveric studies and anatomical text of the adductor canal and its components will help clarify some of these issues.

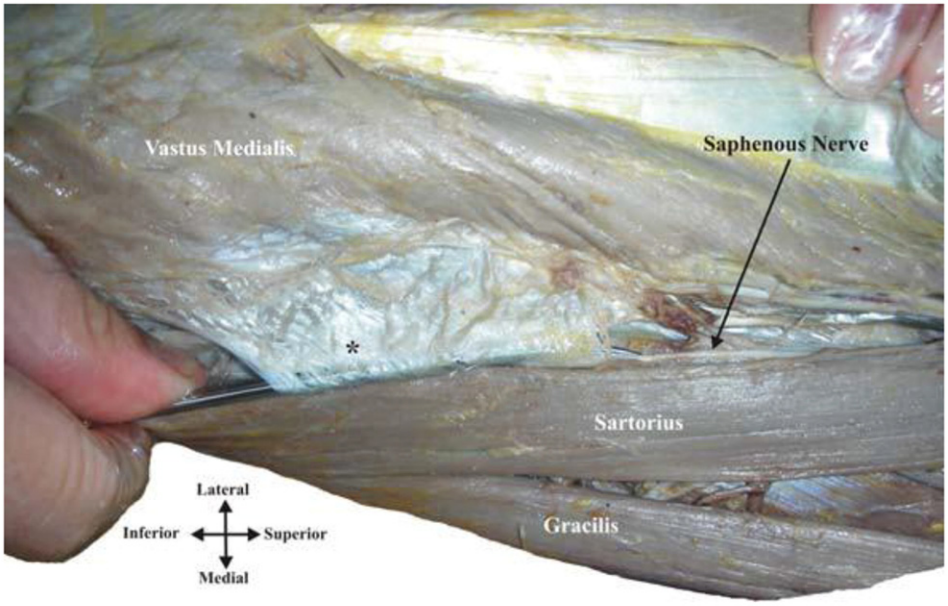
It is generally accepted that the adductor canal has been defined as a musculoaponeurotic tunnel extending from the apex of the femoral triangle to adductor hiatus. The canal is bounded laterally by vastus medialis, medially by adductor magnus and adductor longus, and superiorly by sartorius. The canal consistently contains the superficial femoral vessels, saphenous nerve (sensory), and the nerve to vastus medialis (NVM) (motor and sensory) (Fig. 1). However, the canal may contain the medial femoral cutaneous nerve (sensory) 61% of the time and the anterior cutaneous branch of obturator nerve (sensory) 21% of the time [20]. The motor branches from the obturator nerve leave before entering into the adductor canal. A recent study identified that NVM in conjunction with the saphenous nerve contributes to substantial innervation to the anteromedial aspect of the knee joint including the joint capsule and the medial retinaculum [21]. The sole motor nerve to potentially be anesthetized during ACB is the NVM. Thus, the unique possibility of performing a predominantly sensory block with minimal motor blockade has attracted many providers to perform ACB.

An important aspect of the adductor canal is that it is roofed by the vasoadductor membrane forming an aponeurotic tunnel. The vasoadductor membrane has been identified to have a mean length of 7.6 cm. The mean width of the vasoadductor membrane proximally, midportion, and distally is 2.2, 1.7, and 0.5 cm, respectively. Tubbs et al [22] describe that the "vasoadductor membrane effectively creates a sub compartment within the subsartorial canal." This subcompartment was termed by Bendtsen et al [23] as the *adductor canal proper*. This subcompartment with muscular and saphenous nerve relations is nicely demonstrated during gross dissection in Figure 2 [22]. Editorial commentaries by Bendtsen et al [24] and Jaeger et al [24,25] reveal that the logical target of the ACB is the aponeurotic tunnel or "adductor canal proper." However, Dr Cowlishaw and Kotze [26] have recommended the need for "subsartorial spread of local anesthetic anterior and posterior of the vasoadductor membrane to provide excellent analgesia for knee arthroplasty surgery." This implies that depositing local anesthetic outside of the aponeurotic tunnel will provide improved analgesia. However, one anatomical basis that may be concerning for consistency of a nerve block is the fact that the vasoadductor membrane was fenestrated in only 75% of the time in cadavers. As well, it was identified that only 31% of the time in cadavers did the cutaneous saphenous branches penetrate the vasoadductor membrane [22]. In theory, one could obtain a block if the vasoadductor membrane was fenestrated to allow local anesthetic passage into the



by Saunders, an imprint of Elsevier Inc. Reprinted with permission.

Fig. 1 View of exposed adductor canal demonstrating femoral artery, femoral vein, saphenous nerve, and NVM. Reprinted from Loukas et al. (2013). *Thigh and leg. Gray's clinical photographic dissector of the human body*, Elsevier: 254-266. Copyright 2013 by Saunders, an imprint of Elsevier Inc. Reprinted with permission.



Verlag. Reprinted with permission.

