Review Article/Brief Review

Ultrasonography and stimulating perineural catheters for nerve blocks: a review of the evidence

[L'échographie et les cathéters périneuraux stimulants pour les blocs nerveux : une synthèse des données probantes]

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Purpose: This narrative review summarizes the evidence derived from randomized controlled trials (RCTs) offering blinded assessment and sample size justification, in order to determine the benefits associated with adjunctive ultrasonography (US) and stimulating perineural catheters for nerve blocks.

Source: The literature search for this review was conducted during the second week of December 2007 using the MEDLINE (January 1950 to November 2007) and EMBASE (January 1980 to November 2007) databases. For US-guided peripheral and neuraxial blocks, the following medical subject heading (MeSH) terms were searched: "nerve block", "epidural anesthesia", "epidural analgesia", "epidural injection", "epidural space", "spinal anesthesia", and "spinal injection", the results were combined with "ultrasonography" (MeSH term) and "ultrasound" (key word). For stimulating perineural catheters, the following MeSH terms were cross referenced with the MeSH term, "nerve block": "peripheral catheterization", "indwelling catheterization", "catheterization", and keywords, "nerve catheter" and "continuous". Subsequently, the result of this search was combined to "stimulating" (key word). Fifteen RCTs, offering blinded assessment and sample size justification, were retained for analysis.

Principal findings: For axillary blocks, US guidance yields a higher success rate than a double-injection, transarterial and a triple-injection, neurostimulation-guided technique. Compared to a quadruple-stimulation technique, no major differences can be found. The addition of nerve stimulation to US guidance offers no clear benefits for axillary blocks. For femoral blocks, compared to neurostimulation, echoguidance is associated with a local anesthetic (LA) sparing effect (up to 42%). In children,

US guidance yields a LA sparing effect and a longer duration of action for lower extremity nerve blocks.

Compared to their blind counterparts, stimulating catheters seem to offer limited clinical benefits. Despite providing a sparing effect on LA and opioid consumption, stimulating catheters are not associated with a decrease in side effects or analgesia-related expenditures.

Conclusions: Published reports of RCTs provide evidence to formulate limited recommendations regarding the use of adjunctive US and stimulating perineural catheters. Further well-designed and meticulously executed RCTs are warranted.

Objectif : Cette synthèse narrative résume les données probantes tirées d'études randomisées contrôlées (ERC) disposant d'une évaluation en aveugle et de justification de la taille de l'échantillon afin d'identifier les bienfaits associés à une utilisation conjointe de l'échographie et de cathéters périneuraux stimulants lors de blocs nerveux.

Sources : La recherche de littérature pour cet article de synthèse a été menée la deuxième semaine de décembre 2007 dans les bases de données MEDLINE (janvier 1950 à novembre 2007) et EMBASE (janvier 1980 à novembre 2007). Pour les blocs périphériques et neuraxiaux échoguidés, les termes MeSH suivants ont été recherchés : « nerve block », « epidural anesthesia », « epidural analgesia », « epidural injection », « epidural space », « spinal anesthesia » et « spinal injection », et ont été associés à « ultrasonography »

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Competing interests: None declared.
Accepted for publication February 26, 2008.
Revision accepted March 26, 2008.

(terme MeSH) et « ultrasound » (mot clé). Pour les cathéters péri-
neuraux stimulants, les termes MeSH suivants ont été croisés avec
le terme MeSH « nerve block » : « peripheral catheterization »,
« indwelling catheterization », « catheterization », et les mots clés
« nerve catheter » et « continuous ». Ensuite, les résultats de cette
recherche ont été combinés avec le mot clé « stimulating ». Quinze
ERC disposant d'une évaluation en aveugle et de justification de la
taille de l'échantillon ont été retenues pour être analysées.

