CME

Continuous Peripheral Nerve Blocks: A Review of the Published Evidence

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A continuous peripheral nerve block, also termed "perineural local anesthetic infusion," involves the percutaneous insertion of a catheter adjacent to a peripheral nerve, followed by local anesthetic administration via the catheter, providing anesthesia/analgesia for multiple days or even months. Continuous peripheral nerve blocks may be provided in the hospital setting, but the use of lightweight, portable pumps permits ambulatory infusion as well. This technique's most common application is providing analgesia after surgical procedures. However, additional indications include treating intractable hiccups; inducing a sympathectomy and vasodilation to increase blood flow after a vascular accident, digit transfer/replantation, or limb salvage; alleviating vasospasm of Raynaud disease; and treating peripheral embolism and chronic pain such as complex regional pain syndrome, phantom limb pain, trigeminal neuralgia, and cancer-induced pain. After trauma, perineural infusion can provide analgesia during transportation to a distant treatment center, or while simply awaiting surgical repair. Catheter insertion may be accomplished using many possible modalities, including nerve stimulation, ultrasound guidance, paresthesia induction, fluoroscopic imaging, and simple tactile perceptions ("facial click"). Either a nonstimulating epidural-type catheter may be used, or a "stimulating catheter" that delivers electrical current to its tip. Administered infusate generally includes exclusively long-acting, dilute, local anesthetic delivered as a bolus only, basal only, or basal-bolus combination. Documented benefits appear to be dependent on successfully improving analgesia, and include decreasing baseline/breakthrough/dynamic pain, supplemental analgesic requirements, opioid-related side effects, and sleep disturbances. In some cases, patient satisfaction and ambulation/functioning may be improved; an accelerated resumption of passive joint range-of-motion realized; and the time until discharge readiness as well as actual discharge from the hospital or rehabilitation center achieved. Lastly, postoperative joint inflammation and inflammatory markers may be decreased. Nearly all benefits occur during the infusion itself, but several randomized controlled trials suggest that in some situations there are prolonged benefits after catheter removal as well. Easily rectified minor complications occur somewhat frequently, but major risks including clinically relevant infection and nerve injury are relatively rare. This article is an evidence-based review of the published literature involving continuous peripheral nerve blocks. (Anesth Analg 2011;113:904–25)

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Continuous peripheral nerve blocks (CPNBs) are relatively simple in concept: a catheter is percutaneously inserted adjacent to a peripheral nerve, followed by local anesthetic administration via the catheter (Fig. 1). Thus, the terms CPNB and "perineural local anesthetic infusion" are often used synonymously. Using currently available long-acting local anesthetics, the maximal duration of a single-injection peripheral nerve block is 8 to 24 hours. Therefore, CPNB provides an alternative option when a prolonged neural blockade is desired.[1,2] Since its first description in 1946,[3] CPNB has evolved from an experimental case report involving a needle inserted through a cork taped to a patient's chest, to a well-validated analgesic technique accepted by the medical community with products designed solely for its application. This article is an evidence-based review of the published CPNB literature.

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INDICATIONS

The earliest reports of CPNB describe prolonging intraoperative surgical anesthesia[3,4] and treating intractable hiccups.[5] Later articles report using CPNB-induced sympathectomy and vasodilation to increase blood flow after a vascular accident,[6] digit transfer/replantation,[7,8] or limb salvage[9]; alleviate the vasospasm of Raynaud disease[10]; and treat peripheral embolism.[11] After trauma, CPNB can provide analgesia during transportation to a distant treatment center[12] or while simply awaiting surgical repair.[13] Although yet unvalidated, reports describe CPNB to treat chronic pain, such as complex regional pain syndrome,[14] intractable phantom limb pain,[15] as well as pain from terminal cancer[16] and trigeminal neuralgia.[17] However, the overwhelming majority of CPNB reports involve the perioperative period, and only this application of perineural local anesthetic infusion remains validated with randomized controlled clinical trials (RCTs).[18]

Because there are intrinsic risks with CPNB, most providers restrict its use to surgical procedures that are expected to result in pain not easily controlled with less-invasive analgesic techniques (e.g., oral analgesics, cooling/heating pads)[19] or in

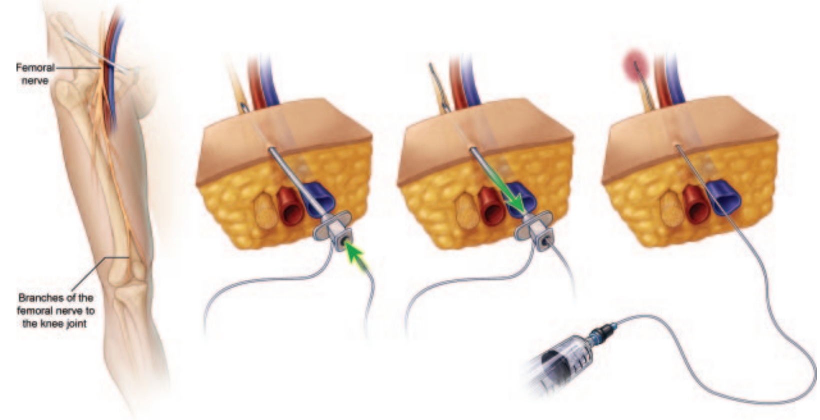

Figure 1. Illustration of a continuous peripheral nerve block involving the femoral nerve. This particular perineural catheter insertion technique employs electrical stimulation alone *via* a stimulating catheter.

patients with an intolerance to alternative analgesics (e.g., opioid-induced nausea).[20,21] The surgical site dictates the anatomic location of catheter insertion (Table 1). Although not as thoroughly validated as in adults, CPNB has been described in hundreds of pediatric patients.[14,22–27]

CATHETER INSERTION (NERVE STIMULATION)

Historically, perineural catheters were inserted using induced paresthesia,[3] a facial "click,"[28] or fluoroscopic guidance.[29] However, after the introduction of portable nerve stimulators in the 1970s, the overwhelming majority of published CPNB reports involve this modality. Originally, this technique involved using electrical current to place an insulated needle adjacent to a peripheral nerve, followed by injection of local anesthetic and subsequent perineural catheter insertion. Although multiple prospective studies document the possible high success rate of this procedure,[30–33] others have found an unacceptably high rate of "secondary block" failure,[34] presumably when the catheter tip was unknowingly misplaced during insertion.[35] To help counter this risk, the perineural catheter may be first inserted, followed by a local anesthetic bolus via the catheter itself.[36–39] However, remaining unknown is whether a relatively large bolus of concentrated local anesthetic resulting in a successful nerve block guarantees that the catheter tip is close enough to the target nerve(s) to provide analgesia during the subsequent infusion with relatively small volumes of dilute local anesthetic. Regardless, even if prediction of successful perineural infusion is provided, the identification of those failed catheters requires waiting at least 15 minutes for block onset/failure, followed by removal of the catheter/dressing, repreparation, and catheter reinsertion, a process requiring a longer period of time than many practices permit.[40] In addition, a partial block is possible, suggesting the catheter tip is not optimally located, but often precluding replacement using electrical current.

An option is the use of a "stimulating catheter" in which an electrical current is used with an insulated needle to locate the target nerve(s), followed by the insertion of a perineural catheter that conducts current to its tip.[19,41,42] If muscle contraction intensity decreases during catheter advancement, it is presumed that the catheter tip is moving away from the target nerve.[43] This provides real-time evidence of catheter-nerve distance.[44] There are data to suggest that in the area of the popliteal fossa, using stimulation during catheter advancement results in the catheter tip being placed closer to the sciatic nerve.[45–48] Although there are limited data suggesting a similar improvement for femoral and interscalene catheters,[43,49,50] the clinical relevance is questionable for these anatomic locations.[51–56]

Unfortunately, continuous muscle contraction guarantees neither surgical block nor postoperative infusion success.[43,57–59] In addition, adequate muscle response cannot always be elicited with catheter advancement[43,59–64]; and stimulating catheters take more time on average for placement and cost more than their nonstimulating counterparts,[48,65] leading some to question their overall benefit.[66] There is minimal,[67] if any, benefit of injecting fluid via the needle before catheter insertion to "open" the perineural space,[68] but D5W is recommended if a bolus is used.[69,70] Lastly, there are few data to provide recommendations on the minimal acceptable current resulting in a muscle response.[71]

The optimal distance to advance a perineural catheter past the needle tip remains unknown, but there are data to suggest that increasing the insertion distance is correlated with an increased risk of catheter coiling, and possibly the final nerve-to-catheter tip distance.[36,72–74] Considering the multiple catheter knots reported with insertion >5 cm,[75–78] and the lack of data suggesting insertion lengths >5 cm is beneficial, recommending a maximal insertion of 5 cm seems warranted.[66] Recently reported "self-coiling catheters" may render this issue moot in the future if they are found reliable and approved for human use.[79] Similarly, the optimal minimum insertion distance remains unknown, with evidence that 0 to 1 cm results in a minimal risk of secondary block failure,[33,80] but possibly an increased risk of subsequent dislodgement.[81]

CATHETER INSERTION (ULTRASOUND)

Unfortunately, data from controlled trials involving electrical stimulation–guided catheter insertion, or even ultrasound-guided single-injection blocks, is not automatically applicable to ultrasound-guided catheter insertion for

Table 1. Catheter Locations

Surgical site	Major approaches	Evaluated with RCT?	Comments	Comparative CPNB studies
Head	Mandibular and maxillary nerves	No[17,324,325]		
Shoulder and proximal humerus	Interscalene	Yes[34,93,173,178,217,230,326–331]	Validated with nerve stimulation[34,38,173,178,217,230,326–328] and ultrasound guidance[93,329]	There are no studies comparing these CPNB techniques.
	Cervical paravertebral	No[332]	Nearly all publications from a single group	
	Intersternocleidomastoid	No[333]	Nearly all publications from a single group	
	Supraclavicular	No[232,233]	Effectiveness of technique for postoperative analgesia unclear without RCT	
	Suprascapular	No[334]	Effectiveness of technique unclear without RCT	
Elbow, forearm, and hand	Supraclavicular	Yes[231]	Caution regarding pneumothorax risk[335] (including with ultrasound guidance)[336]	Infraclavicular provides superior analgesia to both supraclavicular[231] and axillary[a] catheters
	Infraclavicular	Yes[227]		
	Axillary	Yes[153,a]	No benefit of ropivacaine 0.1% or 0.2% over placebo infusion	
	Median nerve	No[337]		
Thorax and breast	Paravertebral	Yes[338,339]	For mastectomy: no infusion benefits over single injection.[338] For open lung surgery: benefits over thoracic epidural.[339]	There are no studies comparing these CPNB techniques
	Intercostal	No[340,341]	Approach aims to place catheter tip in paravertebral space. Effectiveness of this technique unclear without RCT.	
Abdomen, iliac crest, and inguinal region	Transversus abdominus plane	No[234,342–345]	Relatively new technique with risks and benefits yet to be thoroughly investigated. Retrospective study suggests decreased opioid requirements and pain scores in renal transplant recipients.[345]	
Hip and thigh	Posterior lumbar plexus	Yes[13,33,213,238,346–348]		For hip arthroplasty, patients with femoral (versus posterior lumbar plexus) catheters: no difference in resting pain scores, but ambulation suffered[213,346]; dynamic pain scores either higher[346] or no difference[213]; and increased opioid-related side effects and satisfaction[346]
	Femoral	Yes[213,237,242,346,349,350]	Impact of various catheter insertion techniques remains uninvestigated.	
	Parasacral	No[351]	Surgery involving the posterior thigh: reliable analgesia for the posterior femoral cutaneous nerve distribution	
Knee and thigh	Posterior lumbar plexus	Yes[166,239,352]		For knee arthroplasty, no major analgesic differences found among approaches[166,239,353,354]
	Femoral	Yes[2,32,36,49,58,150,159,161,166,167,222,239,243,244,248,250,318,322,353–357]	Most frequently published catheter location for knee surgery. Impact of various catheter insertion techniques remains uninvestigated.	
	Fascia iliaca	Yes[353,354,358,359]		
Leg, ankle, and foot	Parasacral	No[351,360]	Reliable analgesia for the posterior femoral cutaneous nerve distribution	No major analgesic differences found between subgluteal and popliteal[361,362]
	Labat and Raj	No[30,363]	Very few CPNB reports	
	Subgluteal	Yes[361,362]		
	Popliteal	Yes[23,31,173,215,226]	Most common continuous sciatic block published	
	Tibial nerve	No[228,364]		
	Femoral	Yes[240]	Femoral infusion in addition to, and not in place of, popliteal infusion for major ankle surgery	

Only selected references are included because of publication limitations; similarly, only RCTs are included when at least 1 study with this design is available.
RCT = randomized controlled trial; CPNB = continuous peripheral nerve block.
[a] Unpublished data, Mariano and Ilfeld (2011).

multiple reasons. Although the limited length of this review article precludes an in-depth discussion of these issues, the information is available elsewhere.[82] Whereas many relatively large series demonstrate the feasibility of ultrasound-guided catheter insertion,[83–86] there are currently few RCTs to help guide practice.[87] One study suggests that for infraclavicular catheters, there is little difference in the surgical block resulting from a bolus of local anesthetic injected via the needle before catheter insertion compared with the catheter after needle removal.[88] Another RCT demonstrates the difficulty and poorer success rate of inserting a catheter with the longitudinal plane of the needle parallel to the femoral nerve compared with a perpendicular orientation.[89] Lastly, a recent publication suggests that for interscalene catheters, a needle with its long axis parallel to the nerve has distinct benefits compared with a perpendicular needle-to-nerve orientation.[90]

Because of the multiple variables for various blocks/techniques (e.g., bolus via the catheter versus needle, catheter insertion distance, and catheter design), applying the results of one study to others' practices will most likely prove difficult.[82] For example, the results of the above-mentioned infraclavicular catheter study will probably not be replicated with a single catheter injection of local anesthetic via a popliteal sciatic catheter because of differences in perineural anatomy between the 2 sites.[91] Similarly, in the RCT comparing anterolateral and posterior approaches,[90] a relatively rigid 3-orifice catheter was used, greatly increasing the chance that for the posterior approach all 3 orifices would fail to reside within the narrow facial (anterior-posterior) plane containing the brachial plexus.[92] Evidence from other investigations suggests that the posterior approach is highly reliable using a relatively flexible single-orifice catheter,[62,93] and that using a flexible catheter for other needle in-plane approaches may help avoid the catheter tip bypassing the target nerve during insertion.[74,81]

Simply visualizing the catheter tip in close relation to the target nerve intuitively seems to be an obvious solution; however, in practice, identifying the tip is often challenging because, unlike rigid needles, flexible catheters do not usually remain within the ultrasound plane of view. Although there are exceptions,[94,95] many investigators observe the location of fluid,[96] an agitated fluid/air mixture,[97] or simply air[98,99] injected through the catheter. Unfortunately, the positive and negative predictive value of each of these methods remains unknown, and even what constitutes a "positive" or "negative" test has yet to be determined. Future technological developments in equipment such as 3-dimensional ultrasound may render this issue moot.[100]

NERVE STIMULATION VERSUS ULTRASOUND GUIDANCE

Many RCTs suggest that for most anatomic locations, catheters inserted with ultrasound guidance provide at least similar analgesia, and often decrease insertion-related discomfort and insertion time, compared with an electrical technique using an insulated needle and nonstimulating[101–103] or stimulating catheters.[61,62,64,104,105] And while there are reports of combining nerve stimulation and ultrasound guidance for catheter insertion,[43,106] the majority of these reports do not suggest much benefit[93,97,104,107–109]—and often increasing difficulties compared with using one technique alone[104,110,111]—leading some to question the utility of stimulating catheters,[110] and even insulated needles[112] (while others disagree).[19,56,106,113,114] Currently, insufficient data are available to determine the optimal techniques/equipment for these insertion modalities, and their associated risks and benefits.[82] Case in point is 1 RCT providing contrary evidence that for popliteal-sciatic catheters, a stimulating catheter provides improved analgesia in those successfully placed using a strict insertion protocol.[63] Another RCT suggests that combining ultrasound guidance and nerve stimulation for catheter insertion leads to decreased local anesthetic consumption, opioid use, and pain scores.[106]

There are some clinical situations in which ultrasound is a superior modality, at least theoretically, such as after limb amputation,[115] when sensory nerves are solely targeted,[116] with concomitant anticoagulation,[117] or when an electrically induced muscle response is either undesirable[118] or cannot be elicited.[119] However, ultrasound nerve/plexus/needle-tip visualization/identification are often difficult for relatively deep targets, in which case nerve stimulation may prove beneficial.[120–122] There are also situations, such as when placing a posterior lumbar plexus catheter, whereby prepuncture ultrasound visualization may aid subsequent electrical stimulation–guided catheter insertion.[123] Lastly, the relative costs of each insertion modality must be accounted for, with 1 investigation suggesting that for single-injection peripheral nerve blocks, the use of ultrasound guidance is at least as financially competitive, and often becomes a "profit center," depending on the clinical scenario, compared with electrical stimulation.[124]

INFUSATES

Local anesthetic is the primary analgesic infused during CPNB. Although intermediate-duration drugs may be used,[125,126] the most frequently reported drugs are ropivacaine, bupivacaine, and levobupivacaine because of their longer duration of action and favorable sensory:motor block ratio.[127] Because the precise equipotency ratios of perineural local anesthetics remain unknown, comparisons are problematic.[128] Although the available data suggest bupivacaine and levobupivacaine have higher potency than ropivacaine,[129,130] all 3 provide similar analgesia within human trials. However, the ropivacaine concentration is often increased up to 50% to compensate for decreased potency.[20,129–134] One study of interscalene infusion provides evidence that ropivacaine 0.2% induces fewer finger paresthesias and less hand weakness than bupivacaine 0.15%.[133] However, similar investigations using different concentrations of levobupivacaine and ropivacaine suggest that any differences in the induced motor block are minimal as long as the ropivacaine concentration is increased by approximately 50%.[129–132] Conversely, there are data to suggest that when the perineural infusion is discontinued, the sensory and motor effects of bupivacaine greatly outlast those of ropivacaine.[133] This may be relevant when titration of local anesthetic to limit undesired effects is needed (e.g., femoral perineural infusion–induced quadriceps femoris weakness limiting ambulation, or an insensate extremity during infraclavicular or popliteal sciatic infusion). Of note, data derived from laboratory animals suggest that both ropivacaine and bupivacaine induce tissue injury,[135,136] but ropivacaine results in significantly less damage.[137,138] The clinical implications of these data remain unknown.

It also remains unknown whether the primary determinant of CPNB effects is solely local anesthetic dose (mass),[129,131,139,140] or if volume (rate) and/or concentration exert additional influence. For single-injection nerve blocks, volume and concentration primarily determine efficacy when dose is held constant.[141,142] However, for continuous blocks, data from the only study that varied both the infusion rate and concentration in a static ratio so that the total dose was comparable in each treatment group suggest that local anesthetic concentration does not influence block effects as long as the total dose remains constant.[143] Unfortunately, the results from this study of posterior lumbar plexus ropivacaine infusion may not be applicable to other anatomic locations,[140,144–146] local anesthetics,[127,132–134] infusion rates,[67,140,147] local anesthetic concentrations,[133,140,148–150] or bolus dose/volume combinations,[147] and thus further investigation is required for a definitive answer.

To complicate the issue, in the clinical setting, patient-controlled bolus doses and/or an adjustable basal infusion rate are often provided, and therefore total local anesthetic dose varies depending on individual patient requirements.[57,129,144–146,151,152] In these clinical cases, it seems that concentration and rate do influence infusion effects.[145,146,151] Unfortunately, currently published studies provide widely conflicting data, probably because of the many variables influencing infusion effects and analgesic requirements.[129,144–146,151–153] For example, studies involving interscalene ropivacaine infusion report increasing local anesthetic concentration results in increased,[129] decreased,[144] or no[152,153] difference in postoperative analgesia. Similarly, increasing local anesthetic concentration has differing effects on the incidence of an insensate extremity depending on catheter site location: increased for infraclavicular,[145] decreased for popliteal,[146] no difference for axillary,[153] and variable for interscalene.[139,144,152] Therefore, no optimal concentration/rate combination may be recommended for all anatomic locations, and further study is warranted. For bupivacaine/levobupivacaine and ropivacaine, the most frequently cited concentrations are between 0.1% to 0.125% and 0.1% to 0.2%, respectively.