Fig. 2 Wide vasoadductor membrane (asterisk). The probe is deep into this structure. Reprinted from "Anatomy and potential clinical significance of the vasoadductor membrane" by Tubbs et al, 2007, *Surgical and Radiologic Anatomy*, vol 29, p 571. Copyright 2007 by Springer-Verlag. Reprinted with permission.

adductor canal from the subsartorial space superior to the vasoadductor membrane. However, if fenestrations or saphenous nerve perforators are not present, then a consistent block may not be achievable. Thus, targeting the aponeurotic tunnel where the saphenous nerve is consistently present may negate the need to infiltrate superior to the vasoadductor membrane. The study of Andersen et al [27] of 15 cadaveric legs found that the vasoadductor membranes were not fenestrated, and the subsartorial fat dye injection did not explicitly demonstrate saphenous nerve dying. However, the authors did comment that "injection of local anesthetic in the sub-sartorial fat compartment in vivo may block the saphenous nerve" [27]. As well, Andersen et al [27] described the "distinct discriminative features both by ultrasound and by dissection." Although lateral spread has not been consistently demonstrated, vertical spread of injectate to the popliteal fossa and femoral triangle has been described [27,28]. The clinical impact of this spread on muscular weakness has been considered clinically negligible [17]. However, there have been sporadic case reports of the sciatic nerve and the femoral nerve impairment [29,30]. Indeed, local anesthetic volume and concentration should be considered and will be discussed further below.

3. Ultrasound-guided ACB

In multiple studies, ACB has been performed at the midthigh level, approximately halfway between the anterior superior iliac spine and the superior border of the patella [17,31-34]. The superficial femoral artery (SFA) is identified at the midthigh level underneath the sartorius muscle. The saphenous nerve is usually visible as a hyperechoic structure anterolateral to the artery. However, the nerve does cross the SFA and becomes located medially as one traverses the adductor canal more distally [35]. The vastus medialis is visible lateral to neurovascular bundle.

Once the SFA and saphenous nerve are visible in a horizontal cross section on ultrasound, adjust the probe such that neurovascular bundle is on the medial end of the ultrasound screen. Using an in-plane technique, a blunt tip block needle for a single shot or a Touhy needle is introduced from the lateral side of the probe. After the needle is in close proximity to the nerve, local anesthetic is injected for single-shot injection. For the continuous infusion catheter, a catheter is inserted 1-2 cm beyond the tip of the Touhy needle. Local anesthetic is injected through the catheter to confirm its appropriate location. The Touhy needle is then withdrawn and the catheter secured. It is essential to use ultrasound guidance because the adductor canal is a very narrow canal. The success of the block depends on being able to accurately inject local anesthetic and fill up the adductor canal to anesthetize saphenous nerve and NVM. As well, our anecdotal experience suggests that it is easy to inject into several muscle bodies which bound the ACB. In the absence of ultrasound guidance, an acceptable alternative is to perform FNB with a nerve stimulator.

We perform the midthigh level technique at our institution, and this seems to be the most commonly used contemporary technique [16,17,36-39]. There are a few observations of note which should be considered while performing the block. Typically, the saphenous nerve is lateral to the SFA in the proximal part of the adductor canal and then crosses over anteriorly to

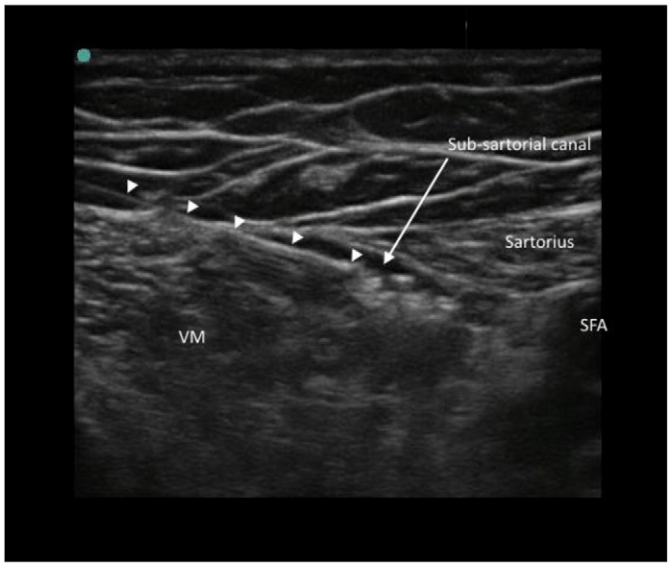
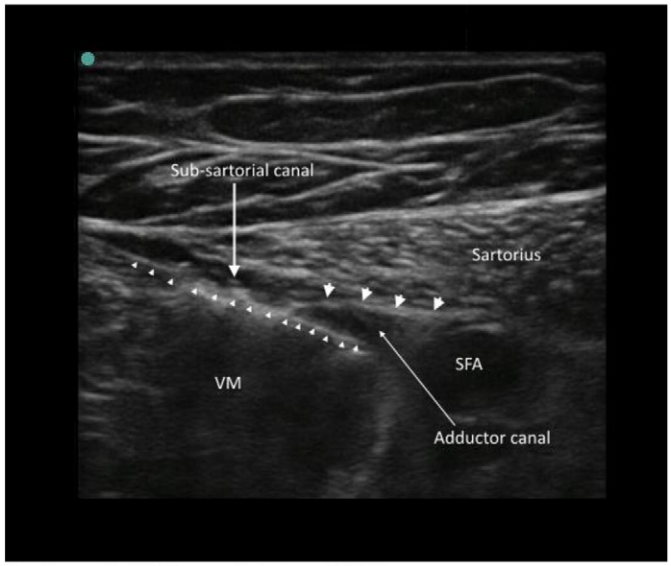