Constatations principales : *Dans le cas de blocs axillaires,
l'échoguidage offre un meilleur taux de réussite qu'une technique
de double injection transartérielle et qu'une technique de triple in-
jection guidée par neurostimulation. Si on compare l'échoguidage
à une technique de quadruple stimulation, aucune différence ma-
jeure n'apparaît. L'ajout de stimulation nerveuse à l'échoguidage
ne procure pas de bienfaits clairs dans le cas des blocs axillaires.
Lorsqu'un bloc fémoral est réalisé, l'échoguidage est associé à un
besoin moindre en anesthésique local (AL) (jusqu'à 42 %) par rap-
port à la neurostimulation. Chez les enfants, l'échoguidage résulte
en un besoin moindre en anesthésique local et une durée prolongée
d'action pour les blocs nerveux des membres inférieurs.*

   *Par rapport à leurs pendants aveugles, les cathéters stimulants
semblent n'offrir que des bienfaits cliniques limités. Malgré le fait
qu'ils génèrent un besoin moins important en anesthésiques locaux
et réduisent la consommation d'opioïdes, les cathéters stimulants
ne sont pas associés à une réduction des effets secondaires ou des
coûts liés à l'analgésie.*

Conclusion : *Les comptes-rendus publiés d'ERC fournissent des
données probantes qui peuvent encourager la formulation de recom-
mandations limitées quant à l'utilisation conjointe d'échoguidage et
de cathéters périneuraux stimulants. D'autres ERC bien conçues et
menées avec soin sont justifiées.*

W ITHIN the last ten years, the field of re-
gional anesthesia has undergone a major
transformation. The widespread use of
low molecular weight heparins and the
implementation of outpatient surgery have compelled
anesthesiologists to rethink postoperative pain control
and to favour nerve blocks over traditional analgesic
modalities. However, like any other technical field, the
development of regional anesthesia necessitated a par-
allel improvement in the equipment available. Thus,
the introduction into clinical practice of adjunctive
ultrasonography (US) and stimulating perineural cath-
eters has clearly contributed to the specialty's increas-
ing popularity. US has revolutionized the practice of
regional anesthesia by allowing the operator to visual-
ize, in real time, the nerve, the needle and, more im-
portantly, the spread of local anesthetic (LA) agents.
Stimulating perineural catheters have contributed to

decrease the failure rate of blind (i.e., non stimulat-
ing) catheters, thus, theoretically improving postop-
erative analgesia for the patient. Despite this enthu-
siasm, many issues pertaining to the efficacy of these
new tools remain ambiguous. Accordingly, a literature
search for the best available evidence (randomized
controlled trials with adequate blinded assessment and
sample size justification) was undertaken, to determine
if US is superior to other adjunctive modalities and if
stimulating catheters are associated with better clinical
outcomes than non stimulating catheters.

Methods
Search strategy and selection criteria
The literature search for this review was conducted
during the second week of December 2007 using
the MEDLINE (January 1950 to the second week of
November 2007) and EMBASE (January 1980 to the
49th week of 2007) databases.

   For US-guided peripheral nerve blocks, the medi-
cal subject heading (MeSH) term, "nerve block",
was searched using the operator, "and". It was then
combined with the MeSH term, "ultrasonography",
as well as the key word, "ultrasound". For US-guided
neuraxial blocks, MeSH terms; "epidural anesthesia",
"epidural analgesia", "epidural injection", "epidu-
ral space", "spinal anesthesia", and "spinal injection"
were also combined with "ultrasonography" (MeSH
term) and "ultrasound" (key word) using the opera-
tor, "and".

   For stimulating perineural catheters, using the oper-
ator, "or", MeSH terms, "peripheral catheterization",
"indwelling catheterization", "catheterization", and
keywords, "nerve catheter" and "continuous" were
combined together. The result of this search was then
cross referenced with the MeSH term, "nerve block",
using "and". Subsequently, the result of this second
search was combined to "stimulating" (key word)
using the operator, "and".