Several medications are occasionally added to the local anesthetic during CPNB in an attempt to improve analgesia without increasing motor block. There are reports of the inclusion of opioid with perineural local anesthetic,[147,154,155] but currently there are insufficient data to draw any conclusions regarding its efficacy.[156,157] Although clonidine was often added in the earlier years of CPNB,[147,154,158–161] 3 subsequent RCTs failed to demonstrate any clinically relevant benefits.[65,162,163] An additional RCT found no benefit to adding epinephrine to perineural ropivacaine,[164] and possible prolonged vasoconstriction places the safety of this practice into doubt.[8,165–167] Additional possible adjuvants have been reported, but none is currently approved for perineural use in patients,[168,169] and some may have unacceptable systemic effects.[169]

LOCAL ANESTHETIC DELIVERY REGIMENS

Infusates may be administered with 3 main strategies: exclusively as a basal infusion or bolus dose, and a combination of these 2 modalities. Unfortunately, similar to the data involving local anesthetic concentration, studies of delivery strategy are somewhat mixed (Table 2).[170,171] In general, RCTs involving femoral and fascia iliaca infusions have reported few differences in analgesia among the various delivery regimens (other than reduced local anesthetic use with bolus-only dosing).[154,158,172] Conversely, for sciatic catheters, providing a basal infusion maximizes analgesia and other benefits,[170,171] although the data regarding the benefits of adding patient-controlled bolus doses are less clear.[170,171,173]

Interestingly, providing automated, hourly, 5-mL bolus doses of levobupivacaine via a popliteal sciatic catheter decreased pain scores compared with patients receiving a continuous, 5-mL basal infusion of 0.125% levobupivacaine[174] (although a similar investigation involving femoral ropivacaine infusion failed to detect differences in sensory or motor effects).[94] However, by adding patient-controlled bolus doses to these 2 regimens, the difference in pain scores disappeared.[175] Importantly, all investigations report less total consumption of local anesthetic with regimens providing patient-controlled bolus doses, suggesting the desirability of including this modality for 3 main reasons: (1) decreasing the required basal infusion rate and thus theoretically decreasing motor block (inadequately investigated to date)[94,133,176]; (2) decreasing the incidence of an insensate extremity[31]; and (3) increasing the duration of infusion/analgesia for ambulatory patients discharged with a finite volume of local anesthetic.[170,177]

In contrast to the lower extremity, investigations of interscalene[147] and infraclavicular[57] perineural infusion are more uniform and suggest that including a basal infusion improves baseline analgesia, decreases the incidence and severity of breakthrough pain, and decreases sleep disturbances and supplemental analgesic requirements. Furthermore, adding patient-controlled bolus doses to a basal infusion decreases total local anesthetic consumption and supplemental analgesic requirements,[57,147,173] allows block reinforcement during dressing changes or physical therapy,[147,178,179] and may provide increased independent activity.[173] Additional RCTs attempting to further refine interscalene dosing report somewhat conflicting results. One study provides evidence that a high basal rate combined with low-volume, patient-controlled bolus doses reduces baseline pain scores and sleep disturbances, and decreases the incidence and severity of breakthrough pain, but at a cost of increasing local anesthetic consumption.[67] However, other similar investigations report few differences in varying the basal infusion rate.[140,173,180]

Unfortunately, because of the heterogenicity of catheter types, insertion techniques, and a myriad of additional factors, there is little evidence for an "optimal" infusion regimen. Until recommendations based on prospectively collected data are available, health care providers may wish

Table 2. Local Anesthetic Delivery Regimens for Continuous Peripheral Nerve Blocks

Catheter location	Infusate(s)	Treatment groups: n	Basal (mL/h)	Bolus (mL)	Lockout (min)	Primary findings
Interscalene[147]	Bupivacaine (0.125%)	20	10	—	—	Improved analgesia versus bolus only
• Nonstimulating catheter	Clonidine (1 μg/mL)	20	5	2.5	30	Improved analgesia versus bolus only
• Anterolateral approach	Sufentanil (0.1 μg/mL)	20	—	5	30	Increased supplemental analgesics versus other 2 groups
Interscalene[180]	Ropivacaine (0.2%)					
• Nonstimulating catheter		38	2	5	60	Note that this group self-administered 6 mandatory bolus doses daily in addition to as-needed bolus doses
• Ultrasound-guided posterior approach		43	5	5	60	Increased incidence of an insensate hand, but no significant differences in pain, analgesics, awakenings
Interscalene[67]	Ropivacaine (0.2%)					
• Stimulating catheter		12	8	2	60	Increased baseline pain, breakthrough pain incidence and intensity, sleep disturbances, and dissatisfaction with analgesia
• Anterolateral approach		12	4	6	60	Increased consumption of local anesthetic with a shorter duration of infusion and analgesia
Interscalene[173]	Ropivacaine (0.2%)					
• Nonstimulating catheter		15	7	—	—	Possibly increased assistance with daily activity and time until 10 min of ambulation (data combined with popliteal infusion; no *P* value provided for ambulation)
• Anterolateral approach		15	5	2	12	Possibly lower incidence of "slight paresthesia" (data combined with popliteal infusion)
Infraclavicular[57]	Ropivacaine (0.2%)	15	12	—[a]	—	Increased supplemental analgesics versus basal bolus
• Stimulating catheter		15	8	4	60	Highest satisfaction scores versus other 2 groups
• Coracoid approach		15	—[a]	9.9	60	Increased breakthrough pain incidence and intensity as well as sleep disturbances versus basal bolus
Axillary[8]	Bupivacaine (0.25%)					
		10	10	—	—	No clinical differences between groups; but, study most likely underpowered to detect any difference
• Nonstimulating catheter		10	—	10	60	Note that this group received automated hourly bolus doses of 10 mL without additional optional bolus doses
Femoral[154]	Bupivacaine (0.125%), clonidine (1 μg/mL), sufentanil (0.1 μg/mL)					
• For hip arthroplasty		15	10	—	—	Increased dynamic pain versus 5-mL bolus group and increased local anesthetic consumption versus others
• Inguinal perivascular approach		15	—	10	60	
• Nonstimulating catheter inserted 10–15 cm using Seldinger technique		15	—	5	30	Highest satisfaction scores versus other 2 groups
Femoral[158]	Bupivacaine (0.125%), clonidine (0.1 μg/mL)					
• For knee arthroplasty		15	10	—	—	Increased local anesthetic consumption versus other 2 groups
• Inguinal perivascular approach		15	5	2.5	30	Trend toward less supplemental analgesic requirements ($P = 0.10$) than other 2 groups
• Nonstimulating catheter inserted 10–15 cm using Seldinger technique		15	—	10	60	

(*Continued*)

Table 2. (*Continued*)

Catheter location	Infusate(s)	*n*	Treatment groups: Basal (mL/h)	Bolus (mL)	Lockout (min)	Primary findings
Fascia iliaca[172]	Ropivacaine (0.2%)					
		46	10	—	—	
• For knee surgery		46	5	5	60	
• Nonstimulating catheter inserted 10–15 cm without Seldinger technique		44	—	10	60	Least local anesthetic consumption versus other 2 groups
Subgluteal sciatic[171]	Ropivacaine (0.2%)	25	10	—	—	Increased consumption of local anesthetic
• Nonstimulating catheter inserted 3–4 cm		25	5	5	60	
Popliteal sciatic[170]		10	12	—[a]	—	Increased consumption of local anesthetic with a shorter duration of infusion and analgesia
• Stimulating catheter		10	8	4	60	
• Posterior approach		10	—[a]	9.9	60	Increased baseline pain, breakthrough pain incidence and intensity, and sleep disturbances versus other 2
Popliteal sciatic[174]	Levobupivacaine (0.125%)					
• Nonstimulating catheter		22	5	—	—	Increased baseline and breakthrough pain intensity; a trend toward increased rescue analgesic requirement ($P = 0.055$)
• Posterior approach		22	—	5	60	Note that this group received automated hourly bolus doses of 5 mL without additional optional bolus doses
Popliteal sciatic[175]		25	5	3	15	Increased local anesthetic consumption
• Nonstimulating catheter		25	—	5	60	Note that this group received automated hourly bolus doses of 5 mL; and optional 3-mL bolus doses
• Posterior approach	Levobupivacaine (0.125%)			3	15	
Popliteal sciatic[173]						
• Nonstimulating catheter	Ropivacaine (0.2%)	15	7	—	—	Possibly increased assistance with daily activity and time until 10 min of ambulation (data combined with interscalene infusion; no *P* value provided for ambulation)
• Posterior approach		15	5	2	12	Possibly lower incidence of "slight paresthesia" (data combined with interscalene infusion)

Due to publication limitations, includes only selected randomized, controlled trials specifically investigating varying local anesthetic delivery method.

— = not included for this treatment group.

[a] Nominal basal infusion rate or bolus volume provided to retain treatment group masking.

to consider that most published investigations report a basal rate of 4 to 10 mL/h (lower rates for catheters of the lower extremity; higher rates for the upper extremity), a bolus volume of 2 to 10 mL, and a bolus lockout period of 20 to 60 minutes. Similarly, the maximum recommended hourly total dose of local anesthetic during perineural infusion remains unknown,[181] but a wide safety margin has been documented in numerous clinical trials,[125,140,148,182–187] with 1 study reporting no toxicity signs or symptoms with perineural ropivacaine 0.2% administered at basal rates up to 14 mL/h and large, repeated boluses of ropivacaine 0.5% (10–60 mL) provided for up to 27 days.[188]

INFUSION PUMPS

Although perineural local anesthetic may be provided using exclusively human-administered bolus doses,[189] both clinical factors (e.g., basal infusion benefits) as well as logistical considerations[190] usually dictate the use of an infusion pump. There is no single optimal device for all situations, given the multitude of clinical scenarios and practice requirements, so pump preference is usually based on the desired device characteristics.[191] Infusion pumps may be (arbitrarily) categorized by their power source. Although spring- and vacuum-powered devices are available, neither is particularly desirable for the purpose of CPNB because of a multitude of factors, including highly variable basal infusion rates and relatively small local anesthetic reservoir volumes, respectively.[192,193] Until recently, elastomeric infusion pumps were severely limited relative to the capabilities of electronic devices[190]; however, with the advent of newer nonelectronic pumps, this is no longer the case.

In general, electronic devices provide very accurate and consistent (±5%) basal infusion rates over the entire course of infusion.[192–195] In contrast, elastomeric pumps usually overinfuse (110%–130% expected) during the initial 3 to 8 hours of infusion and within the final hours before reservoir exhaustion,[192–196] resulting in a shorter infusion duration than anticipated given the initial reservoir volume and set basal infusion rate.[192–195,197,198] However, whether the increased variability is clinically significant, or in which clinical situations it is relevant, remains unknown. Unlike electronic devices, the basal infusion rate of most elastomeric devices increases with increasing ambient temperature and pump height relative to the catheter insertion site,[192–195,198] although these changes are probably clinically relevant only at extreme values.

An adjustable basal infusion rate allows local anesthetic administration titration in case of an insensate extremity,[31] undesired side effects (e.g., muscle weakness),[94,180] inadequate analgesia,[170] or desire to maximize infusion duration (e.g., ambulatory patients with a set reservoir volume).[57,170,177] In addition, a patient-controlled bolus function often provides many clinical benefits.[57,147] All electronic pumps provide an adjustable basal rate, patient-controlled bolus doses, and a variable bolus lockout period.[192–195] Although most elastomeric devices provide a fixed basal infusion rate,[191] a few now provide flexibility similar to their electronic counterparts. Nearly all electronic pumps use an external local anesthetic reservoir that allows for easy reservoir exchanges.[116,188] In contrast, all elastomeric devices have an internal reservoir. Even though refilling such devices has been investigated,[199,200] this procedure is not approved by manufacturers/governments for the majority of devices, requiring the use of an additional unit if continued infusion is desired after reservoir exhaustion.[173,201–203] Regardless of reservoir type, filling the infusion pump/reservoir within the United States must now be executed within an isolation class 5 environment, essentially requiring local anesthetic compounding within a designated pharmacy with a laminar flow workbench.[204]

Nonelectronic infusion pumps are often favored for their relative simplicity in both initially setting and subsequently adjusting the basal infusion rate[205]; for their light weight and smaller size[206]; their lack of audible alarms[206,207] (although there is no warning for a pause in the infusion)[208]; disposability[209]; and for their silent operation (noise generated by electronic pumps may disturb patient sleep).[206] In addition, elastomeric devices with a manufacturer-fixed basal rate and no bolus dose capability are usually relatively inexpensive.[191] Conversely, reusable electronic pumps use inexpensive disposable "cassettes" to provide sterile infusion for individual patients.[177] A limited number of single-use electronic devices are available.[144–146] Lastly, although the reliability for most infusion pumps is high, regardless of power source, certain devices are more dependable than others for both electronic[207,210–213] and nonelectronic pumps.[196,208]

AMBULATORY PERINEURAL INFUSION

First described in 1997,[214] CPNB may be provided to patients outside of the hospital using a portable infusion pump, and nearly every catheter type (i.e., anatomic location) has been reported in ambulatory patients.[191] Perineural infusion is often provided for ambulatory surgery without an overnight hospital stay,[84–86] but the technique may be used to shorten hospitalization[178,215] and/or provide benefits after discharge either home or to a skilled nursing facility.[33,200] Time constraints are often more restrictive in high-turnover ambulatory centers,[85] making insertion techniques with documented time savings frequently desirable (e.g., ultrasound guidance).[61,64,105,216] Because patients are rarely directly monitored outside of the hospital, and not all patients desire or are capable of accepting the additional responsibility of caring for the catheter and pump system, patient selection criteria are often more stringent for ambulatory CPNB. In an effort to avoid local anesthetic toxicity, patients with renal or hepatic insufficiency are often excluded from outpatient perineural infusion.[182] For infusions possibly affecting the phrenic nerve and weakening the ipsilateral diaphragm (e.g., interscalene and paravertebral catheters),[217–219] caution is warranted for individuals with heart/lung disease and in obese patients who may not be able to compensate for mild hypoxia and/or hypercarbia.[220,221] Of note, age alone is not an absolute exclusion criterion, with hundreds of pediatric patients receiving at-home CPNB without complication rates or severity higher than for their adult counterparts.[14,24–26]

Providing ambulatory CPNB often leads to a reduced time until discharge readiness[33,58,178,222] and, in some cases, actual discharge.[178,215] After tricompartmental knee arthroplasty, permitting early discharge with ambulatory femoral infusion results in decreased hospitalization-related costs.[223] However, although ambulatory continuous femoral and posterior lumbar plexus nerve blocks decrease the time until important discharge criteria are met,[33,58,222] an increased incidence of patient falls in patients receiving ropivacaine versus saline through their catheters suggests that increased caution is warranted before implementing early discharge.[176] Nevertheless, relatively small published series demonstrate the feasibility of total joint arthroplasty with only a single-night hospital stay, or even on an outpatient basis, when patients are permitted to continue their hospital-based perineural infusion at home.[84,202,203,224,225]

Although the benefits of home CPNB are well documented with many placebo-controlled RCTs,[31,33,34,58,93,178,222,226,227] there are negligible published data regarding the optimal practice for multiple aspects of ambulatory infusion, such as the requirement of a patient caretaker[86]; method/frequency of patient oversight (e.g., home nursing visits,[173,228,229] telephone calls,[20,205] or simply written instructions with solely patient-initiated contact); and catheter removal protocol (health care provider extraction,[173,229] caretaker withdrawal with instructions provided by telephone,[222] or simply written instructions[226]). Of 40 patients with a hospital-based CPNB, 13% stated they would be unwilling to remove their catheter at home.[230] However, of patients who previously removed a perineural catheter at home, 98% felt "comfortable" doing the procedure with instructions given by telephone, only 4% would have preferred to return to the hospital for health care provider catheter removal, and 43% would have felt comfortable with exclusively written instructions.[205] Of note, at least within the United States, there are no national guidelines regarding the maximal safe CPNB duration.[204]

BENEFITS OF CPNB

Whereas case reports and series suggest numerous possible benefits of CPNB for a wide variety of ailments,[5–17] published RCTs include exclusively postoperative patients. Providing analgesia is the primary indication for postoperative CPNB,[18] and most CPNB benefits seem to be dependent on successfully improving pain control (Table 3).[18] Potent analgesia is most dramatic for surgical sites that are completely innervated by nerves affected by the perineural infusion, as is often the case for shoulder and foot procedures (interscalene and sciatic perineural catheters, respectively).[31,34,93,178,215,226,230] Unfortunately, brachial plexus infusions for procedures at or distal to the elbow seem to provide less-impressive analgesia,[227] even though they (theoretically) cover the entire surgical site. RCT-documented benefits of axillary,[153] supraclavicular,[231–233] and transversus abdominus plane[234] infusion are severely lacking. Although the benefits of infraclavicular infusion are validated,[227] analgesia is often less than optimal unless a high enough dose of local anesthetic is administered, frequently rendering the extremity insensate.[57,145]

Similarly, femoral or posterior lumbar plexus infusion may result in unacceptable quadriceps femoris and hip adductor weakness when a high enough dose of local anesthetic is administered to optimize analgesia.[94] In addition, a single perineural infusion for surgical sites innervated by multiple nerves, most notably the hip, knee, and ankle, may provide less than optimal analgesia without the concurrent use of additional analgesics.[33,58,146] Of published reports, nearly all investigators provide a single infusion, often supplemented with a separate single-injection peripheral nerve block (e.g., sciatic block after knee surgery).[235] Some individuals have proposed inserting a second catheter,[236–238] although there are minimal and somewhat conflicting data to guide clinical practice.[239,240] Whereas a lumbar epidural provides generally equivalent analgesia to femoral perineural infusion for hip and knee arthroplasty, CPNB results in a more favorable side-effect profile without the risk of epidural hematoma during concomitant anticoagulant administration.[159,161,241,242]

Although the evidence for CPNB benefits during local anesthetic infusion is overwhelming, there are few data demonstrating benefits after catheter removal. Exceptions include improved analgesia after a few days[2,32,243] or 6 months[240]; more rapid resumption of unassisted standing and lavatory use[2]; increased health-related quality of life in 1 study[244] (but not 5 others)[245–249]; and faster tolerance of passive knee flexion[2] resulting in earlier discharge from rehabilitation centers.[159,161] Conspicuously lacking is evidence of medium- or long-term improvements in health-related quality-of-life measures.[245–250]

COMPLICATIONS

As with all medical procedures, the potential CPNB benefits must be weighed against the potential risks. Fortunately, infusion-related serious and lasting injuries are uncommon, whereas relatively minor complications occur at a frequency similar to single-injection peripheral nerve blocks.[251] Unfortunately, heterogeneous catheter insertion techniques, equipment, anatomic locations, and infusions render generalizations difficult. For example, various prospective studies report an incidence of secondary block (infusion) failure of 1%,[252] 20%,[34] and 50%.[36] Thus, the specific complication rates provided in this section will not apply to all practices. CPNB-specific complications during catheter insertion include inaccurate catheter tip placement too far from the target nerve to provide postoperative analgesia,[35] and in exceptionally rare cases, epidural,[253–255] intrathecal,[256–258] intravascular,[227,259] intraneural,[260] and even interpleural catheter insertion.[261] Catheter migration after accurate placement has been suggested,[262] but also doubted,[263] and the dearth of published events suggests that it is an exceptionally rare event, if it even occurs at all.

During the perineural infusion, more common (and benign) complications include catheter dislodgement or obstruction[116,173,252] and fluid leakage at the catheter site.[173,227] Although not prospectively investigated, subcutaneous catheter tunneling,[41,264] application of liquid adhesive,[191] use of a catheter anchoring device,[191] and applying 2-octyl cyanoacrylate glue[265] may decrease the incidence of dislodgement and leakage.