Fig. 3 Initiation of ACB with hydrodissection within the subsartorial canal (anterolateral to the vasoadductor membrane). The nerve block needle (white arrowheads) can be seen anterior to the vastus medialis (VM) and posterior to the sartorius muscle within the subsartorial canal. The SFA can be seen inferior to the sartorius muscle.

become medial to the SFA. The point of crossover was examined during embalmed cadaveric thigh dissection by Kapoor et al [35]. The distance from the adductor tubercle to the saphenous nerve/SFA crossover was found to be on average 14.9 + 3.7 (SD) cm. Therefore, the nerve can be either medial or lateral to the artery on ultrasound image depending on injection site location. As demonstrated by Andersen et al [27], adductor canal injectate spread has different ultrasound characteristics than subsartorial fat spread. Figure 3 shows the initial spread of the local anesthetic in the subsartorial canal. Figure 4 illustrates the visualization of the vasoadductor membrane following injection of the subsartorial canal and needle tip placement within the adductor canal. As discussed before, we do recommend that injection should be done in the true adductor canal rather than subsartorial compartment.

Other techniques have also been described to block the saphenous nerve in adductor canal. Manickam et al [40] described ultrasound-guided saphenous nerve block in the distal third of the thigh. SFA is identified below the sartorius muscle by placing the probe in the distal third of the thigh and is tracked



the Superficial Femoral Artery (SFA).

Fig. 4 The vasoadductor membrane is now evident following hydrodissection of the subsartorial canal. The nerve block needle (small white arrowhead) has penetrated the vasoadductor membrane (large white arrowheads), and its tip is located with the adductor canal at the level of the SFA.

Table 1 Trials comparing continuous ACB vs continuous FNB in primary, unilateral TKA

Author	Type of study	Sample size	Outcome
Mudumbai et al [45]	Retrospective cohort study	ACB = 66 FNB = 102	• Median ambulation distances better in ACB group on POD# 1 and POD# 2 • Pain scores, daily opioid consumption, and hospital LOS similar between 2 groups
Machi et al [37]	Prospective randomized controlled trial	ACB = 39 FNB = 41	• No significant difference in median time to attain 4 discharge criteria in ACB which was 55 h (interquartile, 42-63 h) compared with 61 h (49-69 h) for FNB • No significant difference in pain scores at rest and intravenous opioid requirements between 2 groups, but femoral infusion improved dynamic analgesia
Zhang et al [43]	Prospective randomized controlled trial	ACB = 30 FNB = 30	• No significant difference in VAS between 2 groups at 4, 24, or 48 h • Quadriceps strength significantly better in ACB group
Shah et al [44]	Prospective randomized controlled trial	ACB =48 FNB =50	• Significantly better ambulation ability • No difference in VAS and opioid consumption
Jaeger et al [34]	Prospective randomized controlled trial	ACB = 22 FNB = 26	• Significantly higher quadriceps strength at 24 h with ACB compared with FNB • No difference in pain scores or morphine consumption at 24 h between 2 groups
Rasmussen et al [50]	Retrospective cohort study	ACB = 23 FNB = 22	• Workload less in ACB group • 18/23 ACB catheter patients required no intervention vs 2/22 for FNB catheter • No significant difference in postoperative LOS and opioid consumption

POD = postoperative day, VAS = visual analogue score, LOS = length of stay.

down until the artery is seen diving posteriorly. This area is identified as adductor hiatus. The block is performed 2 to 3 cm proximal to this area where saphenous nerve lies in a close relationship with the SFA [40]. Proximal ACB just distal to the apex of the femoral triangle has also been described [28]. Mariano et al [41] compared proximal vs midthigh ACB and found reduced 24-hour morphine consumption with the proximal catheter without increase in the motor blockade. This technique needs further investigation before implementing in clinical practice.

The midthigh catheter placement seems to be the most optimal technique allowing blockage of both saphenous nerve and NVM while minimizing spread to the popliteal fossa or the femoral triangle [21]. It also keeps the catheter away from the site of surgery where a prosthetic device is being placed. A catheter must be well padded because the tourniquet will overlay the catheter site and an increased risk of dislodgment is present if the catheter is not secured properly.

4. Current indications of ACB

4.1. Continuous ACB vs FNB in TKA

Continuous ACB lowers mean pain scores and opioid requirements compared with placebo in patients undergoing TKA [31,42]. Further randomized controlled studies comparing continuous ACB to continuous FNB demonstrated equivalent analgesia and narcotic requirements in patients after TKA (Table 1) [34,37,43-45]. Four recent meta-analyses (Table 2) comparing FNB to ACB demonstrated a similar conclusion and found equivalent analgesia and narcotic requirements [46-48]. The meta-analysis by Li et al [49] found better analgesia with ACB at rest at 0 hour and 24 hours after surgery, although the heterogeneity between studies was high. ACB produces less quadriceps weakness, allows earlier mobilization, and reduces catheter interventions needed beyond daily rounds compared with FNB [34,45,50]. The meta-analysis assessing the difference in quadriceps strength and ambulation ability found either better strength and ambulation with ACB [46,49] or no difference [47]. Whether this will result in attaining earlier discharge remains debatable. Despite conflicting evidence, a general trend toward decreasing the mean length of stay seems to be emerging [37,38,44,51]. Further clinical trials are warranted for delineating effect of ACB on time to discharge.