   The final results of these two initial searches were
limited to peer-reviewed reports of human studies.
Only randomized controlled trials (RCTs) compar-
ing US to traditional, adjunctive modalities and
stimulating to non stimulating perineural catheters
were retained. Furthermore, only RCTs with blinded
assessments and appropriate sample size justification
were considered. After selecting the initial articles, we
examined the reference lists, as well as our personal
files, for additional material. No RCTs were excluded,
based on factors such as definition of intervention,
method of allocation concealment, or separation of
primary and secondary outcomes. However, non-
randomized studies, observational case reports, and

TABLE I Summary of randomized controlled trials comparing ultrasonography to traditional adjunctive modalities

Authors (year)	Surgery	Description	Number of patients/groups	Primary outcome	Main findings
Liu et al.[14] (2005)	Forearm wrist and hand	2-injection NS vs 1-injection US vs 2-injection NS	90/3	Incidence of side effects	Similar rates of surgical anesthesia; 2-injection NS: highest incidence of side effects (paresthesia, vascular puncture, hematoma) and longest performance time
Sites et al.[15] (2006)	Hand	TA vs US-guided AXB	56/2	Failure (defined as conversion to GA or inability to localize the artery)	US: decreased failure rate and shorter performance time
Chan et al.[17] (2007)	Hand	NS- vs US- vs NS/US-guided 3-injection AXB	188/3	Success rate (defined as absence to sensation in the territories of the radial, ulnar and median nerves at 30 minutes)	NS: lowest success rate and rate of surgical anesthesia compared to the 2 other groups; US: shortest performance time compared to the 2 other groups
Casati et al.[18] (2007)	Forearm wrist and hand	4-injection NS- vs US-guided AXB	59/2	Time to readiness for surgery (complete sensory block of all 4 nerves of the hand and complete motor block of at least 3 of the 4 nerves at 30 minutes)	Similar times to readiness for surgery, procedural pain, success rates, and patient satisfaction; US: decreased number of needle passes
Casati et al.[19] (2007)	Knee arthroscopy	NS- vs US-guided FB	60/2	MEAV50	US: 42% decrease in MEAV50
Domingo-Triado et al.[20] (2007)	Foot, ankle	NS- vs NS-US-guided lateral SB	61/2	Number of attempts	Similar performance times, procedural pain and onset/offset times for sensory/motor block; NS-US: decreased number of attempts; improved quality of the sensory block and calf tourniquet tolerance
Obemdorfer et al.[22] (2007)	Lower extremity surgery (in children)	NS- vs US-guided FB ± subgluteal/popliteal SB	46/2	Duration of sensory block	US: longer duration of sensory block and decreased LA consumption

AXB = axillary block; FB = femoral block; LA = local anesthetic agent; MEAV50 = minimal effective volume to block the nerve in 50% of patients; SB = sciatic block; TA = transarterial; US = ultrasound.

TABLE II   Summary of randomized controlled trials comparing stimulating and non-stimulating perineural catheters