Additional possible complications include infusion pump malfunction,[207,266] undesired pause,[208] or disconnection[33]; skin irritation or allergic reactions to the catheter dressing and/or liquid adhesive[267]; and catheter-induced brachial plexus irritation.[268] In addition, a CPNB-induced insensate extremity may prove disconcerting to patients,[269] impede

Table 3. Benefits of Continuous Peripheral Nerve Blocks Documented in Randomized Controlled Trials Including at Least One Treatment Group Without a Regional Analgesic

	Brachial plexus		Femoral nerve			Sciatic nerve
Benefit	Interscalene	Infraclavicular	Posterior lumbar plexus	Femoral	Fascia iliaca	Popliteal
Analgesia (improved)						
Resting	RCT[173,217,326–329,331,a] MPC[34,93,178]	MPC[227]	RCT[13,238,346,b]	RCT[2,159,161,237,243,248,250,349,355,b] MPC[222]	RCT[359]	RCT[173,237,238,a,b] MPC[31,215,226]
Breakthrough	RCT[329] MPC[34,93,178]	MPC[227]		RCT[240,b]	RCT[359]	RCT[240,b] MPC[31,215,226]
Dynamic	RCT[173,329,331,a] MPC[178]		RCT[238,346,b]	RCT[2,159,161,237,240,243] MPC[32,b]		RCT[173,237,238,240,a,b]
>1 d after catheter removal				RCT[2,240,b] MPC[32]		RCT[240,b]
Supplemental analgesic requirements (decreased)						
Oral opioids	MPC[34,93,178]	MPC[227]		RCT[243] MPC[32]		MPC[31,215]
IV opioids	RCT[328,331] MPC[178,230]		RCT[346,348] MPC[352]	RCT[2,36,150,167,240,243,244,250,346,349,355,b]	RCT[359]	RCT[240,b] MPC[215]
NSAID	RCT[173,a]					RCT[173,a]
Other	RCT[327,329]					
Opioid-related side effects (decreased)						
Nausea, vomiting, or antiemetic rescue	RCT[173,217,326,327,331,a] MPC[34]	MPC[227]	RCT[346,348]	RCT[161,242,248,346,356]		RCT[173,a] MPC[31,215]
Pruritus	RCT[173,326,327,a] MPC[34]		RCT[346]	RCT[346]		RCT[173,a] MPC[31]
Sedation, fatigue, dizziness, or bowel function	RCT[173,a] MPC[34]	MPC[227]		RCT[237,248,b]	MPC[358]	RCT[173,237,a,b] MPC[31]
Sleep						
Sleep disturbance	RCT[173,a]	MPC[227]				RCT[173,a] MPC[31,226]
Awakenings	MPC[34,93]	MPC[227]				MPC[31]
Satisfaction	RCT[173,217,327,328,a] MPC[34,93,178]	MPC[227]	RCT[346,348] MPC[33]	RCT[248,250,346]	RCT[359]	RCT[173,a] MPC[31,215]
Discharge (decreased time until ...)						
Discharge readiness	MPC[178]		MPC[33]	MPC[58,222]		
Actual discharge	RCT[173,a] MPC[178]			RCT[159,161]		RCT[173,a] MPC[215]
Resumption of passive joint range of motion (accelerated)						
Shoulder	MPC[178]					
Knee				RCT[2,36,159,161,237,248]		RCT[237,b]
Hip					RCT[359]	
Resumption of ambulation or other functioning (accelerated)	RCT[173,a]		RCT[346] MPC[352]	RCT[2,244]		RCT[173,a]
Inflammation or proinflammatory markers (decrease)			RCT[238,b]	RCT[2]		RCT[238,b]

Only selected references are included because of publication limitations.

RCT = randomized controlled trial (either no placebo control or at least 1 clinical group unmasked to treatment allocation); MPC = RCT with all clinical groups masked to treatment allocation and including a placebo control; NSAID = nonsteroidal antiinflammatory drug.

[a] The study by Capdevila et al.[173] did not separate results for interscalene and popliteal sciatic catheters, and therefore one or both of these anatomic locations may account for all of the difference between treatment groups.

[b] Studies by Bagry et al.,[238] Mistraletti et al.,[237] and Blumenthal et al.[240] compared 2 concurrent continuous peripheral nerve blocks versus no regional intervention, and therefore one or both of these anatomic catheter locations may account for all of the difference between treatment groups.

physical therapy and/or ambulation,[133,222] and be considered a risk factor for injury by some investigators.[145,146] In these cases, the infusion pump is usually paused until sensory perception begins to return, after which the infusion is restarted at a lower basal rate.[31,58] Conversely, inadequate analgesia or breakthrough pain may occur, and is often treated by increasing the basal infusion and providing patient-controlled bolus doses, respectively.[31,227]

More serious (but very rare) complications include myonecrosis with repeated large boluses of bupivacaine[270]; systemic local anesthetic toxicity[126,148,182,271,272]; prolonged Horner syndrome[273]; and catheter knotting,[75,76,274] retention,[57,275] shearing,[126,276,277] or breakage.[278] Although infusions potentially affecting the phrenic nerve may have minimal pulmonary effects for relatively healthy patients,[155,217,279] dyspnea is somewhat common,[67] and lower lobe collapse has occurred.[221] There is limited evidence that the risk of nerve injury from prolonged local anesthetic exposure may be increased in patients with diabetes[280,281] and/or preexisting neuropathy.[282]

There are case reports of peri-catheter hematoma formation,[276,283] often with concurrently administered low-molecular-weight heparin for thromboprophylaxis.[284–286] Most are self-limiting,[285] but more dramatic cases require surgical evacuation.[283] The most recent (Third) American Society of Regional Anesthesia consensus statement on neuraxial anesthesia and anticoagulation explicitly recommends precautions for neuraxial techniques and that anticoagulation be exercised for "deep" perineural catheters (undefined); specifically, that any catheter be removed before administration of various anticoagulants,[287] although this practice has been questioned by various investigators.[288–293] Also concerning is the association between perineural infusions affecting the femoral nerve and patient falls after hip and knee arthroplasty,[176] possibly because of CPNB-induced sensory, proprioception, and/or quadriceps weakness.[94] Correlation does not prove causation; however, until further evidence is published, practitioners should consider interventions that may decrease the risk of falls, such as limiting the local anesthetic dose/mass[143]; providing crutches/walker and a knee immobilizer during ambulation[294]; and educating surgeons, nurses, and physical therapists of possible CPNB-induced deficits and fall precautions.

Although the reported rates of inflammation (3%–4%)[252,266,295] and catheter bacterial colonization (6%–57%) are seemingly high,[296,297] clinically relevant infection is relatively rare (incidence 0%–3%[298,299]; but most reports <1%).[38,126,251,296,300] Risk factors include admission to an intensive care unit, absence of perioperative antibiotic prophylaxis, and male sex.[266] Although 1 multicenter study found a higher risk with axillary and femoral catheters,[266] others have reported the interscalene location as the most problematic.[252,299] Risk of infection is also correlated with infusion duration.[266] Nonetheless, infusions provided during extended medical transport for up to 34 days[116] and provided at home for up to 83 days[200] have been reported with a minimal incidence of infection. There is limited evidence that subcutaneous catheter tunneling[264] may decrease the risk of bacterial colonization and infection.[296] Abscesses have occurred, although the incidence remains unknown, and occasionally require surgical treatment,[301] but often do not if timely antibiotic coverage is provided.[302–304] Although life-threatening catheter-related infections/sepsis have been reported,[305,306] there is currently no case of permanent injury due to CPNB-related infection within the English-language literature.[298]

Perhaps the most feared postinfusion complication is neurologic injury.[307] It is often difficult to determine how much of a neurologic deficit, if any, is attributable to CPNB because all surgical procedures are associated with a variable incidence of nerve injury,[308] regardless of the application of a regional anesthetic/analgesic.[309,310] For example, hip arthroplasty without a regional anesthetic is associated with an incidence of femoral neuropathy as high as 2.3%.[310] So, if a study with a regional anesthetic/analgesic in this same patient population found a 1% incidence of femoral neuropathy, it would suggest that the perineural infusion is actually protective; but such an uncontrolled study would seem alarming with such a high incidence of nerve injury "associated" with CPNB. With this critical limitation in mind, the incidence of transient adverse neurologic symptoms associated with CPNB is 0% to 1.4% for interscalene,[38,251,252,266,276] 0.4% to 0.5% for femoral,[266,276] and 0% to 1.0% for sciatic catheters.[252,266,272,276] An additional investigation found a 0.2% incidence of neurologic deficits lasting longer than 6 weeks in nearly 3500 catheters from multiple anatomic locations.[252] In this latter study, it remains unknown whether the deficits resolved after the 6-week study period, but multiple prospective investigations report that the overwhelming majority of neurologic symptoms present at 4 to 6 weeks resolve spontaneously within 3 months of surgery.[38,251,266]

There are reported cases of long-term and/or permanent nerve injury in patients with perineural infusion.[311] Five large, prospective series[38,251,266,272,276] that followed patients for at least 3 months found 3 cases of unresolved adverse neurologic events: a brachial plexus lesion after interscalene infusion (followed 9 months)[251]; a femoral neuropathy presumably the result of a retroperitoneal hematoma (cause undetermined; months followed not reported)[276]; and a persistent paraesthesia after a popliteal sciatic catheter (followed through 18 months).[272] Combining the results of these studies (4148 subjects) suggests that the risk of neurologic injury lasting longer than 9 months associated with CPNB is 0.07%.[38,251,266,272,276] It remains unknown whether CPNB contributed to these cases, or if they would have occured without the addition of a regional analgesic. Although ultrasound guidance may decrease the incidence of many/most of these reported complications,[312] there are few data supporting this proposition,[313,314] and case reports suggest that completely abolishing such events is unlikely (quite possibly because postoperative neuropathy may occur without any regional anesthetic/analgesic).[315–317]

CONCLUSIONS

Although the published literature presented in this review article provides a plethora of information involving CPNB, many aspects of perineural infusion have yet to be fully elucidated, including the optimal catheter insertion modality and technique; infusate(s) and adjuvants; local anesthetic delivery regimen; details of optimizing ambulatory infusion; possible infusion benefits; and the incidence of all possible risks. Furthermore, although CPNB seems to provide far more potent analgesia than wound catheters,[318–320] and often fewer undesirable side effects than epidural infusion,[23,159,161,242,318] many questions remain regarding the optimal analgesic technique for many surgical procedures.[321,322] Lastly, perineural infusion must be adequately compared with possible new analgesic techniques.[244,323] Only through prospective research will we fully reveal and maximize the potential benefits, while minimizing the potential risks, of CPNB for our patients.

DISCLOSURES

Name: Brian M. Ilfeld, MD, MS.
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FAER'S IMPACT ON MY CAREER

Brian M. Ilfeld, MD, MS (Clinical Investigation).
Two years after completing my regional anesthesia fellowship, I was awarded a Foundation for Anesthesia Education and Research (FAER) Mentored Research Training Grant. This funding provided the opportunity to earn a Master's Degree in Clinical Investigation, as well as allowing completion of multiple pilot studies involving my primary interest at the time, ambulatory continuous peripheral nerve blocks. These exploratory investigations provided data included in a grant proposal sent to the National Institutes of Health (NIH), which was ultimately funded as a 5-year Mentored Career Development Award (in large part because of the Master's Degree the FAER award enabled). The NIH grant provided funding for 80% nonclinical time in addition to specific randomized controlled trials (also involving ambulatory perineural local anesthetic infusion). Five years of protected research time allowed me to take a dozen additional didactic courses to build on knowledge gained during my Master's Degree training; develop skills in designing, executing, and reporting multicenter clinical trials; work with and learn from incredibly talented coinvestigators; serve as an editor for my subspecialty's journal *Regional Anesthesia and Pain Medicine*; successfully compete for additional research funding; and help mentor wonderfully gifted and enthusiastic fellows and faculty members with whom I have been so blessed to cross paths. Most importantly, it gave me the opportunity to work and/or study with extraordinary mentors such as Drs. Kayser Enneking, Nikolaus Gravenstein, Daniel Sessler, Joseph Neal, James Eisenach, Tony Yaksh, and Pamela Duncan, among so many others. Now, 90% of my workweek involves clinical research, and I am very fortunate to serve as the Director of Clinical Research for my section at the University of California San Diego, on the Advisory Board of the UCSD Clinical and Translational Research Institute, and as a reviewer for NIH Special Emphasis Panel/Scientific Review Groups. There is no doubt in my mind that without the investment FAER made in me nearly a decade ago, I would have been able to attain only a small fraction of my career goals. For this, I am, and will for always be, deeply grateful.

REFERENCES

1. Carvalho B, Aleshi P, Horstman DJ, Angst MS. Effect of a preemptive femoral nerve block on cytokine release and hyperalgesia in experimentally inflamed skin of human volunteers. Reg Anesth Pain Med 2010;35:514–9
2. Martin F, Martinez V, Mazoit JX, Bouhassira D, Cherif K, Gentili ME, Piriou P, Chauvin M, Fletcher D. Antiinflammatory effect of peripheral nerve blocks after knee surgery: clinical and biologic evaluation. Anesthesiology 2008;109:484–90
3. Ansbro FP. A method of continuous brachial plexus block. Am J Surg 1946;71:716–22
4. DeKrey JA, Schroeder CF, Buechel DR. Continuous brachial plexus block. Anesthesiology 1969;30:332
5. Sarnoff SJ, Sarnoff LC. Prolonged peripheral nerve block by means of indwelling plastic catheter: treatment of hiccup. Anesthesiology 1951;12:270–5
6. Manriquez RG, Pallares V. Continuous brachial plexus block for prolonged sympathectomy and control of pain. Anesth Analg 1978;57:128–30
7. Berger A, Tizian C, Zenz M. Continuous plexus blockade for improved circulation in microvascular surgery. Ann Plast Surg 1985;14:16–9
8. Mezzatesta JP, Scott DA, Schweitzer SA, Selander DE. Continuous axillary brachial plexus block for postoperative pain relief: intermittent bolus versus continuous infusion. Reg Anesth 1997;22:357–62
9. Loland VJ, Ilfeld BM, Abrams RA, Mariano ER. Ultrasound-guided perineural catheter and local anesthetic infusion in the perioperative management of pediatric limb salvage: a case report. Paediatr Anaesth 2009;19:905–7
10. Greengrass RA, Feinglass NG, Murray PM, Trigg SD. Continuous regional anesthesia before surgical peripheral sympathectomy in a patient with severe digital necrosis associated with Raynaud's phenomenon and scleroderma. Reg Anesth Pain Med 2003;28:354–8
11. Cheeley LN. Treatment of peripheral embolism by continuous sciatic nerve block. Curr Res Anesth Analg 1952;31:211–2
12. Buckenmaier CC III, Rupprecht C, McKnight G, McMillan B, White RL, Gallagher RM, Polomano R. Pain following battlefield injury and evacuation: a survey of 110 casualties from the wars in Iraq and Afghanistan. Pain Med 2009;10:1487–96
13. Chudinov A, Berkenstadt H, Salai M, Cahana A, Perel A. Continuous psoas compartment block for anesthesia and perioperative analgesia in patients with hip fractures. Reg Anesth Pain Med 1999;24:563–8
14. Dadure C, Motais F, Ricard C, Raux O, Troncin R, Capdevila X. Continuous peripheral nerve blocks at home for treatment of recurrent complex regional pain syndrome I in children. Anesthesiology 2005;102:387–91
15. Lierz P, Schroegendorfer K, Choi S, Felleiter P, Kress HG. Continuous blockade of both brachial plexus with ropivacaine in phantom pain: a case report. Pain 1998;78:135–7
16. Fischer HB, Peters TM, Fleming IM, Else TA. Peripheral nerve catheterization in the management of terminal cancer pain. Reg Anesth 1996;21:482–5
17. Umino M, Kohase H, Ideguchi S, Sakurai N. Long-term pain control in trigeminal neuralgia with local anesthetics using an indwelling catheter in the mandibular nerve. Clin J Pain 2002;18:196–9
18. Richman JM, Liu SS, Courpas G, Wong R, Rowlingson AJ, McGready J, Cohen SR, Wu CL. Does continuous peripheral nerve block provide superior pain control to opioids? A meta-analysis. Anesth Analg 2006;102:248–57

19. Boezaart AP. Perineural infusion of local anesthetics. Anesthesiology 2006;104:872–80
20. Rawal N, Allvin R, Axelsson K, Hallen J, Ekback G, Ohlsson T, Amilon A. Patient-controlled regional analgesia (PCRA) at home: controlled comparison between bupivacaine and ropivacaine brachial plexus analgesia. Anesthesiology 2002;96:1290–6
21. Rawal N, Axelsson K, Hylander J, Allvin R, Amilon A, Lidegran G, Hallen J. Postoperative patient-controlled local anesthetic administration at home. Anesth Analg 1998;86:86–9
22. Dadure C, Raux O, Gaudard P, Sagintaah M, Troncin R, Rochette A, Capdevila X. Continuous psoas compartment blocks after major orthopedic surgery in children: a prospective computed tomographic scan and clinical studies. Anesth Analg 2004;98:623–8
23. Dadure C, Bringuier S, Nicolas F, Bromilow L, Raux O, Rochette A, Capdevila X. Continuous epidural block versus continuous popliteal nerve block for postoperative pain relief after major podiatric surgery in children: a prospective, comparative randomized study. Anesth Analg 2006;102:744–9
24. Ludot H, Berger J, Pichenot V, Belouadah M, Madi K, Malinovsky JM. Continuous peripheral nerve block for postoperative pain control at home: a prospective feasibility study in children. Reg Anesth Pain Med 2008;33:52–6
25. Ilfeld BM, Smith DW, Enneking FK. Continuous regional analgesia following ambulatory pediatric orthopedic surgery. Am J Orthop 2004;33:405–8
26. Ganesh A, Rose JB, Wells L, Ganley T, Gurnaney H, Maxwell LG, DiMaggio T, Milovcich K, Scollon M, Feldman JM, Cucchiaro G. Continuous peripheral nerve blockade for inpatient and outpatient postoperative analgesia in children. Anesth Analg 2007;105:1234–42
27. Mariano ER, Ilfeld BM, Cheng GS, Nicodemus HF, Suresh S. Feasibility of ultrasound-guided peripheral nerve block catheters for pain control on pediatric medical missions in developing countries. Paediatr Anaesth 2008;18:598–601
28. Selander D. Catheter technique in axillary plexus block: presentation of a new method. Acta Anaesthesiol Scand 1977;21:324–9
29. Pham-Dang C, Meunier JF, Poirier P, Kick O, Bourreli B, Touchais S, Le Corre P, Pinaud M. A new axillary approach for continuous brachial plexus block: a clinical and anatomic study. Anesth Analg 1995;81:686–93
30. Grant SA, Nielsen KC, Greengrass RA, Steele SM, Klein SM. Continuous peripheral nerve block for ambulatory surgery. Reg Anesth Pain Med 2001;26:209–14
31. Ilfeld BM, Morey TE, Wang RD, Enneking FK. Continuous popliteal sciatic nerve block for postoperative pain control at home: a randomized, double-blinded, placebo-controlled study. Anesthesiology 2002;97:959–65
32. Williams BA, Kentor ML, Vogt MT, Irrgang JJ, Bottegal MT, West RV, Harner CD, Fu FH, Williams JP. 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
33. Ilfeld BM, Ball ST, Gearen PF, Le LT, Mariano ER, Vandenborne K, Duncan PW, Sessler DI, Enneking FK, Shuster JJ, Theriaque DW, Meyer RS. Ambulatory continuous posterior lumbar plexus nerve blocks after hip arthroplasty: a dual-center, randomized, triple-masked, placebo-controlled trial. Anesthesiology 2008;109:491–501
34. Ilfeld BM, Morey TE, Wright TW, Chidgey LK, Enneking FK. Continuous interscalene brachial plexus block for postoperative pain control at home: a randomized, double-blinded, placebo-controlled study. Anesth Analg 2003;96:1089–95
35. Salinas FV. Location, location, location: continuous peripheral nerve blocks and stimulating catheters. Reg Anesth Pain Med 2003;28:79–82
36. Ganapathy S, Wasserman RA, Watson JT, Bennett J, Armstrong KP, Stockall CA, Chess DG, MacDonald C. Modified continuous femoral three-in-one block for postoperative pain after total knee arthroplasty. Anesth Analg 1999;89:1197–202
37. Borgeat A, Blumenthal S, Lambert M, Theodorou P, Vienne P. The feasibility and complications of the continuous popliteal nerve block: a 1001-case survey. Anesth Analg 2006;103:229–33
38. Borgeat A, Dullenkopf A, Ekatodramis G, Nagy L. Evaluation of the lateral modified approach for continuous interscalene block after shoulder surgery. Anesthesiology 2003;99:436–42
39. Capdevila X, Macaire P, Dadure C, Choquet O, Biboulet 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;94:1606–13
40. Torkki PM, Marjamaa RA, Torkki MI, Kallio PE, Kirvela OA. Use of anesthesia induction rooms can increase the number of urgent orthopedic cases completed within 7 hours. Anesthesiology 2005;103:401–5
41. Boezaart AP, de Beer JF, du TC, van Rooyen K. A new technique of continuous interscalene nerve block. Can J Anaesth 1999;46:275–81
42. Kick O, Blanche E, Pham-Dang C, Pinaud M, Estebe JP. A new stimulating stylet for immediate control of catheter tip position in continuous peripheral nerve blocks. Anesth Analg 1999;89:533–4
43. Brull R, Prasad GA, Gandhi R, Ramlogan R, Khan M, Chan VW. Is a patella motor response necessary for continuous femoral nerve blockade performed in conjunction with ultrasound guidance? Anesth Analg 2011;112:982–6
44. Morin AM, Kranke P, Wulf H, Stienstra R, Eberhart LH. The effect of stimulating versus nonstimulating catheter techniques for continuous regional anesthesia: a semiquantitative systematic review. Reg Anesth Pain Med 2010;35:194–9
45. Casati A, Fanelli G, Koscielniak-Nielsen Z, Cappelleri G, Aldegheri G, Danelli G, Fuzier R, Singelyn F. Using stimulating catheters for continuous sciatic nerve block shortens onset time of surgical block and minimizes postoperative consumption of pain medication after halux valgus repair as compared with conventional nonstimulating catheters. Anesth Analg 2005;101:1192–7
46. Rodriguez J, Taboada M, Carceller J, Lagunilla J, Barcena M, Alvarez J. Stimulating popliteal catheters for postoperative analgesia after hallux valgus repair. Anesth Analg 2006;102:258–62
47. Paqueron X, Narchi P, Mazoit JX, Singelyn F, Benichou A, Macaire P. A randomized, observer-blinded determination of the median effective volume of local anesthetic required to anesthetize the sciatic nerve in the popliteal fossa for stimulating and nonstimulating perineural catheters. Reg Anesth Pain Med 2009;34:290–5
48. Casati A, Fanelli G, Danelli G, Baciarello M, Ghisi D, Nobili F, Chelly JE. Stimulating or conventional perineural catheters after hallux valgus repair: a double-blind, pharmaco-economic evaluation. Acta Anaesthesiol Scand 2006;50:1284–9
49. Salinas FV, Neal JM, Sueda LA, Kopacz DJ, Liu SS. Prospective comparison of continuous femoral nerve block with nonstimulating catheter placement versus stimulating catheter-guided perineural placement in volunteers. Reg Anesth Pain Med 2004;29:212–20
50. Stevens MF, Werdehausen R, Golla E, Braun S, Hermanns H, Ilg A, Willers R, Lipfert P. Does interscalene catheter placement with stimulating catheters improve postoperative pain or functional outcome after shoulder surgery? A prospective, randomized and double-blinded trial. Anesth Analg 2007;104:442–7
51. Morin AM, Eberhart LH, Behnke HK, Wagner S, Koch T, Wolf U, Nau W, Kill C, Geldner G, Wulf H. Does femoral nerve catheter placement with stimulating catheters improve effective placement? A randomized, controlled, and observer-blinded trial. Anesth Analg 2005;100:1503–10
52. Hayek SM, Ritchey RM, Sessler D, Helfand R, Samuel S, Xu M, Beven M, Bourdakos D, Barsoum W, Brooks P. Continuous femoral nerve analgesia after unilateral total knee arthroplasty: stimulating versus nonstimulating catheters. Anesth Analg 2006;103:1565–70