4.2. Single-shot vs continuous ACB

Few prospective studies have evaluated single-shot ACB for TKA [16,32,39,52]. The pain is expected to last much longer than the duration of the single-shot block itself. This raises the question about utility of performing a single-shot block as compared with performing a continuous catheter. A study comparing single-shot ACB to intermittent bolus dosing via catheter found better pain control with intermittent bolus dosing on postoperative days 1 and 2 without prolonging the length of stay [36]. A clinical trial comparing single-shot vs continuous infusion catheter in primary TKA is needed to find a more effective way of controlling pain and the effect on time to discharge.

4.3. ACB in revision knee arthroplasty

Evidence regarding the effectiveness of ACB in revision knee arthroplasty is still lacking. Revision arthroplasty is generally assumed to be more painful than primary TKA. A study comparing continuous ACB vs placebo did not find any difference in 24-hour morphine consumption [53]. Further

Table 2 Meta-analysis comparing ACB vs FNB in TKA

Study outcome	Dong et al [47]	Hussain et al [b] [48]	Kuang et al [46]	Li et al [49]
VAS at rest 0-8 h	No difference MD = 5.22 95% CI = −0.93, 11.37	No difference MD = −0.07 95% CI = −2.59, 2.45	No difference MD = −0.03, 95% CI = −0.18, 0.12	ACB better MD = −0.17 95% CI = −0.27 to −0.07
VAS at rest 24 h	No difference MD = 1.34 95% CI −2.35, 5.04	No difference MD = −0.04 95% CI = −0.73, 0.65	ACB better MD = −0.39 95% CI = −0.5, −0.27	ACB better MD = −0.41 95% CI = −0.53, −0.29
VAS at rest 48 h	No difference MD = −0.62 95% CI = −1.50, 0.25	No difference MD = −0.06 95% CI = −0.33, 0.21	No difference MD = −0.06 95% CI = −0.15, 0.03	No difference MD = −0.06 95% CI = −0.15, 0.03
VAS with activity 0-8 h	No difference MD = 3.68 95% CI = −2.88, 10.24	NA	No difference MD = 0.07 95% CI = −0.14, 0.27	No difference MD = 0.00 95% CI = −0.09, 0.09
VAS with activity 24 h	No difference MD = −0.66 95% CI = −1.67, 0.35	NA	No difference MD = 0.02 95% CI = −0.14, 0.17	No difference MD = 0.04 95% CI = −0.11, 0.20
VAS with activity 48 h	No difference MD = −0.85 95% CI = −1.95, 0.23	NA	No difference MD = −0.08 95% CI = −0.18, 0.03	No difference MD = −0.08 95% CI = −0.18 to 0.03
Opioid consumption	No difference MD = −1.1 95% CI = −5.13, 7.50	NA	No difference 48 h MD = −1.90 95% CI = −10.42, 6.62	No difference MD = −1.42 95% CI = − 8.41, 5.58
Quadriceps strength [a]	No difference MD = 96.27 95% CI = −42.69, 235.24	NA	NA	ACB better (<60 y) MD = 37.46 95% CI = 12.27, 62.24 (>60 y) MD = 32.63 95% CI = 6.72, 58.99
Adductor strength [a]	No difference MD = 17.82 95% CI = −6.46, 42.09	NA	NA	No difference (<60 y) MD = 1.51 95% CI = −0.12, 3.15 (>60 y) MD = −4.87 95% CI = −16.13, 6.38
TUG test	NA	NA	ACB better MD = −0.40 95% CI = −0.73, −0.08	ACB better (<60 y) MD = −5.1 95% CI = −6.65, −3.35 (>60 y) MD = −15.84 95% CI = −29.24, −2.43
LOS	No difference MD = −0.09 95% CI = −0.96, 0.77	NA	No difference MD = −0.71 95% CI = −0.71,0.19	NA

TUG = timed up and go test, MD = mean difference, CI = confidence Interval, NA = not applicable.
[a] Measured by maximum voluntary isometric contraction.
[b] Authors did not specify if pain scores were at rest or with activity. We made an assumption that they were at rest.

evaluation of the effectiveness of ACB in revision knee arthroplasty is still needed before using it in clinical practice.

4.4. ACB in minor arthroscopic knee surgical procedures and ACL reconstruction

Studies evaluating single-shot ACB in patients undergoing minor arthroscopic knee surgical procedures and ACL reconstruction have shown conflicting evidence (Table 3) [54-57]. ACB still seems to be a reasonable option as a rescue block in patients with moderate to severe pain after arthroscopic knee surgery except ACL reconstruction [58]. FNB continues to remain as an appropriate choice for ACL reconstruction surgical procedures [5,6,59]. Use of ACB in minor arthroscopic knee procedures needs further evaluation to accept or refute its usefulness.

Box 1 summarizes the current indications of ACB based on the above discussion.