Authors (year)	Surgery	Description	Number of patients/ groups	Primary outcome	Main findings
Stevens et al.[23] (2007)	Shoulder surgery (correction of acromio-clavicular arthropathy, impingement, biceps tendonitis, and calcified tendino-pathy	BC vs SC for ISB	40/ 2	Functional outcome assessed with CMS at 6 weeks	Similar functional outcome assessed with DASH criteria Similar sensory onset, pain scores, performance time, procedure-related pain, LA/ rescue analgesics consumption SC: shorter onset of motor block and improved functional outcome with CMS
Salinas et al.[24] (2004)	Healthy volunteers	BC vs SC for FB	20/ 2	Block success (defined as loss of sensation to cold and pinprick stimuli)	Similar success rate SC: increased tolerance to transcutaneous, electrical stimulation and depth of motor block
Hayek et al.[25] (2006)	TKR	BC vs SC for FB	41/ 2	LA volume required to achieve adequate analgesia	Similar consumption of LA/ rescue opioids, pain scores, performance during physical therapy, and incidence of side effects
Dauri et al.[26] (2007)	ACL repair	BC vs SC for FB	70/ 2	Onset of sensory block	Similar success rates for femoral, lateral femoral cutaneous, and obturator blockade. Similar pain scores and incidence of side effects
Morin et al.[27] (2005)	TKR or ACL repair	BC vs SC for FB	81/ 2	Consumption of rescue opioids	SC: shorter onset of femoral sensory block, decreased consumption of LA/ rescue ketorolac Similar consumption of rescue opioids, pain scores, performance time, procedural pain, onset of sensory and motor blockade, performance during physical therapy, and patient satisfaction
Casati et al.[28] (2005)	Hallux valgus repair	BC vs SC for posterior popliteal SB	98/ 2	LA consumption	Similar performance time, evolution of sensory and motor block, pain scores, incidence of side effects, and patient satisfaction SC: decreased consumption of LA/ rescue opioids and shorter onset of sensory and motor blockade
Casati et al.[29] (2006)	Hallux valgus repair	BC vs SC for posterior popliteal SB	76/ 2	LA consumption	Similar pain scores and incidence of side effects. Similar LA costs (and 40% increase in analgesia-related costs), if 200-mL bags used SC: decrease consumption of LA/ rescue opioids, decrease costs in LA (and no additional analgesia-related costs), if 100-mL bags used. Improved patient satisfaction
Rodriguez et al.[30] (2006)	Hallux valgus repair	BC (infusion of LB 0.125 vs SC (infusion of LB 0.125%) vs SC (infusion of LB 0.0625%)	48/ 3	Pain score (VAS 0-100)	BC: highest LA consumption (compared to the 2 other groups) and higher pain scores at 19-23 hr compared to SC (infusion of LB 0.125%) SC (infusion of LB 0.125%): lowest consumption of rescue opioids, lowest pain scores and highest degree of motor block at 6-8 hours

ACL = anterior cruciate ligament; BC = blind catheter; CMS = Constant Murley Score; DASH = disability of the arm, shoulder, and hand; FB = femoral block; ISB = interscalene block; LA = local anesthetic agent; LB = levobupivacaine; SB = sciatic block; SC = stimulating catheter; TKR = total knee replacement; VAS = visual analogue scale.

cohort studies were excluded, to avoid potential biases introduced by institutional practices.

Results

Our search criteria yielded 28 RCTs. Of these studies, 13 were excluded because they did not provide blinded assessment or sample size justification.[1–13] Of the remaining 15 RCTs, seven compared US to traditional adjunctive modalities for peripheral nerve blocks (Table I), while eight compared stimulating to non-stimulating perineural catheters (Table II).

I. Adjunctive ultrasonography

Axillary block (AXB)