53. Barrington MJ, Olive DJ, McCutcheon CA, Scarff C, Said S, Kluger R, Gillett N, Choong P. Stimulating catheters for continuous femoral nerve blockade after total knee arthroplasty: a randomized, controlled, double-blinded trial. Anesth Analg 2008;106:1316–21
54. Dauri M, Sidiropoulou T, Fabbi E, Giannelli M, Faria S, Mariani P, Sabato AF. Efficacy of continuous femoral nerve block with stimulating catheters versus nonstimulating catheters for anterior cruciate ligament reconstruction. Reg Anesth Pain Med 2007;32:282–7
55. Ilfeld BM, Wright TW, Sessler DI, Chmielewski TL. Valid and relevant outcome measures are critical for objective hypothesis-testing. Anesth Analg 2008;107:722–3
56. Chelly JE, Casati A. Are nonstimulating catheters really inappropriate for continuous nerve block techniques? Reg Anesth Pain Med 2003;28:483
57. Ilfeld BM, Morey TE, Enneking FK. Infraclavicular perineural local anesthetic infusion: a comparison of three dosing regimens for postoperative analgesia. Anesthesiology 2004;100: 395–402
58. Ilfeld BM, Le LT, Meyer RS, Mariano ER, Vandenborne 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 tricompartment total knee arthroplasty: a randomized, triple-masked, placebo-controlled study. Anesthesiology 2008;108: 703–13
59. Pham-Dang C, Kick O, Collet T, Gouin F, Pinaud M. Continuous peripheral nerve blocks with stimulating catheters. Reg Anesth Pain Med 2003;28:83–8
60. Hubler M, Stehr SN. Not all reasons for difficult peripheral nerve blocks are at the proximal end of the needle. Anesth Analg 2006;102:649
61. Mariano ER, Loland VJ, Bellars RH, Sandhu NS, Bishop ML, Abrams RA, Meunier MJ, Maldonado RC, Ferguson EJ, Ilfeld BM. Ultrasound guidance versus electrical stimulation for infraclavicular brachial plexus perineural catheter insertion. J Ultrasound Med 2009;28:1211–8
62. Mariano ER, Loland VJ, Sandhu NS, Bishop ML, Meunier MJ, Afra R, Ferguson EJ, Ilfeld BM. A trainee-based randomized comparison of stimulating interscalene perineural catheters with a new technique using ultrasound guidance alone. J Ultrasound Med 2010;29:329–36
63. Mariano ER, Loland VJ, Sandhu NS, Bishop ML, Lee DK, Schwartz AK, Girard PJ, Ferguson EJ, Ilfeld BM. Comparative efficacy of ultrasound-guided and stimulating popliteal-sciatic perineural catheters for postoperative analgesia. Can J Anaesth 2010;57:919–26
64. Mariano ER, Loland VJ, Sandhu NS, Bellars RH, Bishop ML, Afra R, Ball ST, Meyer RS, Maldonado RC, Ilfeld BM. Ultrasound guidance versus electrical stimulation for femoral perineural catheter insertion. J Ultrasound Med 2009;28: 1453–60
65. Ilfeld BM, Morey TE, Thannikary LJ, Wright TW, Enneking FK. Clonidine added to a continuous interscalene ropivacaine perineural infusion to improve postoperative analgesia: a randomized, double-blind, controlled study. Anesth Analg 2005;100:1172–8
66. Enneking K. Close counts. Reg Anesth Pain Med 2007;32: 280–1
67. Ilfeld BM, Morey TE, Wright TW, Chidgey LK, Enneking FK. Interscalene perineural ropivacaine infusion: a comparison of two dosing regimens for postoperative analgesia. Reg Anesth Pain Med 2004;29:9–16
68. Ficarrotta MR, Morey TE, Boezaart AP. Does "opening the perineural space" before stimulating catheter placement for continuous nerve block add value in clinical practice? Reg Anesth Pain Med 2010;35:245–8
69. Pham DC, Lelong A, Guilley J, Nguyen JM, Volteau C, Venet G, Perrier C, Lejus C, Blanloeil Y. Effect on neurostimulation of injectates used for perineural space expansion before placement of a stimulating catheter: normal saline versus dextrose 5% in water. Reg Anesth Pain Med 2009;34:398–403
70. Tsui BC, Kropelin B. The electrophysiological effect of dextrose 5% in water on single-shot peripheral nerve stimulation. Anesth Analg 2005;100:1837–9
71. Wehling MJ, Koorn R, Leddell C, Boezaart AP. Electrical nerve stimulation using a stimulating catheter: what is the lower limit? Reg Anesth Pain Med 2004;29:230–3
72. De Tran QH, De La Cuadra-Fontaine JC, Chan SY, Kovarik G, Asenjo JF, Finlayson R. Coiling of stimulating perineural catheters. Anesthesiology 2007;106:189–90
73. Capdevila X, Biboulet P, Morau D, Bernard N, Deschodt J, Lopez S, d'Athis F. Continuous three-in-one block for postoperative pain after lower limb orthopedic surgery: where do the catheters go? Anesth Analg 2002;94:1001–6
74. Luyet C, Eichenberger U, Greif R, Vogt A, Szucs FZ, Moriggl B. Ultrasound-guided paravertebral puncture and placement of catheters in human cadavers: an imaging study. Br J Anaesth 2009;102:534–9
75. Burgher AH, Hebl JR. Minimally invasive retrieval of knotted nonstimulating peripheral nerve catheters. Reg Anesth Pain Med 2007;32:162–6
76. Offerdahl MR, Lennon RL, Horlocker TT. Successful removal of a knotted fascia iliaca catheter: principles of patient positioning for peripheral nerve catheter extraction. Anesth Analg 2004;99:1550–2
77. David M. Knotted peripheral nerve catheter. Reg Anesth Pain Med 2003;28:487–8
78. MacLeod DB, Grant SA, Martin G, Breslin DS. Identification of coracoid process for infraclavicular blocks. Reg Anesth Pain Med 2003;28:485
79. Luyet C, Seiler R, Herrmann G, Hatch GM, Ross S, Eichenberger U. Newly designed, self-coiling catheters for regional anesthesia: an imaging study. Reg Anesth Pain Med 2011;36:171–6
80. Borgeat A, Ekatodramis G, Dumont C. An evaluation of the infraclavicular block via a modified approach of the Raj technique. Anesth Analg 2001;93:436–41
81. Ilfeld BM, Sandhu NS, Loland VJ, Suresh PJ, Mariano ER, Madison SJ, Bishop ML, Schwartz AK, Lee DK. Ultrasound-guided (needle-in-plane) perineural catheter insertion: the effect of catheter insertion distance on postoperative analgesia. Reg Anesth Pain Med 2011;36:261–5
82. Ilfeld BM, Fredrickson MJ, Mariano ER. Ultrasound-guided perineural catheter insertion: three approaches but few illuminating data. Reg Anesth Pain Med 2010;35:123–6
83. Davis JJ, Swenson JD, Greis PE, Burks RT, Tashjian RZ. Interscalene block for postoperative analgesia using only ultrasound guidance: the outcome in 200 patients. J Clin Anesth 2009;21:272–7
84. Swenson JD, Bay N, Loose E, Bankhead B, Davis J, Beals TC, Bryan NA, Burks RT, Greis PE. Outpatient management of continuous peripheral nerve catheters placed using ultrasound guidance: an experience in 620 patients. Anesth Analg 2006;103:1436–43
85. Fredrickson MJ, Ball CM, Dalgleish AJ. Successful continuous interscalene analgesia for ambulatory shoulder surgery in a private practice setting. Reg Anesth Pain Med 2008;33:122–8
86. Bryan NA, Swenson JD, Greis PE, Burks RT. Indwelling interscalene catheter use in an outpatient setting for shoulder surgery: technique, efficacy, and complications. J Shoulder Elbow Surg 2007;16:388–95
87. Liu SS, Ngeow JE, YaDeau JT. Ultrasound-guided regional anesthesia and analgesia: a qualitative systematic review. Reg Anesth Pain Med 2009;34:47–59
88. Slater ME, Williams SR, Harris P, Brutus JP, Ruel M, Girard F, Boudreault D. Preliminary evaluation of infraclavicular catheters inserted using ultrasound guidance: through-the-catheter anesthesia is not inferior to through-the-needle blocks. Reg Anesth Pain Med 2007;32:296–302
89. Wang AZ, Gu L, Zhou QH, Ni WZ, Jiang W. Ultrasound-guided continuous femoral nerve block for analgesia after total knee arthroplasty: catheter perpendicular to the nerve versus catheter parallel to the nerve. Reg Anesth Pain Med 2010;35:127–31

90. Fredrickson MJ, Ball CM, Dalgleish AJ. Posterior versus anterolateral approach interscalene catheter placement: a prospective randomized trial. Reg Anesth Pain Med 2011;36:125–33
91. Morau D, Levy F, Bringuier S, Biboulet P, Choquet O, Kassim M, Bernard N, Capdevila X. Ultrasound-guided evaluation of the local anesthetic spread parameters required for a rapid surgical popliteal sciatic nerve block. Reg Anesth Pain Med 2010;35:559–64
92. Fegley AJ, Lerman J, Wissler R. Epidural multiorifice catheters function as single-orifice catheters: an in vitro study. Anesth Analg 2008;107:1079–81
93. Mariano ER, Afra R, Loland VJ, Sandhu NS, Bellars RH, Bishop ML, Cheng GS, Choy LP, Maldonado RC, Ilfeld BM. Continuous interscalene brachial plexus block via an ultrasound-guided posterior approach: a randomized, triple-masked, placebo-controlled study. Anesth Analg 2009;108:1688–94
94. Charous MT, Madison SJ, Suresh PJ, Sandhu NS, Loland JV, 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 Jun 17. [Epub ahead of print]
95. Koscielniak-Nielsen ZJ, Rasmussen H, Hesselbjerg L. Long-axis ultrasound imaging of the nerves and advancement of perineural catheters under direct vision: a preliminary report of four cases. Reg Anesth Pain Med 2008;33:477–82
96. Antonakakis JG, Sites BD, Shiffrin J. Ultrasound-guided posterior approach for the placement of a continuous interscalene catheter. Reg Anesth Pain Med 2009;34:64–8
97. Dhir S, Ganapathy S. Use of ultrasound guidance and contrast enhancement: a study of continuous infraclavicular brachial plexus approach. Acta Anaesthesiol Scand 2008;52:338–42
98. Swenson JD, Davis JJ, DeCou JA. A novel approach for assessing catheter position after ultrasound-guided placement of continuous interscalene block. Anesth Analg 2008;106:1015–6
99. Sandhu NS, Capan LM. Ultrasound-guided infraclavicular brachial plexus block. Br J Anaesth 2002;89:254–59
100. Feinglass NG, Clendenen SR, Torp KD, Wang RD, Castello R, Greengrass RA. Real-time three-dimensional ultrasound for continuous popliteal blockade: a case report and image description. Anesth Analg 2007;105:272–4
101. Fredrickson MJ, Danesh-Clough TK. Ambulatory continuous femoral analgesia for major knee surgery: a randomised study of ultrasound-guided femoral catheter placement. Anaesth Intensive Care 2009;37:758–66
102. Fredrickson MJ, Ball CM, Dalgleish AJ, Stewart AW, Short TG. A prospective randomized comparison of ultrasound and neurostimulation as needle end points for interscalene catheter placement. Anesth Analg 2009;108:1695–700
103. Bendtsen TF, Nielsen TD, Rohde CV, Kibak K, Linde F. Ultrasound guidance improves a continuous popliteal sciatic nerve block when compared with nerve stimulation. Reg Anesth Pain Med 2011;36:181–4
104. Dhir S, Ganapathy S. Comparative evaluation of ultrasound-guided continuous infraclavicular brachial plexus block with stimulating catheter and traditional technique: a prospective-randomized trial. Acta Anaesthesiol Scand 2008;52:1158–66
105. Mariano ER, Cheng GS, Choy LP, Loland VJ, Bellars RH, Sandhu NS, Bishop ML, Lee DK, Maldonado RC, Ilfeld BM. Electrical stimulation versus ultrasound guidance for popliteal-sciatic perineural catheter insertion: a randomized controlled trial. Reg Anesth Pain Med 2009;34:480–5
106. Aveline C, Le Roux A, Le Hetet H, Vautier P, Cognet F, Bonnet F. Postoperative efficacies of femoral nerve catheters sited using ultrasound combined with neurostimulation compared with neurostimulation alone for total knee arthroplasty. Eur J Anaesthesiol 2010;27:978–84
107. van Geffen GJ, Gielen M. Ultrasound-guided subgluteal sciatic nerve blocks with stimulating catheters in children: a descriptive study. Anesth Analg 2006;103:328–33
108. van Geffen GJ, Scheuer M, Muller A, Garderniers J, Gielen M. Ultrasound-guided bilateral continuous sciatic nerve blocks with stimulating catheters for postoperative pain relief after bilateral lower limb amputations. Anaesthesia 2006;61:1204–7
109. Niazi AU, Prasad A, Ramlogan R, Chan VW. Methods to ease placement of stimulating catheters during in-plane ultrasound-guided femoral nerve block. Reg Anesth Pain Med 2009;34:380–1
110. Walker A, Roberts S. Stimulating catheters: a thing of the past? Anesth Analg 2007;104:1001–2
111. Fredrickson MJ. The sensitivity of motor response to needle nerve stimulation during ultrasound guided interscalene catheter placement. Reg Anesth Pain Med 2008;33:291–6
112. Chidiac EJ, Perov S. Outpatient continuous peripheral nerve catheters. Anesth Analg 2007;104:1303–4
113. Chelly JE, Casati A. Perineural infusion of local anesthetics: "more to the review." Anesthesiology 2007;106:191–2
114. Boezaart AP. That which we call a rose by any other name would smell as sweet—and its thorns would hurt as much. Reg Anesth Pain Med 2009;34:3–7
115. Plunkett AR, Brown DS, Rogers JM, Buckenmaier CC III. Supraclavicular continuous peripheral nerve block in a wounded soldier: when ultrasound is the only option. Br J Anaesth 2006;97:715–7
116. Stojadinovic A, Auton A, Peoples GE, McKnight GM, Shields C, Croll SM, Bleckner LL, Winkley J, Maniscalco-Theberge ME, Buckenmaier CC III. Responding to challenges in modern combat casualty care: innovative use of advanced regional anesthesia. Pain Med 2006;7:330–8
117. Bigeleisen PE. Ultrasound-guided infraclavicular block in an anticoagulated and anesthetized patient. Anesth Analg 2007;104:1285–7
118. Renes SH, van Geffen GJ, Rettig HC, Gielen MJ, Scheffer GJ. Ultrasound-guided continuous phrenic nerve block for persistent hiccups. Reg Anesth Pain Med 2010;35:455–7
119. Minville V, Zetlaoui PJ, Fessenmeyer C, Benhamou D. Ultrasound guidance for difficult lateral popliteal catheter insertion in a patient with peripheral vascular disease. Reg Anesth Pain Med 2004;29:368–70
120. Ben Ari AY, Joshi R, Uskova A, Chelly JE. Ultrasound localization of the sacral plexus using a parasacral approach. Anesth Analg 2009;108:1977–80
121. Karmakar MK, Ho AM, Li X, Kwok WH, Tsang K, Ngan Kee WD. Ultrasound-guided lumbar plexus block through the acoustic window of the lumbar ultrasound trident. Br J Anaesth 2008;100:533–7
122. Doi K, Sakura S, Hara K. A modified posterior approach to lumbar plexus block using a transverse ultrasound image and an approach from the lateral border of the transducer. Anaesth Intensive Care 2010;38:213–4
123. Ilfeld BM, Loland VJ, Mariano ER. Prepuncture ultrasound imaging to predict transverse process and lumbar plexus depth for psoas compartment block and perineural catheter insertion: a prospective, observational study. Anesth Analg 2010;110:1725–8
124. Liu SS, John RS. Modeling cost of ultrasound versus nerve stimulator guidance for nerve blocks with sensitivity analysis. Reg Anesth Pain Med 2010;35:57–63
125. Buettner J, Klose R, Hoppe U, Wresch P. Serum levels of mepivacaine-HCl during continuous axillary brachial plexus block. Reg Anesth 1989;14:124–7
126. Bergman BD, Hebl JR, Kent J, Horlocker TT. Neurologic complications of 405 consecutive continuous axillary catheters. Anesth Analg 2003;96:247–52
127. Casati A, Vinciguerra F, Scarioni M, Cappelleri G, Aldegheri G, Manzoni P, Fraschini G, Chelly JE. Lidocaine versus ropivacaine for continuous interscalene brachial plexus block after open shoulder surgery. Acta Anaesthesiol Scand 2003;47: 355–60
128. Butterworth JF IV. Potency ratios for local anesthetics in regional blocks: how long must we wait? Reg Anesth Pain Med 2008;33:1–3
129. Borghi B, Facchini F, Agnoletti V, Adduci A, Lambertini A, Marini E, Gallerani P, Sassoli V, Luppi M, Casati A. Pain relief and motor function during continuous interscalene analgesia after open shoulder surgery: a prospective, randomized, double-blind comparison between levobupivacaine 0.25%, and ropivacaine 0.25% or 0.4%. Eur J Anaesthesiol 2006;23:1005–9