5. Local anesthetic volume and concentration

There is no standard volume or concentration for the block that has been agreed upon, which is apparent from different concentrations, volumes, and local anesthetics used in

Table 3 ACB in arthroscopic knee surgical procedures

Author	Study	Number	Surgery	Type of study	Outcome
Espelund et al [56]	Single-shot ACB vs placebo	ACB = 36 Placebo = 35	Minor arthroscopic knee surgery	Prospective randomized controlled trial	• No significant difference in pain while standing at 2 h after surgery using VAS
Espelund et al [54]	ACB vs placebo	ACB = 25 Placebo = 24	Arthroscopic ACL repair with same-side graft harvest	Prospective randomized controlled trial	• No significant difference in pain score while standing 2 h after surgery
Hanson et al [55]	Single-shot ACB vs placebo	ACB = 25 Placebo = 24	Arthroscopic medial meniscectomy	Prospective randomized controlled trial	• Resting pain score in PACU was significantly improved and 24-h morphine consumption reduced in ACB group
Chisolm et al [57]	Single-Shot ACB vs single-Shot FNB	FNB = 41 ACB = 39	ACL reconstruction with Patellar tendon autograft	Prospective randomized controlled trial	• No difference in pain score or opioid consumption in 2 groups

PACU = postanesthesia care unit.

different studies. Most clinical studies have used 30-mL volume of local anesthetic [16,31,33,34,36,37,44,60]. A magnetic resonance imaging performed by Lund et al [31] after 30 mL of local anesthetic showed proximal spread 8-10 cm beyond femoral triangle to 7 cm above patella filling the adductor canal. However, case reports of both quadriceps weakness and posterior motor weakness have been described with 20-mL local anesthetic volume [29,30]. Cadaveric limb study using 30 mL of aqueous dye injected into adductor demonstrated proximal spread into the femoral triangle dyeing anterior and posterior divisions of the femoral nerve [61]. Another study using 15 mL of aqueous dye in cadaveric limb showed proximal spread into femoral triangle and distally 1-2 cm beyond adductor hiatus while filling the entire adductor canal [27]. Although cadaveric and radiological studies have indicated apparent spread of injectate out of the adductor canal, it is important to review the data from clinical trials to ascertain the true impact of injectate spread on muscle weakness. Several studies of have used higher concentrations with relatively low volumes resulting in quadriceps sparing. For instance, Kwofie et al [10] using 15 mL of 3% chloroprocaine for ACB did not demonstrate any difference in quadriceps strength from baseline. As well, Kim et al [39] used 15 mL of 0.5% bupivacaine with 5 μg/mL epinephrine for their block and found equivalent analgesia to FNB in patients undergoing TKA with relative quadriceps sparing. Higher volume and lower local anesthetic concentration have provided similar outcomes. Grevstad et al [16] used 30 mL of ropivacaine 0.2% in their ACB. They found a statistically significant increase in quadriceps muscle strength for patients in severe pain after TKA following ACB. Jaeger et al [17] performed their randomized, double-blind, placebo-controlled, crossover study in healthy volunteers comparing placebo and 30 mL of 0.1% ropivacaine in FNB or ACB. They found only an 8% decrease in quadriceps strength when comparing placebo to ACB. The authors also further contended that an 8% reduction is "probably not clinically relevant, as a side-to-side difference of 10% is common in healthy individuals without functional importance" [34,62,63]. Progressing to higher volumes and concentration, Jaeger et al [34] compared continuous FNB to ACB using catheter. Although this study involved continuous catheter, the initial injection was 30 mL of 0.5% ropivacaine which resulted in significantly higher quadriceps strength as a percentage of the baseline when comparing FNB to ACB. In summary, it appears that aberrant local anesthetic spread out of the canal may likely have no clinically significant impact on muscle weakness when using single-shot or catheter loading volumes of 15 to 30 mL at a ropivacaine concentration of 0.2% or 0.5%. As well, ACB-derived pain control appears to be equivalent to FNB at these local anesthetic concentrations and volume in patients who have undergone primary TKA [16,39].

Box 1 Current indications of ACB.

- ➢ Primary Unilateral Total Knee Arthroplasty
- ➢ Rescue Block after Minor Arthroscopic Knee Surgery

Motor weakness has also been reported while using 8 mL/h of continuous infusion of local anesthetic via adductor canal catheter [64]. A later fluoroscopic study using 0.2% ropivacaine for 20 hours did not demonstrate any contrast spread beyond the level of lesser trochanter that is the level of common femoral nerve. Therefore, 8 mL/h of local anesthetic still seems to be a reasonable infusion rate to provide analgesia still keeping in mind the possibility of muscle weakness.

With the possibility of proximal spread of local anesthetic, there has been an argument laid forward about ACB being an indirect FNB [65,66]. But clinical trials have consistently shown quadriceps sparing. This maybe as a result of motor nerves to quadriceps leaving right below the inguinal canal where local anesthetic usually does not spread [61].

The type of local anesthetic used is more dependent on the time of intended onset and duration of the block. No studies have been conducted to our knowledge to determine the lowest effective concentration for a successful ACB.

6. Adverse effects

Apart from reports of muscle weakness following ACB due to farther spread, no major complications have been reported with the block [29,30,64]. The weakness reversed after effect of local anesthetic disappeared. In a study of 97 patients, no long-term nerve injury from ACB was reported [67]. Thus, ACB appears to be a safe block, albeit no study has been completed which has a large enough patient population to identify the risk of long-term neurological injury. Although ACB leads to relative quadriceps sparing, the quadriceps muscle function does not remain completely normal [10,17,29,30,64]. This warrants continued fall precautions on every patient with ACB until proven otherwise in a clinical trial.