Four RCTs have compared AXB using traditional adjuncts and US. Liu *et al*.[14] randomized 90 patients undergoing forearm/ hand surgery to an AXB. They used a two-injection, neurostimulation-guided technique, with equal volume injections around the median and radial nerves (stimulation thresholds and pulse widths not specified); a one-injection, US technique (with injection around the lateral aspect of the axillary artery); and a two-injection, US technique (with equal volume injections around the lateral and the medial aspects of the artery). All subjects received 0.5 mL·kg^{-1} of lidocaine 1.5% with epinephrine 5 µg·mL^{-1}. Compared to the US groups, these authors reported a longer performance time (8.2 ± 1.5 *vs* 6.5-6.7 ± 1.3 min; *P* < 0.05) and a higher incidence of side effects (paresthesia, vascular puncture, hematoma) (20 *vs* 0% of patients; *P* = 0.03) with neurostimulation. However, no differences were noted in success of surgical anesthesia (83–90%) and in the rate of complete blocks at 40 min (70–73%). Despite the fact that one important benefit of US-guided nerve block resides in the visualization of LA spread and the repositioning of the needle tip to achieve circumferential, perivascular or perineural spread, Liu *et al*.[14] elected to keep the needle in a static position during the injection for their two US groups. This may explain the lack of difference in success rates between US and neurostimulation (NS). Using a technique relying on multiple injections to achieve circumferential LA spread around the artery, Sites *et al*.[15] compared US guidance to a transarterial technique (with two equal volume injections in front and behind the artery) in 56 patients undergoing hand surgery. Using 35 mL of lidocaine 1.5% with epinephrine 5 µg·mL^{-1}, these authors found that echoguidance yielded a shorter performance time (7.9 ± 3.9 *vs* 11.1 ± 5.7 min; *P* < 0.05) and a lower failure rate, defined as conversion to general anesthesia or the inability to localize the artery (0 *vs* 28.6% of patients; *P* = 0.01). The low success rate of the transarterial technique echoes the findings of a recent review article, which reported that, for AXB, a three- or four-NS technique offers the highest efficacy.[16] Thus, after enrolling 188 patients undergoing hand surgery, Chan *et al*.[17] performed a three-injection AXB (with injections around the median, radial, and ulnar nerves) and randomized the adjunctive technique to NS, US, or NS combined with US. All patients received 42 mL of an adrenalized, equal-part mix of lidocaine 2% and bupivacaine 0.5%. For the NS and the NS-US groups, a stimulation threshold of 0.5 mA or less (pulse width = 0.1 msec) was deemed satisfactory. Forearm pronation/ thumb opposition, fourth/ fifth finger flexion, and forearm/ wrist extension were considered acceptable motor responses for stimulation of the median, ulnar, and radial nerves, respectively. These authors found that patients in the NS group displayed the lowest success rate (defined as the absence of tactile sensation in all three nerve territories at 30 min) (62.9 *vs* 80.7–82.8% of patients; *P* = 0.03). Subjects in the US and the US-NS groups exhibited similar success rates and incidences of surgical anesthesia (92–95%). However, the addition of NS to US resulted in a longer performance time (12.4 ± 4.8 *vs* 9.3 ± 4 min; *P* = 0.01). There were no differences in the incidence of side effects. In 59 patients undergoing upper limb surgery below the elbow, Casati *et al*.[18] compared a four-injection AXB using NS or US. All subjects received 5 mL of ropivacaine 0.75% per nerve. For patients randomized to NS, a stimulation threshold of 0.5 mA or less (pulse width = 0.15 msec) was required for each nerve. Wrist/ second and third finger flexion, fourth and fifth finger flexion, forearm/ finger extension, and forearm flexion were considered acceptable motor responses for stimulation of the median, ulnar, radial, and musulocutaneous nerves, respectively. Despite a shorter onset of sensory blockade in the US group, these authors reported no difference in readiness for surgery (defined as complete sensory block in the four nerve territories and complete motor block in at least three nerve territories) (26–28 min). No failed block was reported in either group. Furthermore, procedural pain scores and patient satisfaction were also similar.

Femoral block (FB)

In 60 patients requiring FB (using ropivacaine 0.5%) for knee arthroscopy, after randomizing the technique to NS or US, Casati *et al*.[19] set out to elucidate the minimum effective anesthetic volume (MEAV). Starting with an initial volume of 12 mL, LA volume was decreased by 3 mL in each subsequent patient if effective femoral nerve block was achieved within 30

min of injection. Conversely, LA volume was increased by 3 mL in the subsequent patient, if a failure occurred. For NS, a stimulation threshold of 0.4 mA or less (pulse width = 0.05 msec) and quadricipital contraction (with patellar movement), as the evoked motor response, were sought. These authors found a 42% reduction in LA requirement with US; the MEAV50 were 15 ± 4 and 26 ± 4 mL for US and NS, respectively (P = 0.002). The effective dose in 95% of cases (ED_{95}), through probit transformation and logistic regression analysis, was calculated to be 22 and 41 mL, for US and NS, respectively.