130. Heid F, Muller N, Piepho T, Bares M, Giesa M, Drees P, Rumelin A, Werner C. Postoperative analgesic efficacy of peripheral levobupivacaine and ropivacaine: a prospective, randomized double-blind trial in patients after total knee arthroplasty. Anesth Analg 2008;106:1559–61
131. Casati A, Vinciguerra F, Cappelleri G, Aldegheri G, Grispigni C, Putzu M, Rivoltini P. Levobupivacaine 0.2% or 0.125% for continuous sciatic nerve block: a prospective, randomized, double-blind comparison with 0.2% ropivacaine. Anesth Analg 2004;99:919–23
132. Casati A, Borghi B, Fanelli G, Montone N, Rotini R, Fraschini G, Vinciguerra F, Torri G, Chelly J. Interscalene brachial plexus anesthesia and analgesia for open shoulder surgery: a randomized, double-blinded comparison between levobupivacaine and ropivacaine. Anesth Analg 2003;96:253–9
133. Borgeat A, Kalberer F, Jacob H, Ruetsch YA, Gerber C. Patient-controlled interscalene analgesia with ropivacaine 0.2% versus bupivacaine 0.15% after major open shoulder surgery: the effects on hand motor function. Anesth Analg 2001;92:218–23
134. Eroglu A, Uzunlar H, Sener M, Akinturk Y, Erciyes N. A clinical comparison of equal concentration and volume of ropivacaine and bupivacaine for interscalene brachial plexus anesthesia and analgesia in shoulder surgery. Reg Anesth Pain Med 2004;29:539–43
135. Nouette-Gaulain K, Dadure C, Morau D, Pertuiset C, Galbes O, Hayot M, Mercier J, Sztark F, Rossignol R, Capdevila X. Age-dependent bupivacaine-induced muscle toxicity during continuous peripheral nerve block in rats. Anesthesiology 2009;111:1120–7
136. Nouette-Gaulain K, Bellance N, Prevost B, Passerieux E, Pertuiset C, Galbes O, Smolkova K, Masson F, Miraux S, Delage JP, Letellier T, Rossignol R, Capdevila X, Sztark F. Erythropoietin protects against local anesthetic myotoxicity during continuous regional analgesia. Anesthesiology 2009;110:648–59
137. Zink W, Seif C, Bohl JR, Hacke N, Braun PM, Sinner B, Martin E, Fink RH, Graf BM. The acute myotoxic effects of bupivacaine and ropivacaine after continuous peripheral nerve blockades. Anesth Analg 2003;97:1173–9
138. Zink W, Bohl JR, Hacke N, Sinner B, Martin E, Graf BM. The long term myotoxic effects of bupivacaine and ropivacaine after continuous peripheral nerve blocks. Anesth Analg 2005;101:548–54
139. Borgeat A, Aguirre J, Marquardt M, Mrdjen J, Blumenthal S. Continuous interscalene analgesia with ropivacaine 0.2% versus ropivacaine 0.3% after open rotator cuff repair: the effects on postoperative analgesia and motor function. Anesth Analg 2010;111:1543–7
140. Ekatodramis G, Borgeat A, Huledal G, Jeppsson L, Westman L, Sjovall J. Continuous interscalene analgesia with ropivacaine 2 mg/mL after major shoulder surgery. Anesthesiology 2003;98:143–50
141. Vester-Andersen T, Christiansen C, Sorensen M, Kaalund-Jorgensen HO, Saugbjerg P, Schultz-Moller K. Perivascular axillary block II: influence of injected volume of local anaesthetic on neural blockade. Acta Anaesthesiol Scand 1983;27:95–8
142. Taboada MM, Rodriguez J, Bermudez M, Valino C, Blanco N, Amor M, Aguirre P, Masid A, Cortes J, Alvarez J, Atanassoff PG. Low volume and high concentration of local anesthetic is more efficacious than high volume and low concentration in Labat's sciatic nerve block: a prospective, randomized comparison. Anesth Analg 2008;107:2085–8
143. Ilfeld BM, Moeller LK, Mariano ER, Loland VJ, Stevens-Lapsley JE, Fleisher AS, Girard PJ, Donohue MC, Ferguson EJ, Ball ST. Continuous peripheral nerve blocks: is local anesthetic dose the only factor, or do concentration and volume influence infusion effects as well? Anesthesiology 2010;112:347–54
144. Le LT, Loland VJ, Mariano ER, Gerancher JC, Wadhwa AN, Renehan EM, Sessler DI, Shuster JJ, Theriaque DW, Maldonado RC, Ilfeld BM. Effects of local anesthetic concentration and dose on continuous interscalene nerve blocks: a dual-center, randomized, observer-masked, controlled study. Reg Anesth Pain Med 2008;33:518–25
145. Ilfeld BM, Le LT, Ramjohn J, Loland VJ, Wadhwa AN, Gerancher JC, Renehan EM, Sessler DI, Shuster JJ, Theriaque DW, Maldonado RC, Mariano ER. The effects of local anesthetic concentration and dose on continuous infraclavicular nerve blocks: a multicenter, randomized, observer-masked, controlled study. Anesth Analg 2009;108:345–50
146. Ilfeld BM, Loland VJ, Gerancher JC, Wadhwa AN, Renehan EM, Sessler DI, Shuster JJ, Theriaque DW, Maldonado RC, Mariano ER. The effects of varying local anesthetic concentration and volume on continuous popliteal sciatic nerve blocks: a dual-center, randomized, controlled study. Anesth Analg 2008;107:701–7
147. Singelyn FJ, Seguy S, Gouverneur JM. Interscalene brachial plexus analgesia after open shoulder surgery: continuous versus patient-controlled infusion. Anesth Analg 1999;89:1216–20
148. Tuominen M, Pitkanen M, Rosenberg PH. Postoperative pain relief and bupivacaine plasma levels during continuous interscalene brachial plexus block. Acta Anaesthesiol Scand 1987;31:276–8
149. Tetzlaff JE, Andrish J, O'Hara J Jr, Dilger J, Yoon HJ. Effectiveness of bupivacaine administered via femoral nerve catheter for pain control after anterior cruciate ligament repair. J Clin Anesth 1997;9:542–5
150. Seet E, Leong WL, Yeo AS, Fook-Chong S. Effectiveness of 3-in-1 continuous femoral block of differing concentrations compared to patient controlled intravenous morphine for post total knee arthroplasty analgesia and knee rehabilitation. Anaesth Intensive Care 2006;34:25–30
151. Brodner G, Buerkle H, Van Aken H, Lambert R, Schweppe-Hartenauer ML, Wempe C, Gogarten W. Postoperative analgesia after knee surgery: a comparison of three different concentrations of ropivacaine for continuous femoral nerve blockade. Anesth Analg 2007;105:256–62
152. Fredrickson MJ, Price DJ. Analgesic effectiveness of ropivacaine 0.2% vs 0.4% via an ultrasound-guided C5-6 root/superior trunk perineural ambulatory catheter. Br J Anaesth 2009;103:434–9
153. Salonen MH, Haasio J, Bachmann M, Xu M, Rosenberg PH. Evaluation of efficacy and plasma concentrations of ropivacaine in continuous axillary brachial plexus block: high dose for surgical anesthesia and low dose for postoperative analgesia. Reg Anesth Pain Med 2000;25:47–51
154. Singelyn FJ, Vanderelst PE, Gouverneur JM. Extended femoral nerve sheath block after total hip arthroplasty: continuous versus patient-controlled techniques. Anesth Analg 2001;92:455–9
155. Pere P. The effect of continuous interscalene brachial plexus block with 0.125% bupivacaine plus fentanyl on diaphragmatic motility and ventilatory function. Reg Anesth 1993;18:93–7
156. Picard PR, Tramer MR, McQuay HJ, Moore RA. Analgesic efficacy of peripheral opioids (all except intra-articular): a qualitative systematic review of randomised controlled trials. Pain 1997;72:309–18
157. Murphy DB, McCartney CJ, Chan VW. Novel analgesic adjuncts for brachial plexus block: a systematic review. Anesth Analg 2000;90:1122–8
158. Singelyn FJ, Gouverneur JM. Extended "three-in-one" block after total knee arthroplasty: continuous versus patient-controlled techniques. Anesth Analg 2000;91:176–80
159. Singelyn FJ, Deyaert M, Joris D, Pendeville E, Gouverneur JM. Effects of intravenous patient-controlled analgesia with morphine, continuous epidural analgesia, and continuous three-in-one block on postoperative pain and knee rehabilitation after unilateral total knee arthroplasty. Anesth Analg 1998;87:88–92
160. Singelyn FJ, Aye F, Gouverneur JM. Continuous popliteal sciatic nerve block: an original technique to provide postoperative analgesia after foot surgery. Anesth Analg 1997;84:383–6
161. Capdevila X, Barthelet Y, Biboulet 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
162. Ilfeld BM, Morey TE, Enneking FK. Continuous infraclavicular perineural infusion with clonidine and ropivacaine compared with ropivacaine alone: a randomized, double-blinded, controlled study. Anesth Analg 2003;97:706–12

163. Casati A, Vinciguerra F, Cappelleri G, Aldegheri G, Fanelli G, Putzu M, Chelly JE. Adding clonidine to the induction bolus and postoperative infusion during continuous femoral nerve block delays recovery of motor function after total knee arthroplasty. Anesth Analg 2005;100:866–72
164. Weber A, Fournier R, Van Gessel E, Riand N, Gamulin Z. Epinephrine does not prolong the analgesia of 20 mL ropivacaine 0.5% or 0.2% in a femoral three-in-one block. Anesth Analg 2001;93:1327–31
165. Partridge BL. The effects of local anesthetics and epinephrine on rat sciatic nerve blood flow. Anesthesiology 1991;75: 243–50
166. Kaloul I, Guay J, Cote 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 Anaesth 2004;51:45–51
167. Serpell MG, Millar FA, Thomson MF. Comparison of lumbar plexus block versus conventional opioid analgesia after total knee replacement [see comments]. Anaesthesia 1991;46:275–7
168. Brummett CM, Norat MA, Palmisano JM, Lydic R. Perineural administration of dexmedetomidine in combination with bupivacaine enhances sensory and motor blockade in sciatic nerve block without inducing neurotoxicity in rat. Anesthesiology 2008;109:502–11
169. Esmaoglu A, Yegenoglu F, Akin A, Turk CY. Dexmedetomidine added to levobupivacaine prolongs axillary brachial plexus block. Anesth Analg 2010;111:1548–51
170. Ilfeld BM, Thannikary LJ, Morey TE, Vander Griend RA, Enneking FK. Popliteal sciatic perineural local anesthetic infusion: a comparison of three dosing regimens for postoperative analgesia. Anesthesiology 2004;101:970–7
171. di Benedetto P, Casati A, Bertini L. Continuous subgluteus sciatic nerve block after orthopedic foot and ankle surgery: comparison of two infusion techniques. Reg Anesth Pain Med 2002;27:168–72
172. Eledjam JJ, Cuvillon P, Capdevila X, Macaire P, Serri S, Gaertner E, Jochum D. Postoperative analgesia by femoral nerve block with ropivacaine 0.2% after major knee surgery: continuous versus patient-controlled techniques. Reg Anesth Pain Med 2002;27:604–11
173. Capdevila X, Dadure C, Bringuier S, Bernard N, Biboulet P, Gaertner E, Macaire P. Effect of patient-controlled perineural analgesia on rehabilitation and pain after ambulatory orthopedic surgery: a multicenter randomized trial. Anesthesiology 2006;105:566–73
174. Taboada M, Rodriguez J, Bermudez M, Valino C, Ulloa B, Aneiros F, Gude F, Cortes J, Alvarez J, Atanassoff PG. A "new" automated bolus technique for continuous popliteal block: a prospective, randomized comparison with a continuous infusion technique. Anesth Analg 2008;107:1433–7
175. Taboada M, Rodriguez J, Bermudez M, Amor M, Ulloa B, Aneiros F, Sebate S, Cortes J, Alvarez J, Atanassoff PG. Comparison of continuous infusion versus automated bolus for postoperative patient-controlled analgesia with popliteal sciatic nerve catheters. Anesthesiology 2009;110:150–4
176. 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
177. Ilfeld BM, Enneking FK. A portable mechanical pump providing over four days of patient-controlled analgesia by perineural infusion at home. Reg Anesth Pain Med 2002;27:100–4
178. Ilfeld BM, Vandenborne K, Duncan PW, Sessler DI, Enneking FK, Shuster JJ, Theriaque DW, Chmielewski TL, Spadoni EH, Wright TW. Ambulatory continuous interscalene nerve blocks decrease the time to discharge readiness after total shoulder arthroplasty: a randomized, triple-masked, placebo-controlled study. Anesthesiology 2006;105:999–1007
179. Ilfeld BM, Wright TW, Enneking FK, Morey TE. Joint range of motion after total shoulder arthroplasty with and without a continuous interscalene nerve block: a retrospective, case-control study. Reg Anesth Pain Med 2005;30:429–33
180. Fredrickson MJ, Abeysekera A, Price DJ, Wong AC. Patient-initiated mandatory boluses for ambulatory continuous interscalene analgesia: an effective strategy for optimizing analgesia and minimizing side-effects. Br J Anaesth 2011;106:239–45
181. Rosenberg PH, Veering BT, Urmey WF. Maximum recommended doses of local anesthetics: a multifactorial concept. Reg Anesth Pain Med 2004;29:564–75
182. Denson DD, Raj PP, Saldahna F, Finnsson RA, Ritschel WA, Joyce TH III, Turner JL. Continuous perineural infusion of bupivacaine for prolonged analgesia: pharmacokinetic considerations. Int J Clin Pharmacol Ther Toxicol 1983;21:591–7
183. Kaloul I, Guay J, Cote C, Halwagi A, Varin F. Ropivacaine plasma concentrations are similar during continuous lumbar plexus blockade using the anterior three-in-one and the posterior psoas compartment techniques. Can J Anaesth 2004;51:52–6
184. Pere P, Tuominen M, Rosenberg PH. Cumulation of bupivacaine, desbutylbupivacaine and 4-hydroxybupivacaine during and after continuous interscalene brachial plexus block. Acta Anaesthesiol Scand 1991;35:647–50
185. Tuominen M, Haasio J, Hekali R, Rosenberg PH. Continuous interscalene brachial plexus block: clinical efficacy, technical problems and bupivacaine plasma concentrations. Acta Anaesthesiol Scand 1989;33:84–8
186. Anker-Moller E, Spangsberg N, Dahl JB, Christensen EF, Schultz P, Carlsson P. Continuous blockade of the lumbar plexus after knee surgery: a comparison of the plasma concentrations and analgesic effect of bupivacaine 0.250% and 0.125%. Acta Anaesthesiol Scand 1990;34:468–72
187. Rosenberg PH, Pere P, Hekali R, Tuominen M. Plasma concentrations of bupivacaine and two of its metabolites during continuous interscalene brachial plexus block. Br J Anaesth 1991;66:25–30
188. Bleckner LL, Bina S, Kwon KH, McKnight G, Dragovich A, Buckenmaier CC III. Serum ropivacaine concentrations and systemic local anesthetic toxicity in trauma patients receiving long-term continuous peripheral nerve block catheters. Anesth Analg 2010;110:630–4
189. Paauwe JJ, Thomassen BJ, Weterings J, van Rossum E, Ausems ME. Femoral nerve block using ropivacaine 0.025%, 0.05% and 0.1%: effects on the rehabilitation programme following total knee arthroplasty—a pilot study. Anaesthesia 2008;63:948–53
190. Ilfeld BM, Morey TE. Use of term "patient-controlled" may be confusing in study of elastometric pump. Anesth Analg 2003;97:916–7
191. Ilfeld BM, Enneking FK. Continuous peripheral nerve blocks at home: a review. Anesth Analg 2005;100:1822–33
192. Ilfeld BM, Morey TE, Enneking FK. The delivery rate accuracy of portable infusion pumps used for continuous regional analgesia. Anesth Analg 2002;95:1331–6
193. Ilfeld BM, Morey TE, Enneking FK. Portable infusion pumps used for continuous regional analgesia: delivery rate accuracy and consistency. Reg Anesth Pain Med 2003;28:424–32
194. Ilfeld BM, Morey TE, Enneking FK. Delivery rate accuracy of portable, bolus-capable infusion pumps used for patient-controlled continuous regional analgesia. Reg Anesth Pain Med 2003;28:17–23
195. Ilfeld BM, Morey TE, Enneking FK. New portable infusion pumps: real advantages or just more of the same in a different package? Reg Anesth Pain Med 2004;29:371–6
196. Valente M, Aldrete JA. Comparison of accuracy and cost of disposable, nonmechanical pumps used for epidural infusions. Reg Anesth 1997;22:260–6
197. Ganapathy S, Amendola A, Lichfield R, Fowler PJ, Ling E. Elastomeric pumps for ambulatory patient controlled regional analgesia. Can J Anaesth 2000;47:897–902
198. Ackermann M, Maier S, Ing H, Bonnabry P. Evaluation of the design and reliability of three elastomeric and one mechanical infusers. J Oncol Pharm Pract 2007;13:77–84
199. Grant CR, Fredrickson MJ. Regional anaesthesia elastomeric pump performance after a single use and subsequent refill: a laboratory study. Anaesthesia 2009;64:770–5