7. Conclusion

ACB provides equivalent analgesia to FNB for primary TKA with the added advantage of less quadriceps weakness, early ambulation, and a trend toward earlier discharge. It can also be used as a rescue block in patients with moderate to severe pain after minor arthroscopic knee procedures. The ultrasound-guided midthigh technique using 0.2% ropivacaine or equivalent local anesthetic with 15-30 mL volume seems to be the optimal approach. Further research is warranted to delineate effect of ACB on time to discharge, the use of single-shot vs continuous ACB, and usefulness of ACB in revision knee arthroplasty. ACB has the potential to replace FNB as the standard of care in primary TKA.

References

[1] Kehlet H, Jensen TS, Woolf CJ. Persistent postsurgical pain: risk factors and prevention. Lancet 2006;367:1618-25.

[2] Kehlet H, Søballe K. Fast-track hip and knee replacement—what are the issues? Acta Orthop 2010;81:271-2.

[3] Auyong DB, Allen CJ, Pahang JA, Clabeaux JJ, MacDonald KM, Hanson NA. Reduced length of hospitalization in primary total knee arthroplasty patients using an updated enhanced recovery after orthopedic surgery (ERAS) pathway. J Arthroplasty 2015;30(10):1705-9.

[4] Kehlet H, Dahl JB. The value of "multimodal" or "balanced analgesia" in postoperative pain treatment. Anesth Analg 1993;77:1048-56.

[5] Williams BA, Kentor ML, Vogt MT, Irrgang JJ, Bottegal MT, West RV, et al. Reduction of verbal pain scores after anterior cruciate ligament reconstruction with 2-day continuous femoral nerve block: a randomized clinical trial. Anesthesiology 2006;104:315-27.

[6] Wulf H, Löwe J, Gnutzmann KH, Steinfeldt T. Femoral nerve block with ropivacaine or bupivacaine in day case anterior crucial ligament reconstruction. Acta Anaesthesiol Scand 2010;54:414-20.

[7] Paul JE, Arya A, Hurlburt L, Cheng J, Thabane L, Tidy A, et al. Femoral nerve block improves analgesia outcomes after total knee arthroplasty: a meta-analysis of randomized controlled trials. Anesthesiology 2010;113:1144-62.

[8] Bauer M, Wang L, Onibonoje OK, Parrett C, Sessler DI, Mounir-Soliman L, et al. Continuous femoral nerve blocks: decreasing local anesthetic concentration to minimize quadriceps femoris weakness. Anesthesiology 2012;116:665-72.

[9] 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;111:1552-4.

[10] Kwofie MK, Shastri UD, Gadsden JC, Sinha SK, Abrams JH, Xu D, et al. The effects of ultrasound-guided adductor canal block versus femoral nerve block on quadriceps strength and fall risk: a blinded, randomized trial of volunteers. Reg Anesth Pain Med 2013;38:321-5.

[11] Wasserstein D, Farlinger C, Brull R, Mahomed N, Gandhi R. Advanced age, obesity and continuous femoral nerve blockade are independent risk factors for inpatient falls after primary total knee arthroplasty. J Arthroplasty 2013;28:1121-4.

[12] Kandasami M, Kinninmonth AWG, Sarungi M, Baines J, Scott NB. Femoral nerve block for total knee replacement—a word of caution. Knee 2009;16:98-100.

[13] 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;110:518-28.

[14] Johnson RL, Duncan CM, Ahn KS, Schroeder DR, Horlocker TT, Kopp SL. Fall-prevention strategies and patient characteristics that impact fall rates after Total knee arthroplasty. Anesth Analg 2014;119:1113-8.

[15] Memtsoudis SG, Danninger T, Rasul R, Poeran J, Gerner P, Stundner O, et al. Inpatient falls after total knee arthroplasty: the role of anesthesia type and peripheral nerve blocks. Anesthesiology 2014;120:551-63.

[16] 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;40:3-10.

[17] Jaeger P, Nielsen ZJ, 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. Anesthesiology 2013;118:409-15.

[18] Standring S. Pelvic girdle, gluteal region and thigh. In: Standring S, Anand N, Birch R, Collins P, Crossman RA, Gleeson M, et al, editors. Gray's anatomy: the anatomical basis of clinical practice. New York: Elsevier Limited; 2016. p. 1337-75.

[19] O'Rahilly RMF, Carpenter S, Swenson R. Basic human anatomy: a regional study of human structure. http://www.dartmouth.edu/~humananatomy/part_3/chapter_15.html#chpt_15_adductor_canal/; 2008. [2008 [Accessed 07/20/2016]].

[20] Horner G, Dellon AL. Innervation of the human knee joint and implications for surgery. Clin Orthop Relat Res 1994:221-6.

[21] Burckett-St Laurant D, Peng P, Giron Arango L, Niazi AU, Chan VW, Agur A, et al. The nerves of the adductor canal and the innervation of the knee: an anatomic study. Reg Anesth Pain Med 2016;41:321-7.

[22] Tubbs RS, Loukas M, Shoja MM, Apaydin N, Oakes WJ, Salter EG. Anatomy and potential clinical significance of the vastoadductor membrane. Surg Radiol Anat 2007;29:569-73.

[23] Bendtsen TF, Moriggl B, Chan V, Børglum J. Basic topography of the saphenous nerve in the femoral triangle and the adductor canal. Reg Anesth Pain Med 2015;40:391-2.

[24] Bendtsen TF, Moriggl B, Chan V, Pedersen EM, Borglum J. Defining adductor canal block. Reg Anesth Pain Med 2014;39:253-4.

[25] Jaeger P, Lund J, Jenstrup MT, Brøndum V, Dahl JB. Reply to Dr Bendtsen. Reg Anesth Pain Med 2014;39:254-5.

[26] Cowlishaw P, Kotze P. Reply to Dr Bendtsen. Reg Anesth Pain Med 2015;40:392-3.

[27] Andersen HL, Andersen SL, Tranum-Jensen J. The spread of injectate during saphenous nerve block at the adductor canal: a cadaver study. Acta Anaesthesiol Scand 2015;59:238-45.

[28] Ishiguro S, Yokochi A, Yoshioka K, Asano N, Deguchi A, Iwasaki Y, et al. Technical communication: anatomy and clinical implications of ultrasound-guided selective femoral nerve block. Anesth Analg 2012;115:1467-70.

[29] Chen J, Lesser JB, Hadzic A, Reiss W, Resta-Flarer F. Adductor canal block can result in motor block of the quadriceps muscle. Reg Anesth Pain Med 2014;39:170-1.