200. Borghi B, D'Addabbo M, White PF, Gallerani P, Toccaceli L, Raffaeli W, Tognu A, Fabbri N, Mercuri M. The use of prolonged peripheral neural blockade after lower extremity amputation: the effect on symptoms associated with phantom limb syndrome. Anesth Analg 2010;111:1308–15
201. Rich DS. Evaluation of a disposable, elastomeric infusion device in the home environment. Am J Hosp Pharm 1992;49: 1712–6
202. Ilfeld BM, Wright TW, Enneking FK, Mace JA, Shuster JJ, Spadoni EH, Chmielewski TL, Vandenborne K. Total shoulder arthroplasty as an outpatient procedure using ambulatory perineural local anesthetic infusion: a pilot feasibility study. Anesth Analg 2005;101:1319–22
203. Ilfeld BM, Wright TW, Enneking FK, Vandenborne K. Total elbow arthroplasty as an outpatient procedure using a continuous infraclavicular nerve block at home: a prospective case report. Reg Anesth Pain Med 2006;31:172–6
204. Head S, Enneking FK. Infusate contamination in regional anesthesia: what every anesthesiologist should know. Anesth Analg 2008;107:1412–8
205. Ilfeld BM, Esener DE, Morey TE, Enneking FK. Ambulatory perineural infusion: the patients' perspective. Reg Anesth Pain Med 2003;28:418–23
206. Zahnd D, Aebi S, Rusterholz S, Fey MF, Borner MM. A randomized crossover trial assessing patient preference for two different types of portable infusion-pump devices. Ann Oncol 1999;10:727–9
207. Capdevila X, Macaire P, Aknin P, Dadure C, Bernard N, Lopez S. Patient-controlled perineural analgesia after ambulatory orthopedic surgery: a comparison of electronic versus elastomeric pumps. Anesth Analg 2003;96:414–7
208. Remerand F, Vuitton AS, Palud M, Buchet S, Pourrat X, Baud A, Laffon M, Fusciardi J. Elastomeric pump reliability in postoperative regional anesthesia: a survey of 430 consecutive devices. Anesth Analg 2008;107:2079–84
209. Schleis TG, Tice AD. Selecting infusion devices for use in ambulatory care. Am J Health Syst Pharm 1996;53:868–77
210. Sawaki Y, Parker RK, White PF. Patient and nurse evaluation of patient-controlled analgesia delivery systems for postoperative pain management. J Pain Symptom Manage 1992;7: 443–53
211. Baxter Healthcare infusion pump recall. FDA Consum 2005; 39:3
212. FDA and Baxter announce details of colleague infusion pump recall. Health Devices 2010;39:294–5
213. Ilfeld BM, Mariano ER, Madison SJ, Loland VJ, Sandhu NS, Suresh PJ, Bishop ML, Kim TE, Donohue MC, Kulidjian AA, Ball ST. Continuous femoral versus posterior lumbar plexus nerve blocks for analgesia following hip arthroplasty: a randomized, controlled study. Anesth Analg (in press)
214. Rawal N, Hylander J, Nydahl PA, Olofsson I, Gupta A. Survey of postoperative analgesia following ambulatory surgery. Acta Anaesthesiol Scand 1997;41:1017–22
215. White PF, Issioui T, Skrivanek GD, Early JS, Wakefield C. The use of a continuous popliteal sciatic nerve block after surgery involving the foot and ankle: does it improve the quality of recovery? Anesth Analg 2003;97:1303–9
216. Mariano ER, Loland VJ, Ilfeld BM. Interscalene perineural catheter placement using an ultrasound-guided posterior approach. Reg Anesth Pain Med 2009;34:60–3
217. Borgeat A, Perschak H, Bird P, Hodler J, Gerber C. Patient-controlled interscalene analgesia with ropivacaine 0.2% versus patient-controlled intravenous analgesia after major shoulder surgery: effects on diaphragmatic and respiratory function. Anesthesiology 2000;92:102–8
218. Renes SH, van Geffen GJ, Rettig HC, Gielen MJ, Scheffer GJ. Minimum effective volume of local anesthetic for shoulder analgesia by ultrasound-guided block at root C7 with assessment of pulmonary function. Reg Anesth Pain Med 2010;35: 529–34
219. Renes SH, van Geffen GJ, Snoeren MM, Gielen MJ, Groen GJ. Ipsilateral brachial plexus block and hemidiaphragmatic paresis as adverse effect of a high thoracic paravertebral block. Reg Anesth Pain Med 2011;36:198–201
220. Smith MP, Tetzlaff JE, Brems JJ. Asymptomatic profound oxyhemoglobin desaturation following interscalene block in a geriatric patient. Reg Anesth Pain Med 1998;23:210–3
221. Sardesai AM, Chakrabarti AJ, Denny NM. Lower lobe collapse during continuous interscalene brachial plexus local anesthesia at home. Reg Anesth Pain Med 2004;29:65–8
222. 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;150:477–84
223. Ilfeld BM, Mariano ER, Williams BA, Woodard JN, 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
224. Ilfeld BM, Gearen PF, Enneking FK, Berry LF, Spadoni EH, George SZ, Vandenborne K. Total knee arthroplasty as an overnight-stay procedure using continuous femoral nerve blocks at home: a prospective feasibility study. Anesth Analg 2006;102:87–90
225. Ilfeld BM, Gearen PF, Enneking FK, Berry LF, Spadoni EH, George SZ, Vandenborne K. Total hip arthroplasty as an overnight-stay procedure using an ambulatory continuous psoas compartment nerve block: a prospective feasibility study. Reg Anesth Pain Med 2006;31:113–8
226. Zaric D, Boysen K, Christiansen J, Haastrup U, Kofoed H, Rawal N. Continuous popliteal sciatic nerve block for outpatient foot surgery: a randomized, controlled trial. Acta Anaesthesiol Scand 2004;48:337–41
227. Ilfeld BM, Morey TE, Enneking FK. Continuous infraclavicular brachial plexus block for postoperative pain control at home: a randomized, double-blinded, placebo-controlled study. Anesthesiology 2002;96:1297–304
228. Macaire P, Gaertner E, Capdevila X. Continuous postoperative regional analgesia at home. Minerva Anestesiol 2001;67:109–16
229. Russon K, Sardesai AM, Ridgway S, Whitear J, Sildown D, Boswell S, Chakrabarti A, Denny NM. Postoperative shoulder surgery initiative (POSSI): an interim report of major shoulder surgery as a day case procedure. Br J Anaesth 2006;97:869–73
230. Klein SM, Grant SA, Greengrass RA, Nielsen KC, Speer KP, White W, Warner DS, Steele SM. Interscalene brachial plexus block with a continuous catheter insertion system and a disposable infusion pump. Anesth Analg 2000;91:1473–8
231. Mariano ER, Sandhu NS, Loland VJ, Bishop ML, Madison SJ, Abrams RA, Meunier MJ, Ferguson EJ, Ilfeld BM. A randomized comparison of infraclavicular and supraclavicular continuous peripheral nerve blocks for postoperative analgesia. Reg Anesth Pain Med 2011;36:26–31
232. Cornish PB. Supraclavicular regional anaesthesia revisited: the bent needle technique. Anaesth Intensive Care 2000;28: 676–9
233. Cornish PB, Leaper CJ, Nelson G, Anstis F, McQuillan C, Stienstra R. Avoidance of phrenic nerve paresis during continuous supraclavicular regional anaesthesia. Anaesthesia 2007;62:354–8
234. Heil JW, Ilfeld BM, Loland VJ, Sandhu NS, Mariano ER. Ultrasound-guided transversus abdominis plane catheters and ambulatory perineural infusions for outpatient inguinal hernia repair. Reg Anesth Pain Med 2010;35:556–8
235. Pham DC, Gautheron E, Guilley J, Fernandez M, Waast D, Volteau C, Nguyen JM, Pinaud M. The value of adding sciatic block to continuous femoral block for analgesia after total knee replacement. Reg Anesth Pain Med 2005;30:128–33
236. Ben David B, Schmalenberger K, Chelly JE. Analgesia after total knee arthroplasty: is continuous sciatic blockade needed in addition to continuous femoral blockade? Anesth Analg 2004;98:747–9

237. Mistraletti G, De La Cuadra-Fontaine JC, Asenjo FJ, Donatelli F, Wykes L, Schricker T, Carli F. Comparison of analgesic methods for total knee arthroplasty: metabolic effect of exogenous glucose. Reg Anesth Pain Med 2006;31:260–9
238. Bagry H, de la Cuadra Fontaine JC, Asenjo JF, Bracco D, Carli F. Effect of a continuous peripheral nerve block on the inflammatory response in knee arthroplasty. Reg Anesth Pain Med 2008;33:17–23
239. 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 (psoas compartment) block, a continuous femoral nerve block, and the combination of a continuous femoral and sciatic nerve block. Reg Anesth Pain Med 2005;30:434–45
240. Blumenthal S, Borgeat A, Neudorfer C, Bertolini R, Espinosa N, Aguirre J. Additional femoral catheter in combination with popliteal catheter for analgesia after major ankle surgery. Br J Anaesth 2011;106:387–93
241. Fowler SJ, Symons J, Sabato S, Myles PS. Epidural analgesia compared with peripheral nerve blockade after major knee surgery: a systematic review and meta-analysis of randomized trials. Br J Anaesth 2008;100:154–64
242. Singelyn FJ, Ferrant T, Malisse MF, Joris D. Effects of intravenous patient-controlled analgesia with morphine, continuous epidural analgesia, and continuous femoral nerve sheath block on rehabilitation after unilateral total-hip arthroplasty. Reg Anesth Pain Med 2005;30:452–7
243. 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;102:1234–9
244. Carli F, Clemente A, Asenjo JF, Kim DJ, Mistraletti G, Gomarasca M, Morabito A, Tanzer M. Analgesia and functional outcome after total knee arthroplasty: periarticular infiltration vs continuous femoral nerve block. Br J Anaesth 2010;105:185–95
245. Ilfeld BM, Ball ST, Gearen PF, Mariano ER, Le LT, Vandenborne K, Duncan PW, Sessler DI, Enneking FK, Shuster JJ, Maldonado RC, Meyer RS. Health-related quality of life after hip arthroplasty with and without an extended-duration continuous posterior lumbar plexus nerve block: a prospective, 1-year follow-up of a randomized, triple-masked, placebo-controlled study. Anesth Analg 2009;109:586–91
246. Ilfeld BM, Meyer RS, Le LT, Mariano ER, Williams BA, Vandenborne K, Duncan PW, Sessler DI, Enneking FK, Shuster JJ, Maldonado RC, Gearen PF. Health-related quality of life after tricompartment knee arthroplasty with and without an extended-duration continuous femoral nerve block: a prospective, 1-year follow-up of a randomized, triple-masked, placebo-controlled study. Anesth Analg 2009;108:1320–5
247. Ilfeld BM, Shuster JJ, Theriaque DW, Mariano ER, Girard PJ, Loland VJ, Meyer S, Donovan JF, Pugh GA, Le LT, Sessler DI, Ball ST. Long-term pain, stiffness, and functional disability after total knee arthroplasty with and without an extended ambulatory continuous femoral nerve block: a prospective, 1-year follow-up of a multicenter, randomized, triple-masked, placebo-controlled trial. Reg Anesth Pain Med 2011;36:116–20
248. Kadic L, Boonstra MC, De Waal MC, Lako SJ, Van Egmond J, Driessen JJ. Continuous femoral nerve block after total knee arthroplasty? Acta Anaesthesiol Scand 2009;53:914–20
249. Williams BA, Dang Q, Bost JE, Irrgang JJ, Orebaugh SL, Bottegal MT, Kentor ML. General health and knee function outcomes from 7 days to 12 weeks after spinal anesthesia and multimodal analgesia for anterior cruciate ligament reconstruction. Anesth Analg 2009;108:1296–302
250. Shum CF, Lo NN, Yeo SJ, Yang KY, Chong HC, Yeo SN. Continuous femoral nerve block in total knee arthroplasty: immediate and two-year outcomes. J Arthroplasty 2009;24: 204–9
251. Borgeat A, Ekatodramis G, Kalberer F, Benz C. Acute and nonacute complications associated with interscalene block and shoulder surgery: a prospective study. Anesthesiology 2001;95:875–80
252. Neuburger M, Breitbarth J, Reisig F, Lang D, Buttner J. Complications and adverse events in continuous peripheral regional anesthesia: results of investigations on 3,491 catheters [in German]. Anaesthesist 2006;55:33–40
253. Cook LB. Unsuspected extradural catheterization in an interscalene block. Br J Anaesth 1991;67:473–5
254. Mahoudeau G, Gaertner E, Launoy A, Ocquidant P, Loewenthal A. Interscalenic block: accidental catheterization of the epidural space [in French]. Ann Fr Anesth Reanim 1995;14: 438–41
255. Faust A, Fournier R, Hagon O, Hoffmeyer P, Gamulin Z. Partial sensory and motor deficit of ipsilateral lower limb after continuous interscalene brachial plexus block. Anesth Analg 2006;102:288–90
256. Litz RJ, Vicent O, Wiessner D, Heller AR. Misplacement of a psoas compartment catheter in the subarachnoid space. Reg Anesth Pain Med 2004;29:60–4
257. Pousman RM, Mansoor Z, Sciard D. Total spinal anesthetic after continuous posterior lumbar plexus block. Anesthesiology 2003;98:1281–2
258. Lekhak B, Bartley C, Conacher ID, Nouraei SM. Total spinal anaesthesia in association with insertion of a paravertebral catheter. Br J Anaesth 2001;86:280–2
259. Tuominen MK, Pere P, Rosenberg PH. Unintentional arterial catheterization and bupivacaine toxicity associated with continuous interscalene brachial plexus block. Anesthesiology 1991;75:356–8
260. Rodriguez J, Taboada M, Blanco M, Oliveira J, Barcena M, Alvarez J. Intraneural catheterization of the sciatic nerve in humans: a pilot study. Reg Anesth Pain Med 2008;33:285–90
261. Souron V, Reiland Y, De Traverse A, Delaunay L, Lafosse L. Interpleural migration of an interscalene catheter. Anesth Analg 2003;97:1200–1
262. Jenkins CR, Karmakar MK. An unusual complication of interscalene brachial plexus catheterization: delayed catheter migration. Br J Anaesth 2005;95:535–7
263. Harrop-Griffiths W, Denny N. Migration of interscalene catheter: not proven. Br J Anaesth 2006;96:266–7
264. Ekatodramis G, Borgeat A. Subcutaneous tunneling of the interscalene catheter. Can J Anaesth 2000;47:716–7
265. Klein SM, Nielsen KC, Buckenmaier CC III, Kamal AS, Rubin Y, Steele SM. 2-Octyl cyanoacrylate glue for the fixation of continuous peripheral nerve catheters. Anesthesiology 2003;98: 590–1
266. Capdevila X, Pirat P, Bringuier S, Gaertner E, Singelyn F, Bernard N, Choquet O, Bouaziz H, Bonnet F. Continuous peripheral nerve blocks in hospital wards after orthopedic surgery: a multicenter prospective analysis of the quality of postoperative analgesia and complications in 1,416 patients. Anesthesiology 2005;103:1035–45
267. Williams BA, Bolland MA, Orebaugh SL, Bottegal MT, Kentor ML. Skin reactions at the femoral perineural catheter insertion site: retrospective summary of a randomized clinical trial. Anesth Analg 2007;104:1309–10
268. Ribeiro FC, Georgousis H, Bertram R, Scheiber G. Plexus irritation caused by interscalene brachial plexus catheter for shoulder surgery. Anesth Analg 1996;82:870–2
269. Klein SM, Eck J, Nielsen K, Steele SM. Anesthetizing the phantom: peripheral nerve stimulation of a nonexistent extremity. Anesthesiology 2004;100:736–7
270. Hogan Q, Dotson R, Erickson S, Kettler R, Hogan K. Local anesthetic myotoxicity: a case and review. Anesthesiology 1994;80:942–7
271. Dhir S, Ganapathy S, Lindsay P, Athwal GS. Case report: ropivacaine neurotoxicity at clinical doses in interscalene brachial plexus block. Can J Anaesth 2007;54:912–6
272. Compere V, Rey N, Baert O, Ouennich A, Fourdrinier V, Roussignol X, Beccari R, Dureuil B. Major complications after 400 continuous popliteal sciatic nerve blocks for postoperative analgesia. Acta Anaesthesiol Scand 2009;53:339–45
273. Ekatodramis G, Macaire P, Borgeat A. Prolonged Horner syndrome due to neck hematoma after continuous interscalene block. Anesthesiology 2001;95:801–3

274. Motamed C, Bouaziz H, Mercier FJ, Benhamou D. Knotting of a femoral catheter. Reg Anesth 1997;22:486–7
275. Buckenmaier CC III, Auton AA, Flournoy WS. Continuous peripheral nerve block catheter tip adhesion in a rat model. Acta Anaesthesiol Scand 2006;50:694–8
276. 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;104:1578–82
277. Lee BH, Goucke CR. Shearing of a peripheral nerve catheter. Anesth Analg 2002;95:760–1
278. Chin KJ, Chee V. Perforation of a Pajunk stimulating catheter after traction-induced damage. Reg Anesth Pain Med 2006;31: 389–90
279. Pere P, Pitkanen M, Rosenberg PH, Bjorkenheim JM, Linden H, Salorinne Y, Tuominen M. Effect of continuous interscalene brachial plexus block on diaphragm motion and on ventilatory function. Acta Anaesthesiol Scand 1992;36:53–7
280. Williams BA, Murinson BB. Diabetes mellitus and subclinical neuropathy: a call for new paths in peripheral nerve block research. Anesthesiology 2008;109:361–2
281. Horlocker TT, O'Driscoll SW, Dinapoli RP. Recurring brachial plexus neuropathy in a diabetic patient after shoulder surgery and continuous interscalene block. Anesth Analg 2000;91:688–90
282. Blumenthal S, Borgeat A, Maurer K, Beck-Schimmer B, Kliesch U, Marquardt M, Urech J. Preexisting subclinical neuropathy as a risk factor for nerve injury after continuous ropivacaine administration through a femoral nerve catheter. Anesthesiology 2006;105:1053–6
283. Johr M. A complication of continuous blockade of the femoral nerve [in German]. Reg Anaesth 1987;10:37–8
284. Weller RS, Gerancher JC, Crews JC, Wade KL. Extensive retroperitoneal hematoma without neurologic deficit in two patients who underwent lumbar plexus block and were later anticoagulated. Anesthesiology 2003;98:581–5
285. Klein SM, D'Ercole F, Greengrass RA, Warner DS. Enoxaparin associated with psoas hematoma and lumbar plexopathy after lumbar plexus block. Anesthesiology 1997;87:1576–9
286. Bickler P, Brandes J, Lee M, Bozic K, Chesbro B, Claassen J. Bleeding complications from femoral and sciatic nerve catheters in patients receiving low molecular weight heparin. Anesth Analg 2006;103:1036–7
287. Horlocker TT, Wedel DJ, Rowlingson JC, Enneking FK, Kopp SL, Benzon HT, Brown DL, Heit JA, Mulroy MF, Rosenquist RW, Tryba M, Yuan CS. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American Society of Regional Anesthesia and Pain Medicine Evidence-Based Guidelines (Third Edition). Reg Anesth Pain Med 2010;35:64–101
288. Chelly JE, Greger JR, Casati A, Gebhard R, Ben David B. What has happened to evidence-based medicine? Anesthesiology 2003;99:1028–9
289. Chelly JE. The most recent recommendations for "deep blocks" and thromboprophylaxis: evidence not supporting a "thromboprophylaxis therapeutic window." Reg Anesth Pain Med 2010;35:402–3
290. Chelly JE, Schilling D. Thromboprophylaxis and peripheral nerve blocks in patients undergoing joint arthroplasty. J Arthroplasty 2008;23:350–4
291. Chelly JE, Szczodry DM, Neumann KJ. International normalized ratio and prothrombin time values before the removal of a lumbar plexus catheter in patients receiving warfarin after total hip replacement. Br J Anaesth 2008;101:250–4
292. Ben David B, Chelly JE. Peripheral nerve block catheters and low molecular weight heparin. Anesth Analg 2007;104:990–1
293. Chelly JE. Do we really need an interval between administering fondaparinux and removing a lumbar plexus catheter? Anesth Analg 2009;108:670–1
294. Muraskin SI, Conrad B, Zheng N, Morey TE, Enneking FK. Falls associated with lower-extremity-nerve blocks: a pilot investigation of mechanisms. Reg Anesth Pain Med 2007;32: 67–72
295. Borgeat A, Capdevila X. Neurostimulation/ultrasonography: the Trojan war will not take place. Anesthesiology 2007;106: 896–8
296. Compere V, Legrand JF, Guitard PG, Azougagh K, Baert O, Ouennich A, Fourdrinier V, Frebourg N, Dureuil B. Bacterial colonization after tunneling in 402 perineural catheters: a prospective study. Anesth Analg 2009;108:1326–30
297. Cuvillon P, Ripart J, Lalourcey L, Veyrat E, L'Hermite J, Boisson C, Thouabtia E, Eledjam JJ. The continuous femoral nerve block catheter for postoperative analgesia: bacterial colonization, infectious rate and adverse effects. Anesth Analg 2001;93:1045–9
298. Capdevila X, Bringuier S, Borgeat A. Infectious risk of continuous peripheral nerve blocks. Anesthesiology 2009;110:182–8
299. Neuburger M, Buttner J, Blumenthal S, Breitbarth J, Borgeat A. Inflammation and infection complications of 2285 perineural catheters: a prospective study. Acta Anaesthesiol Scand 2007;51:108–14
300. Borgeat A, Blumenthal S, Karovic D, Delbos A, Vienne P. Clinical evaluation of a modified posterior anatomical approach to performing the popliteal block. Reg Anesth Pain Med 2004;29:290–6
301. Tucker CJ, Kirk KL, Ficke JR. Posterior thigh abscess as a complication of continuous popliteal nerve catheter. Am J Orthop (Belle Mead NJ) 2010;39:E25–7
302. Neuburger M, Lang D, Buttner J. Abscess of the psoas muscle caused by a psoas compartment catheter: case report of a rare complication of peripheral catheter regional anaesthesia [in German]. Anaesthesist 2005;54:341–5
303. Compere V, Cornet C, Fourdrinier V, Maitre AM, Mazirt N, Biga N, Dureuil B. Thigh abscess as a complication of continuous popliteal sciatic nerve block. Br J Anaesth 2005;95: 255–6
304. Adam F, Jaziri S, Chauvin M. Psoas abscess complicating femoral nerve block catheter. Anesthesiology 2003;99:230–1
305. Capdevila X, Jaber S, Pesonen P, Borgeat A, Eledjam JJ. Acute neck cellulitis and mediastinitis complicating a continuous interscalene block. Anesth Analg 2008;107:1419–21
306. Clendenen SR, Robards CB, Wang RD, Greengrass RA. Case report: continuous interscalene block associated with neck hematoma and postoperative sepsis. Anesth Analg 2010;110: 1236–8
307. Hogan QH. Pathophysiology of peripheral nerve injury during regional anesthesia. Reg Anesth Pain Med 2008;33:435–41
308. Casati A, Chelly JE. Neurological complications after interscalene brachial plexus blockade: what to make of it? Anesthesiology 2002;97:279–80
309. Wirth MA, Rockwood CA Jr. Complications of shoulder arthroplasty. Clin Orthop Relat Res 1994;307:47–69
310. Simmons C Jr, Izant TH, Rothman RH, Booth RE Jr, Balderston RA. Femoral neuropathy following total hip arthroplasty: anatomic study, case reports, and literature review. J Arthroplasty 1991;6:S57–66
311. Dullenkopf A, Zingg P, Curt A, Borgeat A. Persistent neurological deficit of the upper extremity after a shoulder operation under general anesthesia combined with a preoperatively placed interscalene catheter [in German]. Anaesthesist 2002;51: 547–51
312. Swenson JD, Davis JJ. Ultrasound-guided regional anesthesia: why can't we all just stay away from the nerve? Anesthesiology 2008;109:748–9
313. Neal JM. Ultrasound-guided regional anesthesia and patient safety: an evidence-based analysis. Reg Anesth Pain Med 2010;35:S59–67
314. Hebl JR. Ultrasound-guided regional anesthesia and the prevention of neurologic injury: fact or fiction? Anesthesiology 2008;108:186–8
315. Neal JM, Wedel DJ. Ultrasound guidance and peripheral nerve injury: is our vision as sharp as we think it is? Reg Anesth Pain Med 2010;35:335–7
316. Reiss W, Kurapati S, Shariat A, Hadzic A. Nerve injury complicating ultrasound/electrostimulation-guided supraclavicular brachial plexus block. Reg Anesth Pain Med 2010;35:400–1