[30] Gautier PE, Lecoq J-P, Vandepitte C, Harstein G, Brichant JF. Impairment of sciatic nerve function during adductor canal block. Reg Anesth Pain Med 2015;40:85-9.
[31] Lund J, Jenstrup MT, Jaeger P, Sørensen AM, Dahl JB. Continuous adductor-canal-blockade for adjuvant post-operative analgesia after major knee surgery: preliminary results. Acta Anaesthesiol Scand 2011;55:14-9.
[32] Jaeger P, Grevstad U, Henningsen MH, Gottschau B, Mathiesen O, Dahl JB. Effect of adductor-canal-blockade on established, severe postoperative pain after total knee arthroplasty: a randomised study. Acta Anaesthesiol Scand 2012;56:1013-9.
[33] Jenstrup MT, Jæger P, Lund J, Fomsgaard JS, Bache S, Mathiesen O, et al. Effects of adductor-canal-blockade on pain and ambulation after total knee arthroplasty: a randomized study. Acta Anaesthesiol Scand 2012;56:357-64.
[34] Jaeger P, Zaric D, Fomsgaard JS, Hilsted KL, Bjerregaard J, Gyrn J, 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;38:526-32.
[35] Kapoor R, Adhikary SD, Siefring C, McQuillan PM. The saphenous nerve and its relationship to the nerve to the vastus medialis in and around the adductor canal: an anatomical study. Acta Anaesthesiol Scand 2012;56:365-7.
[36] Shah NA, Jain NP, Panchal KA. Adductor canal blockade following total knee arthroplasty—continuous or single shot technique? Role in postoperative analgesia, ambulation ability and early functional recovery: a randomized controlled trial. J Arthroplasty 2015;30:1476-81.
[37] Machi AT, Sztain JF, Kormylo NJ, Madison SJ, Abramson WB, Monahan AM, et al. Discharge readiness after tricompartment knee arthroplasty: adductor canal versus femoral continuous nerve blocks—a dual-center, randomized trial. Anesthesiology 2015;123:444-56.
[38] Ludwigson JL, Tillmans SD, Galgon RE, Chambers TA, Heiner JP, Schroeder KMA. Comparison of single shot adductor canal block versus femoral nerve catheter for total knee arthroplasty. J Arthroplasty 2015;30:68-71.
[39] Kim DH, Lin Y, Goytizolo EA, Kahn RL, Maalouf DB, Manohar A, et al. Adductor canal block versus femoral nerve block for total knee arthroplasty: a prospective, randomized, controlled trial. Anesthesiology 2014;120:540-50.
[40] 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;34:578-80.
[41] Mariano ER, Kim TE, Wagner MJ, Funck N, Harrison TK, Walters T, et al. A randomized comparison of proximal and distal ultrasound-guided adductor canal catheter insertion sites for knee arthroplasty. J Ultrasound Med 2014;33:1653-62.
[42] Hanson NA, Allen CJ, Hostetter LS, Nagy R, Derby RE, Slee AE, et al. Continuous ultrasound-guided adductor canal block for total knee arthroplasty: a randomized, double-blind trial. Anesth Analg 2014;118:1370-7.
[43] Zhang W, Hu Y, Tao Y, Liu X, Wang G. Ultrasound-guided continuous adductor canal block for analgesia after total knee replacement. Chin Med J 2014;127:4077-81.
[44] 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;29:2224-9.
[45] Mudumbai SC, Kim TE, Howard SK, Workman JJ, Giori N, Woolson S, et al. Continuous adductor canal blocks are superior to continuous femoral nerve blocks in promoting early ambulation after TKA. Clin Orthop Relat Res 2014;472:1377-83.
[46] Kuang MJ, LY X, Ma JX, Wang Y, Zhao J, Lu B, et al. Adductor canal block versus continuous femoral nerve block in primary total knee arthroplasty: a meta-analysis. Int J Surg 2016;31:17-24.
[47] Dong CC, Dong SL, He FC. Comparison of adductor canal block and femoral nerve block for postoperative pain in total knee arthroplasty: a systematic review and meta-analysis. Medicine (Baltimore) 2016;95:e2983.
[48] Hussain N, Ferreri TG, Prusick PJ, Banfield L, Long B, Prusick VR, et al. Adductor canal block versus femoral canal block for total knee arthroplasty: a meta-analysis: what does the evidence suggest? Reg Anesth Pain Med 2016;41:314-20.
[49] Li D, Yang Z, Xie X, Zhao J, Kang P. Adductor canal block provides better performance after total knee arthroplasty compared with femoral nerve block: a systematic review and meta-analysis. Int Orthop 2016;40:925-33.
[50] Rasmussen M, Kim E, Kim TE, Howard SK, Mudumbai S, Giori NJ, et al. A retrospective comparative provider workload analysis for femoral nerve and adductor canal catheters following knee arthroplasty. J Anesth 2015;29:303-7.
[51] Sztain JF, Machi AT, Kormylo NJ, Abramson WB, Madison SJ, Monahan AM, et al. Continuous adductor canal versus continuous femoral nerve blocks: relative effects on discharge readiness following unicompartment knee arthroplasty. Reg Anesth Pain Med 2015;40(5):559-67.
[52] Memtsoudis SG, Yoo D, Stundner O, Danninger T, Ma Y, Poultsides L, et al. Subsartorial adductor canal vs femoral nerve block for analgesia after total knee replacement. Int Orthop 2015;39:673-80.
[53] Jaeger P, Koscielniak-Nielsen ZJ, Schrøder HM, Mathiesen O, Henningsen MH, Lund J, et al. Adductor canal block for postoperative pain treatment after revision knee arthroplasty: a blinded, randomized, placebo-controlled study. PLoS One 2014;9 [e111951-e].
[54] Espelund M, Fomsgaard JS, Haraszuk J, Mathiesen O, Dahl JB. Analgesic efficacy of ultrasound-guided adductor canal blockade after arthroscopic anterior cruciate ligament reconstruction: a randomised controlled trial. Eur J Anaesthesiol 2013;30:422-8.
[55] Hanson NA, Derby RE, Auyong DB, Salinas FV, Delucca C, Nagy R, et al. Ultrasound-guided adductor canal block for arthroscopic medial meniscectomy: a randomized, double-blind trial. Can J Anaesth 2013;60:874-80.
[56] Espelund M, Fomsgaard JS, Haraszuk J, Dahl JB, Mathiesen O. The efficacy of adductor canal blockade after minor arthroscopic knee surgery—a randomised controlled trial. Acta Anaesthesiol Scand 2014;58:273-80.
[57] Chisholm MF, Bang H, Maalouf DB, Marcello D, Lotano MA, Marx RG, et al. Postoperative analgesia with saphenous block appears equivalent to femoral nerve block in ACL reconstruction. HSS J 2014;10:245-51.
[58] Espelund M, Grevstad U, Jaeger P, Hölmich P, Kjeldsen L, Mathiesen O, et al. Adductor canal blockade for moderate to severe pain after arthroscopic knee surgery: a randomized controlled trial. Acta Anaesthesiol Scand 2014;58:1220-7.
[59] Iskandar H, Benard A, Ruel-Raymond J, Cochard G, Manaud B. Femoral block provides superior analgesia compared with intra-articular ropivacaine after anterior cruciate ligament reconstruction. Reg Anesth Pain Med 2003;28:29-32.
[60] Grevstad U, Mathiesen O, Lind T, Dahl JB. Effect of adductor canal block on pain in patients with severe pain after total knee arthroplasty: a randomized study with individual patient analysis. Br J Anaesth 2014;112:912-9.
[61] Davis JJ, Bond TS, Swenson JD. Adductor canal block: more than just the saphenous nerve? Reg Anesth Pain Med 2009;34:618-9.
[62] Krishnan C, Williams GN. Evoked tetanic torque and activation level explain strength differences by side. Eur J Appl Physiol 2009;106:769-74.
[63] Ostenberg A, Roos E, Ekdahl C, Roos H. Isokinetic knee extensor strength and functional performance in healthy female soccer players. Scand J Med Sci Sports 1998;8:257-64.
[64] Veal C, Auyong DB, Hanson NA, Allen CJ, Strodtbeck W. Delayed quadriceps weakness after continuous adductor canal block for total knee arthroplasty: a case report. Acta Anaesthesiol Scand 2014;58:362-4.
[65] Deloach JK, Boezaart AP. Is an adductor canal block simply an indirect femoral nerve block? Anesthesiology 2014;121:1349-50.
[66] Boezaart AP, Parvataneni HK. Adductor canal block may just be an (unreliable) indirect femoral nerve block. Reg Anesth Pain Med 2014;39 [556-].
[67] Henningsen MH, Jaeger P, Hilsted KL, Dahl JB. Prevalence of saphenous nerve injury after adductor-canal-blockade in patients receiving total knee arthroplasty. Acta Anaesthesiol Scand 2013;57:112-7.