317. Cohen JM, Gray AT. Functional deficits after intraneural injection during interscalene block. Reg Anesth Pain Med 2010;35:397–9
318. Dauri M, Polzoni M, Fabbi E, Sidiropoulou T, Servetti S, Coniglione F, Mariani P, Sabato AF. Comparison of epidural, continuous femoral block and intraarticular analgesia after anterior cruciate ligament reconstruction. Acta Anaesthesiol Scand 2003;47:20–5
319. Delaunay L, Souron V, Lafosse L, Marret E, Toussaint B. Analgesia after arthroscopic rotator cuff repair: subacromial versus interscalene continuous infusion of ropivacaine. Reg Anesth Pain Med 2005;30:117–22
320. Tran KM, Ganley TJ, Wells L, Ganesh A, Minger KI, Cucchiaro G. Intraarticular bupivacaine-clonidine-morphine versus femoral-sciatic nerve block in pediatric patients undergoing anterior cruciate ligament reconstruction. Anesth Analg 2005; 101:1304–10
321. Klein SM, Steele SM, Nielsen KC, Pietrobon R, Warner DS, Martin A, Greengrass RA. The difficulties of ambulatory interscalene and intra-articular infusions for rotator cuff surgery: a preliminary report. Can J Anaesth 2003;50:265–9
322. Johnson CB, Steele-Moses SK. The use of continuous femoral nerve blocks versus extended release epidural morphine: a study comparing outcomes in total knee arthroplasty procedures. Orthopaedic Nurs 2011;30:44–53
323. Kehlet H, Andersen LO. Local infiltration analgesia in joint replacement: the evidence and recommendations for clinical practice. Acta Anaesthesiol Scand 2011;55:778–84
324. Kumar A, Banerjee A. Continuous maxillary and mandibular nerve block for perioperative pain relief: the excision of a complicated pleomorphic adenoma. Anesth Analg 2005;101:1531–2
325. Singh B, Bhardwaj V. Continuous mandibular nerve block for pain relief: a report of two cases. Can J Anaesth 2002;49:951–3
326. Borgeat A, Schappi B, Biasca N, Gerber C. Patient-controlled analgesia after major shoulder surgery: patient-controlled interscalene analgesia versus patient-controlled analgesia. Anesthesiology 1997;87:1343–7
327. Borgeat A, Tewes E, Biasca N, Gerber C. Patient-controlled interscalene analgesia with ropivacaine after major shoulder surgery: PCIA vs PCA. Br J Anaesth 1998;81:603–5
328. Kean J, Wigderowitz CA, Coventry DM. Continuous interscalene infusion and single injection using levobupivacaine for analgesia after surgery of the shoulder: a double-blind, randomised controlled trial. J Bone Joint Surg Br 2006;88:1173–7
329. Fredrickson MJ, Ball CM, Dalgleish AJ. Analgesic effectiveness of a continuous versus single-injection interscalene block for minor arthroscopic shoulder surgery. Reg Anesth Pain Med 2010;35:28–33
330. Lehtipalo S, Koskinen LO, Johansson G, Kolmodin J, Biber B. Continuous interscalene brachial plexus block for postoperative analgesia following shoulder surgery. Acta Anaesthesiol Scand 1999;43:258–64
331. Hofmann-Kiefer K, Eiser T, Chappell D, Leuschner S, Conzen P, Schwender D. Does patient-controlled continuous interscalene block improve early functional rehabilitation after open shoulder surgery? Anesth Analg 2008;106:991–6
332. Boezaart AP, de Beer JF, Nell ML. Early experience with continuous cervical paravertebral block using a stimulating catheter. Reg Anesth Pain Med 2003;28:406–13
333. Pham-Dang C, Gunst JP, Gouin F, Poirier P, Touchais S, Meunier JF, Kick O, Drouet JC, Bourreli B, Pinaud M. A novel supraclavicular approach to brachial plexus block. Anesth Analg 1997;85:111–6
334. Meier G, Bauereis C, Maurer H. The modified technique of continuous suprascapular nerve block: a safe technique in the treatment of shoulder pain [in German]. Anaesthesist 2002;51: 747–53
335. Matsuda M, Kato N, Hosoi M. Continuous brachial plexus block for replantation in the upper extremity. Hand 1982;14:129–34
336. Bhatia A, Lai J, Chan VW, Brull R. Case report: pneumothorax as a complication of the ultrasound-guided supraclavicular approach for brachial plexus block. Anesth Analg 2010;111:817–9
337. Taras JS, Behrman MJ. Continuous peripheral nerve block in replantation and revascularization. J Reconstr Microsurg 1998;14:17–21
338. Buckenmaier CC III, Kwon KH, Howard RS, McKnight GM, Shriver CD, Fritz WT, Garguilo GA, Joltes KH, Stojadinovic A. Double-blinded, placebo-controlled, prospective randomized trial evaluating the efficacy of paravertebral block with and without continuous paravertebral block analgesia in outpatient breast cancer surgery. Pain Med 2010;11:790–9
339. Pintaric TS, Potocnik I, Hadzic A, Stupnik T, Pintaric M, Jankovic VN. Comparison of continuous thoracic epidural with paravertebral block on perioperative analgesia and hemodynamic stability in patients having open lung surgery. Reg Anesth Pain Med 2011;36:256–60
340. Burns DA, Ben David B, Chelly JE, Greensmith JE. Intercostally placed paravertebral catheterization: an alternative approach to continuous paravertebral blockade. Anesth Analg 2008;107:339–41
341. Ben Ari A, Moreno M, Chelly JE, Bigeleisen PE. Ultrasound-guided paravertebral block using an intercostal approach. Anesth Analg 2009;109:1691–4
342. Gucev G, Yasui GM, Chang TY, Lee J. Bilateral ultrasound-guided continuous ilioinguinal-iliohypogastric block for pain relief after cesarean delivery. Anesth Analg 2008;106:1220–2
343. Allcock E, Spencer E, Frazer R, Applegate G, Buckenmaier C III. Continuous transversus abdominis plane (TAP) block catheters in a combat surgical environment. Pain Med 2010;11: 1426–9
344. Hebbard PD, Barrington MJ, Vasey C. Ultrasound-guided continuous oblique subcostal transversus abdominis plane blockade: description of anatomy and clinical technique. Reg Anesth Pain Med 2010;35:436–41
345. Jankovic ZB, Pollard SG, Nachiappan MM. Continuous transversus abdominis plane block for renal transplant recipients. Anesth Analg 2009;109:1710–1
346. Marino J, Russo J, Kenny M, Herenstein R, Livote E, Chelly JE. Continuous lumbar plexus block for postoperative pain control after total hip arthroplasty: a randomized controlled trial. J Bone Joint Surg Am 2009;91:29–37
347. Turker G, Uckunkaya N, Yavascaoglu B, Yilmazlar A, Ozcelik S. Comparison of the catheter-technique psoas compartment block and the epidural block for analgesia in partial hip replacement surgery. Acta Anaesthesiol Scand 2003;47:30–6
348. Siddiqui ZI, Cepeda MS, Denman W, Schumann R, Carr DB. Continuous lumbar plexus block provides improved analgesia with fewer side effects compared with systemic opioids after hip arthroplasty: a randomized controlled trial. Reg Anesth Pain Med 2007;32:393–8
349. Griffith JP, Whiteley S, Gough MJ. Prospective randomized study of a new method of providing postoperative pain relief following femoropopliteal bypass. Br J Surg 1996;83:1735–8
350. Spansberg NL, Anker-Moller E, Dahl JB, Schultz P, Christensen EF. The value of continuous blockade of the lumbar plexus as an adjunct to acetylsalicyclic acid for pain relief after surgery for femoral neck fractures. Eur J Anaesthesiol 1996;13: 410–2
351. Gaertner E, Lascurain P, Venet C, Maschino X, Zamfir A, Lupescu R, Hadzic A. Continuous parasacral sciatic block: a radiographic study. Anesth Analg 2004;98:831–4
352. 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;30:541–7
353. Capdevila X, Biboulet P, Bouregba M, Barthelet Y, Rubenovitch J, d'Athis F. Comparison of the three-in-one and fascia iliaca compartment blocks in adults: clinical and radiographic analysis. Anesth Analg 1998;86:1039–44
354. Morau D, Lopez S, Biboulet P, Bernard N, Amar J, Capdevila X. Comparison of continuous 3-in-1 and fascia iliaca compartment blocks for postoperative analgesia: feasibility, catheter migration, distribution of sensory block, and analgesic efficacy. Reg Anesth Pain Med 2003;28:309–14

355. Edwards ND, Wright EM. Continuous low-dose 3-in-1 nerve blockade for postoperative pain relief after total knee replacement. Anesth Analg 1992;75:265–7
356. Hirst GC, Lang SA, Dust WN, Cassidy JD, Yip RW. Femoral nerve block: single injection versus continuous infusion for total knee arthroplasty. Reg Anesth 1996;21:292–7
357. Long WT, Ward SR, Dorr LD, Raya J, Boutary M, Sirianni LE. Postoperative pain management following total knee arthroplasty: a randomized comparison of continuous epidural versus femoral nerve infusion. J Knee Surg 2006;19:137–43
358. Lako SJ, Steegers MA, van Egmond J, Gardeniers J, Staals LM, van Geffen GJ. Incisional continuous fascia iliaca block provides more effective pain relief and fewer side effects than opioids after pelvic osteotomy in children. Anesth Analg 2009;109:1799–803
359. Cuignet O, Pirson J, Boughrouph J, Duville D. The efficacy of continuous fascia iliaca compartment block for pain management in burn patients undergoing skin grafting procedures. Anesth Analg 2004;98:1077–81
360. Morris GF, Lang SA. Continuous parasacral sciatic nerve block: two case reports. Reg Anesth 1997;22:469–72
361. di Benedetto P, Casati A, Bertini L, Fanelli G, Chelly JE. Postoperative analgesia with continuous sciatic nerve block after foot surgery: a prospective, randomized comparison between the popliteal and subgluteal approaches. Anesth Analg 2002;94:996–1000
362. Taboada M, Rodriguez J, Valino C, Vazquez M, Laya A, Garea M, Carceller J, Alvarez J, Atanassoff V, Atanassoff PG. A prospective, randomized comparison between the popliteal and subgluteal approaches for continuous sciatic nerve block with stimulating catheters. Anesth Analg 2006;103:244–7
363. Robards C, Wang RD, Clendenen S, Ladlie B, Greengrass R. Sciatic nerve catheter placement: success with using the Raj approach. Anesth Analg 2009;109:972–5
364. Larrabure P, Pandin P, Vancutsem N, Vandesteene A. Tibial nerve block: evaluation of a novel midleg approach in 241 patients. Can J Anaesth 2005;52:276–80

Tripping Over Perineural Catheters

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Continuous peripheral nerve blockade (CPNB) is a technique that promises much, delivers plenty, and may yet be capable of more. Attractive to patients and clinicians alike for its ability to prolong the duration of analgesia, and to allow individualized dosing to be tailored to need, the uses of CPNB extend beyond the confines of hospitals to the continuation of high-quality analgesia in the ambulatory setting. Postoperative benefits of CPNB include reduced use of opioids (and consequently reduced side effects),[1–3] reduced pain on movement,[1,4] and improved quality of sleep.[5] Numerous other indications have been described, including the retrieval of trauma patients, and the induction of sympathectomy to improve peripheral perfusion.[3] Technical advancements in equipment and nerve localization, combined with a range of local anesthetic drugs and delivery systems, provide the anesthesiologist with what may seem a dizzying array of variables in the practical application of this technique. In this issue of *Anesthesia & Analgesia*, Brian Ilfeld, himself a major contributor to evidence in the field of CPNB, reviews a very large and heterogeneous body of work relating to the applications of CPNB in modern anesthetic practice.[3] The result is a comprehensive summary and insightful interpretation of the literature to date, as well as the exposure of many significant voids that still remain regarding the optimal use and delivery of this important treatment modality.

The postoperative aims of CPNB are intimately related to the surgical procedure concerned, whether or not a period of intense pain is expected (and for how long), and how motor blockade may impact upon the rehabilitation phase. A case in point is the use of continuous femoral nerve block (CFNB) following total knee arthroplasty (TKA), a surgical procedure often associated with severe pain, whose site is innervated by more than one major peripheral nerve, and which requires a period of intense postoperative physical therapy and rehabilitation. This is one of the most extensively researched applications of CPNB, with over 30 of the articles referred to in the accompanying review relating to CFNB in the setting of TKA.[3] However, CFNB has been associated with quadriceps weakness,[6,7] which may impair active participation in physical therapy, and has been implicated in falls.[8] In fact, dense motor block to reduce muscle spasm was the postoperative goal for successful CFNB in one of the landmark studies designed to investigate the use of CFNB following TKA.[4] This outdated paradigm included prolonged admissions in rehabilitation centers and involved passive motion rehabilitation techniques, as did another influential study of CFNB.[9] In the modern-day reality of accelerated clinical pathways, the seemingly competing goals of analgesia and mobility surrounding TKA therefore merit thoughtful consideration and further evaluation. Furthermore, the ideal local anesthetic regime for CPNB must be defined by clinically meaningful outcomes for contemporary practice, especially pain and mobility during hospitalization and functional recovery in the longer term.

Delving more deeply into the objectives of CPNB therefore generates more questions. How may sensory and motor block be optimally balanced and how may this balance change at different anatomical sites? Whereas the combination of opioids and low-concentration local anesthetics in epidural infusions can produce effective analgesia with minimal motor block,[10,11] there are limited data for how volume, concentration, and total mass of local anesthetic influence motor and sensory blocks in CPNB. It appears likely that the site of block may have a bearing on this, with anatomical differences in the spaces around nerves and topographical differences within the nerves themselves potentially playing a role in the relationship between concentration, volume, and clinical effects.[12,13] Total drug dose appears to be the primary determinant of clinical effects in continuous lumbar plexus block,[14] whereas profound sensory block appears more common in low-concentration, high-volume popliteal–sciatic block,[12] and mixed results have been presented for continuous interscalene block.[3] There are limited data on the optimal dose and concentration for CFNB following TKA, with most investigations focusing on the analgesic effects of changing concentration[2,15] and scant evidence regarding the effects of concentration on motor block and mobility.[16] Ilfeld and colleagues recently attempted to quantify the effects of a 4-day CFNB infusion, in comparison with a CFNB infusion stopped the morning after surgery, on readiness to hospital discharge following TKA, according

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to 3 explicit criteria relating to both mobility and analgesia.[6,17] In 2 studies of near-identical methodology, but different settings (research center versus general orthopedic ward), the time to readiness to discharge in the 4-day CFNB group was significantly shorter, although the effect was less marked in the general orthopedic ward setting. Because all patients were ASA physical status II, and preoperative daily opioid use was an exclusion criterion, it is uncertain whether these results are generalizable to the wider TKA population. It is also noteworthy that although the mode of local anesthetic administration, patient-controlled bolus dosing instead of continuous rate infusion, can reduce the total consumption of local anesthetic without compromising analgesia,[18–20] there is insufficient evidence to support any relative preservation of motor function.

In his review, Ilfeld addresses the evidence for alternatives to CPNB, and duly calls for further research.[3] By targeting nerves more peripherally, CPNB could be used to more elegantly achieve analgesia with fewer troubling motor effects. One interesting and promising trial of continuous blockade of the obturator and saphenous nerves (adductor canal block) has reported pain scores and morphine consumption following TKA comparable to studies using femoral nerve block.[21] Adductor canal block should theoretically have minimal motor effects; unfortunately, quadriceps strength was not an outcome measured in this preliminary study.

There is also a growing body of evidence around local infiltration analgesia (LIA) during and after major joint arthroplasty. The simplicity and apparent safety of this approach to analgesia, combined with an avoidance of the motor block associated with CPNB, make it particularly appealing as an alternative strategy. A recent review of the evidence on LIA for hip and knee arthroplasty commented on a number of methodological issues complicating data interpretation, but concluded that there is evidence to recommend intraoperative LIA for TKA for an initial postoperative analgesic effect of around 6 to 12 hours.[22] There have been few direct comparisons of CFNB and LIA and only 1 double-blind randomized comparison of these 2 techniques.[23] This study reported significantly less morphine use, and improved functional recovery at 6 weeks, in the CFNB group. In addition, there was no difference between groups in the secondary outcome of 2-minute walk tests on postoperative days 1 to 3. This is in contrast to a nonblinded comparison of CFNB with LIA, which reported lower pain scores, less morphine consumption, and a greater number of patients mobilizing more than 3 m on postoperative day 1 in the LIA group, although the CFNB local anesthetic infusion regimen was most unconventional.[24] Another recent comparison of LIA and CFNB following TKA found pain scores and morphine consumption to be similar in the first 24 postoperative hours, but was not blinded, and had less robust methodology for data collection than did the study by Carli and colleagues.[23,25] It is clear that high-quality double-blind trials are needed to further evaluate the roles of CFNB and LIA in the context of TKA.

Finally and importantly, with the exception of the comparison of CFNB and LIA by Carli and colleagues,[23] most investigations of long-term outcomes suggest little impact of extended CPNB on measures of function in the months and years following hip or knee arthroplasty.[1,4,9,26–31]

Where then do catheters belong in modern practice? The potential applications are many, the variables in practice are myriad, but the aims of adequate analgesia combined with early mobilization, rapid hospital discharge, and the best possible long-term outcomes present a challenge not yet fully answered.

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REFERENCES

1. 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;102:1234–9
2. Seet E, Leong WL, Yeo ASN, Fook-Chong S. Effectiveness of 3-in-1 continuous femoral block of differing concentrations compared to patient controlled intravenous morphine for post total knee arthroplasty analgesia and knee rehabilitation. Anaesth Intensive Care 2006;34:25–30
3. Ilfeld BM. Continuous peripheral nerve blocks: a review of the published evidence. Anesth Analg 2011;113:904–25
4. Capdevila X, Barthelet Y, Biboulet 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
5. Mariano ER, Afra R, Loland VJ, Sandhu NS, Bellars RH, Bishop ML, Cheng GS, Choy LP, Maldonado RC, Ilfeld BM. Continuous interscalene brachial plexus block via an ultrasound-guided posterior approach: a randomized, triple-masked, placebo-controlled study. Anesth Analg 2009;108:1688–94
6. Ilfeld BM, Le LT, Meyer RS, Mariano ER, Vandenborne 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 tricompartment total knee arthroplasty: a randomized, triple-masked, placebo-controlled study. Anesthesiology 2008;108:703–13
7. Barrington MJ, Olive D, Low K, Scott DA, Brittain J, Choong P. Continuous femoral nerve blockade or epidural analgesia after total knee replacement: a prospective randomized controlled trial. Anesth Analg 2005;101:1824
8. 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
9. Singelyn FJ, Deyaert M, Joris D, Pendeville E, Gouverneur JM. Effects of intravenous patient-controlled analgesia with morphine, continuous epidural analgesia, and continuous three-in-one block on postoperative pain and knee rehabilitation after unilateral total knee arthroplasty. Anesth Analg 1998;87:88–92
10. Cohen SE, Yeh JY, Riley ET, Vogel TM. Walking with labor epidural analgesia: the impact of bupivacaine concentration and a lidocaine–epinephrine test dose. Anesthesiology 2000;92:387–92
11. Wilson MJA, MacArthur C, Cooper GM, Shennan A, COMET Study group UK. Ambulation in labour and delivery mode: a randomised controlled trial of high-dose vs mobile epidural analgesia. Anaesthesia 2009;64:266–72

12. Ilfeld BM, Loland VJ, Gerancher JC, Wadhwa AN, Renehan EM, Sessler DI, Shuster JJ, Theriaque DW, Maldonado RC, Mariano ER. The effects of varying local anesthetic concentration and volume on continuous popliteal sciatic nerve block: a dual-center, randomized, controlled study. Anesth Analg 2008;107:701–7
13. Le LT, Loland VJ, Mariano ER, Gerancher JC, Wadhwa AN, Renehan EM, Sessler DI, Shuster JJ, Theriaque DW, Maldonado RC, Ilfeld BM. Effects of local anesthetic concentration and dose on continuous interscalene nerve blocks: a dual-center, randomized, observer-masked, controlled study. Reg Anesth Pain Med 2008;33:518–25
14. Ilfeld BM, Moeller LK, Mariano ER, Loland VJ, Stevens-Lapsley JE, Fleisher AS, Girard PJ, Donohue MC, Ferguson EJ, Ball ST. Continuous peripheral nerve blocks: is local anesthetic dose the only factor, or do concentration and volume influence infusion effects as well? Anesthesiology 2010;112:347–54
15. Brodner G, Buerkle H, Van Aken H, Lambert R, Schweppe-Hartenauer ML, Wempe C, Gogarten W. Postoperative analgesia after knee surgery: a comparison of three different concentrations of ropivacaine for continuous femoral nerve blockade. Anesth Analg 2007;105:256–62
16. Paauwe JJ, Thomassen BJ, Weterings J, van Rossum E, Ausems ME. Femoral nerve block using ropivacaine 0.025%, 0.05% and 0.1%: effects on the rehabilitation programme following total knee arthroplasty: a pilot study. Anaesthesia 2008;63:948–53
17. 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;150:477–84
18. Singelyn FJ, Vanderelst PE, Gouverneur JM. Extended femoral nerve sheath block after total hip arthroplasty: continuous versus patient-controlled techniques. Anesth Analg 2001;92:455–9
19. Singelyn FJ, Gouverneur JM. Extended "three-in-one" block after total knee arthroplasty: continuous versus patient-controlled techniques. Anesth Analg 2000;91:176–80
20. Eledjam JJ, Cuvillon P, Capdevila X, Macaire P, Serri S, Gaertner E, Jochum D. Postoperative analgesia by femoral nerve block with ropivacaine 0.2% after major knee surgery: continuous versus patient-controlled techniques. Reg Anesth Pain Med 2002;27:604–11
21. Lund J, Jenstrup MT, Jaeger P, Sørenson 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
22. Kehlet, Anderson LO. Local infiltration analgesia in joint replacement: the evidence and recommendations for clinical practice. Acta Anaesthesiol Scand 2011 April 4 EPub ahead of print
23. Carli F, Clemente A, Asenjo JF, Kim DJ, Mistraletti G, Gomarasca M, Morabito A, Tanzer M. Analgesia and functional outcome after total knee arthroplasty: periarticular infiltration vs continuous femoral nerve block. Br J Anaesth 2010;105:185–95
24. Toftdahl K, Nikolajsen L, Haraldsted V, Madsen F, Tonnesen EK, Soballe K. Comparison of peri- and intraarticular analgesia with femoral nerve block after total knee arthroplasty: a randomized clinical trial. Acta Orthop 2007;78:172–9
25. Affas F, Nygards EB, Stiller CO, Wretenberg P, Olofsson C. Pain control after total knee arthroplasty: a randomized trial comparing local infiltration anesthesia and continuous femoral block. Acta Orthop 2011;82 EPub ahead of print
26. 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 (psoas compartment) block, a continuous femoral nerve block, and the combination of a continuous femoral and sciatic nerve block. Reg Anesth Pain Med 2005;30:434–45
27. Ilfeld BM, Ball ST, Gearen PF, Mariano ER, Le LT, Vandenborne K, Duncan PW, Sessler DI, Enneking FK, Shuster JJ, Maldonado RC, Meyer RS. Health-related quality of life after hip arthroplasty with and without an extended-duration continuous posterior lumbar plexus nerve block: a prospective, 1-year follow-up of a randomized, triple-masked, placebo-controlled study. Anesth Analg 2009;109:586–91
28. Ilfeld BM, Meyer RS, Le LT, Mariano ER, Williams BA, Vandenborne K, Duncan PW, Sessler DI, Enneking FK, Shuster JJ, Maldonado RC, Gearen PF. Health-related quality of life after tricompartment knee arthroplasty with and without an extended-duration continuous femoral nerve block: a prospective, 1-year follow-up of a randomized, triple-masked, placebo-controlled study. Anesth Analg 2009;108:1320–5
29. Ilfeld BM, Shuster JJ, Theriaque DW, Mariano ER, Girard PJ, Loland VJ, Meyer S, Donovan JF, Pugh GA, Le LT, Sessler DI, Ball ST. Long-term pain, stiffness, and functional disability after total knee arthroplasty with and without an extended ambulatory continuous femoral nerve block: a prospective, 1-year follow-up of a multicenter, randomized, triple-masked, placebo-controlled trial. Reg Anesth Pain Med 2011;36:116–20
30. 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;53:914–20
31. Shum CF, Lo NN, Yeo SJ, Yang KY, Chong HC, Yeo SN. Continuous femoral nerve block in total knee arthroplasty: immediate and two-year outcomes. J Arthroplasty 2009;24:204–9

Tripping Over Perineural Catheters

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Continuous peripheral nerve blockade (CPNB) is a technique that promises much, delivers plenty, and may yet be capable of more. Attractive to patients and clinicians alike for its ability to prolong the duration of analgesia, and to allow individualized dosing to be tailored to need, the uses of CPNB extend beyond the confines of hospitals to the continuation of high-quality analgesia in the ambulatory setting. Postoperative benefits of CPNB include reduced use of opioids (and consequently reduced side effects),[1–3] reduced pain on movement,[1,4] and improved quality of sleep.[5] Numerous other indications have been described, including the retrieval of trauma patients, and the induction of sympathectomy to improve peripheral perfusion.[3] Technical advancements in equipment and nerve localization, combined with a range of local anesthetic drugs and delivery systems, provide the anesthesiologist with what may seem a dizzying array of variables in the practical application of this technique. In this issue of *Anesthesia & Analgesia*, Brian Ilfeld, himself a major contributor to evidence in the field of CPNB, reviews a very large and heterogeneous body of work relating to the applications of CPNB in modern anesthetic practice.[3] The result is a comprehensive summary and insightful interpretation of the literature to date, as well as the exposure of many significant voids that still remain regarding the optimal use and delivery of this important treatment modality.

The postoperative aims of CPNB are intimately related to the surgical procedure concerned, whether or not a period of intense pain is expected (and for how long), and how motor blockade may impact upon the rehabilitation phase. A case in point is the use of continuous femoral nerve block (CFNB) following total knee arthroplasty (TKA), a surgical procedure often associated with severe pain, whose site is innervated by more than one major peripheral nerve, and which requires a period of intense postoperative physical therapy and rehabilitation. This is one of the most extensively researched applications of CPNB, with over 30 of the articles referred to in the accompanying review relating to CFNB in the setting of TKA.[3] However, CFNB has been associated with quadriceps weakness,[6,7] which may impair active participation in physical therapy, and has been implicated in falls.[8] In fact, dense motor block to reduce muscle spasm was the postoperative goal for successful CFNB in one of the landmark studies designed to investigate the use of CFNB following TKA.[4] This outdated paradigm included prolonged admissions in rehabilitation centers and involved passive motion rehabilitation techniques, as did another influential study of CFNB.[9] In the modern-day reality of accelerated clinical pathways, the seemingly competing goals of analgesia and mobility surrounding TKA therefore merit thoughtful consideration and further evaluation. Furthermore, the ideal local anesthetic regime for CPNB must be defined by clinically meaningful outcomes for contemporary practice, especially pain and mobility during hospitalization and functional recovery in the longer term.

Delving more deeply into the objectives of CPNB therefore generates more questions. How may sensory and motor block be optimally balanced and how may this balance change at different anatomical sites? Whereas the combination of opioids and low-concentration local anesthetics in epidural infusions can produce effective analgesia with minimal motor block,[10,11] there are limited data for how volume, concentration, and total mass of local anesthetic influence motor and sensory blocks in CPNB. It appears likely that the site of block may have a bearing on this, with anatomical differences in the spaces around nerves and topographical differences within the nerves themselves potentially playing a role in the relationship between concentration, volume, and clinical effects.[12,13] Total drug dose appears to be the primary determinant of clinical effects in continuous lumbar plexus block,[14] whereas profound sensory block appears more common in low-concentration, high-volume popliteal–sciatic block,[12] and mixed results have been presented for continuous interscalene block.[3] There are limited data on the optimal dose and concentration for CFNB following TKA, with most investigations focusing on the analgesic effects of changing concentration[2,15] and scant evidence regarding the effects of concentration on motor block and mobility.[16] Ilfeld and colleagues recently attempted to quantify the effects of a 4-day CFNB infusion, in comparison with a CFNB infusion stopped the morning after surgery, on readiness to hospital discharge following TKA, according

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to 3 explicit criteria relating to both mobility and analgesia.[6,17] In 2 studies of near-identical methodology, but different settings (research center versus general orthopedic ward), the time to readiness to discharge in the 4-day CFNB group was significantly shorter, although the effect was less marked in the general orthopedic ward setting. Because all patients were ASA physical status II, and preoperative daily opioid use was an exclusion criterion, it is uncertain whether these results are generalizable to the wider TKA population. It is also noteworthy that although the mode of local anesthetic administration, patient-controlled bolus dosing instead of continuous rate infusion, can reduce the total consumption of local anesthetic without compromising analgesia,[18–20] there is insufficient evidence to support any relative preservation of motor function.

In his review, Ilfeld addresses the evidence for alternatives to CPNB, and duly calls for further research.[3] By targeting nerves more peripherally, CPNB could be used to more elegantly achieve analgesia with fewer troubling motor effects. One interesting and promising trial of continuous blockade of the obturator and saphenous nerves (adductor canal block) has reported pain scores and morphine consumption following TKA comparable to studies using femoral nerve block.[21] Adductor canal block should theoretically have minimal motor effects; unfortunately, quadriceps strength was not an outcome measured in this preliminary study.

There is also a growing body of evidence around local infiltration analgesia (LIA) during and after major joint arthroplasty. The simplicity and apparent safety of this approach to analgesia, combined with an avoidance of the motor block associated with CPNB, make it particularly appealing as an alternative strategy. A recent review of the evidence on LIA for hip and knee arthroplasty commented on a number of methodological issues complicating data interpretation, but concluded that there is evidence to recommend intraoperative LIA for TKA for an initial postoperative analgesic effect of around 6 to 12 hours.[22] There have been few direct comparisons of CFNB and LIA and only 1 double-blind randomized comparison of these 2 techniques.[23] This study reported significantly less morphine use, and improved functional recovery at 6 weeks, in the CFNB group. In addition, there was no difference between groups in the secondary outcome of 2-minute walk tests on postoperative days 1 to 3. This is in contrast to a nonblinded comparison of CFNB with LIA, which reported lower pain scores, less morphine consumption, and a greater number of patients mobilizing more than 3 m on postoperative day 1 in the LIA group, although the CFNB local anesthetic infusion regimen was most unconventional.[24] Another recent comparison of LIA and CFNB following TKA found pain scores and morphine consumption to be similar in the first 24 postoperative hours, but was not blinded, and had less robust methodology for data collection than did the study by Carli and colleagues.[23,25] It is clear that high-quality double-blind trials are needed to further evaluate the roles of CFNB and LIA in the context of TKA.

Finally and importantly, with the exception of the comparison of CFNB and LIA by Carli and colleagues,[23] most investigations of long-term outcomes suggest little impact of extended CPNB on measures of function in the months and years following hip or knee arthroplasty.[1,4,9,26–31]

Where then do catheters belong in modern practice? The potential applications are many, the variables in practice are myriad, but the aims of adequate analgesia combined with early mobilization, rapid hospital discharge, and the best possible long-term outcomes present a challenge not yet fully answered.

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REFERENCES

1. 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;102:1234–9
2. Seet E, Leong WL, Yeo ASN, Fook-Chong S. Effectiveness of 3-in-1 continuous femoral block of differing concentrations compared to patient controlled intravenous morphine for post total knee arthroplasty analgesia and knee rehabilitation. Anaesth Intensive Care 2006;34:25–30
3. Ilfeld BM. Continuous peripheral nerve blocks: a review of the published evidence. Anesth Analg 2011;113:904–25
4. Capdevila X, Barthelet Y, Biboulet 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
5. Mariano ER, Afra R, Loland VJ, Sandhu NS, Bellars RH, Bishop ML, Cheng GS, Choy LP, Maldonado RC, Ilfeld BM. Continuous interscalene brachial plexus block via an ultrasound-guided posterior approach: a randomized, triple-masked, placebo-controlled study. Anesth Analg 2009;108:1688–94
6. Ilfeld BM, Le LT, Meyer RS, Mariano ER, Vandenborne 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 tricompartment total knee arthroplasty: a randomized, triple-masked, placebo-controlled study. Anesthesiology 2008;108:703–13
7. Barrington MJ, Olive D, Low K, Scott DA, Brittain J, Choong P. Continuous femoral nerve blockade or epidural analgesia after total knee replacement: a prospective randomized controlled trial. Anesth Analg 2005;101:1824
8. 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
9. Singelyn FJ, Deyaert M, Joris D, Pendeville E, Gouverneur JM. Effects of intravenous patient-controlled analgesia with morphine, continuous epidural analgesia, and continuous three-in-one block on postoperative pain and knee rehabilitation after unilateral total knee arthroplasty. Anesth Analg 1998;87:88–92
10. Cohen SE, Yeh JY, Riley ET, Vogel TM. Walking with labor epidural analgesia: the impact of bupivacaine concentration and a lidocaine–epinephrine test dose. Anesthesiology 2000;92:387–92
11. Wilson MJA, MacArthur C, Cooper GM, Shennan A, COMET Study group UK. Ambulation in labour and delivery mode: a randomised controlled trial of high-dose vs mobile epidural analgesia. Anaesthesia 2009;64:266–72

12. Ilfeld BM, Loland VJ, Gerancher JC, Wadhwa AN, Renehan EM, Sessler DI, Shuster JJ, Theriaque DW, Maldonado RC, Mariano ER. The effects of varying local anesthetic concentration and volume on continuous popliteal sciatic nerve block: a dual-center, randomized, controlled study. Anesth Analg 2008;107:701–7
13. Le LT, Loland VJ, Mariano ER, Gerancher JC, Wadhwa AN, Renehan EM, Sessler DI, Shuster JJ, Theriaque DW, Maldonado RC, Ilfeld BM. Effects of local anesthetic concentration and dose on continuous interscalene nerve blocks: a dual-center, randomized, observer-masked, controlled study. Reg Anesth Pain Med 2008;33:518–25
14. Ilfeld BM, Moeller LK, Mariano ER, Loland VJ, Stevens-Lapsley JE, Fleisher AS, Girard PJ, Donohue MC, Ferguson EJ, Ball ST. Continuous peripheral nerve blocks: is local anesthetic dose the only factor, or do concentration and volume influence infusion effects as well? Anesthesiology 2010;112:347–54
15. Brodner G, Buerkle H, Van Aken H, Lambert R, Schweppe-Hartenauer ML, Wempe C, Gogarten W. Postoperative analgesia after knee surgery: a comparison of three different concentrations of ropivacaine for continuous femoral nerve blockade. Anesth Analg 2007;105:256–62
16. Paauwe JJ, Thomassen BJ, Weterings J, van Rossum E, Ausems ME. Femoral nerve block using ropivacaine 0.025%, 0.05% and 0.1%: effects on the rehabilitation programme following total knee arthroplasty: a pilot study. Anaesthesia 2008;63:948–53
17. 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;150:477–84
18. Singelyn FJ, Vanderelst PE, Gouverneur JM. Extended femoral nerve sheath block after total hip arthroplasty: continuous versus patient-controlled techniques. Anesth Analg 2001;92:455–9
19. Singelyn FJ, Gouverneur JM. Extended "three-in-one" block after total knee arthroplasty: continuous versus patient-controlled techniques. Anesth Analg 2000;91:176–80
20. Eledjam JJ, Cuvillon P, Capdevila X, Macaire P, Serri S, Gaertner E, Jochum D. Postoperative analgesia by femoral nerve block with ropivacaine 0.2% after major knee surgery: continuous versus patient-controlled techniques. Reg Anesth Pain Med 2002;27:604–11
21. Lund J, Jenstrup MT, Jaeger P, Sørenson 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
22. Kehlet, Anderson LO. Local infiltration analgesia in joint replacement: the evidence and recommendations for clinical practice. Acta Anaesthesiol Scand 2011 April 4 EPub ahead of print
23. Carli F, Clemente A, Asenjo JF, Kim DJ, Mistraletti G, Gomarasca M, Morabito A, Tanzer M. Analgesia and functional outcome after total knee arthroplasty: periarticular infiltration vs continuous femoral nerve block. Br J Anaesth 2010;105:185–95
24. Toftdahl K, Nikolajsen L, Haraldsted V, Madsen F, Tonnesen EK, Soballe K. Comparison of peri- and intraarticular analgesia with femoral nerve block after total knee arthroplasty: a randomized clinical trial. Acta Orthop 2007;78:172–9
25. Affas F, Nygards EB, Stiller CO, Wretenberg P, Olofsson C. Pain control after total knee arthroplasty: a randomized trial comparing local infiltration anesthesia and continuous femoral block. Acta Orthop 2011;82 EPub ahead of print
26. 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 (psoas compartment) block, a continuous femoral nerve block, and the combination of a continuous femoral and sciatic nerve block. Reg Anesth Pain Med 2005;30:434–45
27. Ilfeld BM, Ball ST, Gearen PF, Mariano ER, Le LT, Vandenborne K, Duncan PW, Sessler DI, Enneking FK, Shuster JJ, Maldonado RC, Meyer RS. Health-related quality of life after hip arthroplasty with and without an extended-duration continuous posterior lumbar plexus nerve block: a prospective, 1-year follow-up of a randomized, triple-masked, placebo-controlled study. Anesth Analg 2009;109:586–91
28. Ilfeld BM, Meyer RS, Le LT, Mariano ER, Williams BA, Vandenborne K, Duncan PW, Sessler DI, Enneking FK, Shuster JJ, Maldonado RC, Gearen PF. Health-related quality of life after tricompartment knee arthroplasty with and without an extended-duration continuous femoral nerve block: a prospective, 1-year follow-up of a randomized, triple-masked, placebo-controlled study. Anesth Analg 2009;108:1320–5
29. Ilfeld BM, Shuster JJ, Theriaque DW, Mariano ER, Girard PJ, Loland VJ, Meyer S, Donovan JF, Pugh GA, Le LT, Sessler DI, Ball ST. Long-term pain, stiffness, and functional disability after total knee arthroplasty with and without an extended ambulatory continuous femoral nerve block: a prospective, 1-year follow-up of a multicenter, randomized, triple-masked, placebo-controlled trial. Reg Anesth Pain Med 2011;36:116–20
30. 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;53:914–20
31. Shum CF, Lo NN, Yeo SJ, Yang KY, Chong HC, Yeo SN. Continuous femoral nerve block in total knee arthroplasty: immediate and two-year outcomes. J Arthroplasty 2009;24:204–9