Sciatic block (SB)
In 61 patients undergoing foot or ankle surgery, Domingo-Triado et al.[20] performed a lateral, midfemoral SB using 35 mL of ropivacaine 0.5%. They randomized the adjunctive technique to isolated NS or US-NS. Despite the fact that one important benefit of US-guided nerve block resides in the visualization of LA spread and the repositioning of the needle tip to achieve circumferential perineural spread, these authors used US mainly to guide the stimulating needle towards the nerve. Moreover, despite the fact that tibial nerve electrostimulation is associated with a higher success rate for lateral, midfemoral SB,[21] both tibial and peroneal nerve stimulation were deemed satisfactory endpoints. A saphenous nerve block was also performed when the surgical incision extended over the saphenous nerve's innervation area. For SB, both groups displayed a similar median stimulating threshold (0.5 mA; pulse width = 0.3 msec). In the NS group, stimulation of the posterior tibial nerve occurred more often (58 *vs* 30% of patients; P = 0.04). Despite this, more patients in the US-NS group displayed a complete sensory block (96.7 *vs* 71% of patients; P = 0.01) and tolerance to calf tourniquet (93.3 *vs* 48.4% of patients; P = 0.001). There were no significant differences in procedural pain, performance time, sensory and motor block onset times, or block duration. In 46 pediatric patients undergoing lower extremity surgery, Oberndorfer et al.[22] performed isolated SB (n = 32) or SB combined with FB (n = 14). They randomized the adjunctive technique to US or NS. Sciatic block was carried out using the subgluteal (n = 23) or the popliteal (n = 23) approaches. For neurostimulation of the sciatic nerve, a minimal, stimulation threshold of 0.3 mA or less (pulse width = 0.3 msec) and plantar flexion, as the evoked motor response, were deemed satisfactory. For stimulation of the femoral nerve, a minimal stimulation threshold of 0.3 mA or less (pulse width = 0.3 msec) and quadricipital contraction, as the evoked

motor response, were sought. For US-guided SB and FB, the authors used a multiple-injection technique to achieve circumferential LA spread around the nerve. All subjects received levobupivacaine 0.5%, either at a fixed dose of 0.3 mL·kg⁻¹ per nerve (NS group), or until the target nerve was surrounded by LA (US group). Despite receiving a lower amount of LA for both SB (0.20 ± 0.06 *vs* 0.3 mL·kg⁻¹; P < 0.001) and FB (0.15 ± 0.04 *vs* 0.3 mL·kg⁻¹; P < 0.01), patients in the US group had longer lasting blocks (508 ± 178 *vs* 335 ± 169 min; P < 0.001).

Interpretation
In the setting of AXB, multiple-injection US guidance yields a higher success rate compared to a double-injection, transarterial and a three-NS technique. Compared to a four-NS technique, both methods result in similar success rates, procedural pain scores, readiness for surgery, and patient satisfaction. The addition of NS to US guidance offers no clear benefits for AXB; in fact, a marginally longer performance time (3.1 min) is seen when both modalities are combined. In the setting of FB, compared to NS, echoguidance is associated with a LA sparing effect (up to 42%). In children, US guidance yields a LA sparing effect and a longer duration of action for lower extremity nerve blocks.

Because of the limited number of studies, caution should be exercised when interpreting the data available in the literature. So far, no RCT with blinded assessments and appropriate sample size justification, has investigated US as a substitute to NS, in the context of cervical paravertebral block, interscalene block, supraclavicular block, infraclavicular block, humeral canal block, lumbar plexus block, and SB, using approaches other than the subgluteal and posterior popliteal approaches. Furthermore, no RCT has compared US- and NS-guided continuous peripheral nerve blocks.

II. Stimulating perineural catheters
Interscalene block (ISB)
In 40 patients undergoing corrective surgery for acromioclavicular arthropathy, impingement, biceps tendonitis, and calcified tendinopathy, Stevens et al.[23] compared blind and stimulating interscalene catheters (median stimulation threshold of the catheter = 0.4 mA; pulse width = 0.1 msec). Both catheters were injected with 40 mL of prilocaine 1% and with 10 mL of ropivacaine 0.75% and were also infused with ropivacaine 0.2% (8 mL·hr⁻¹ with 2 mL each 20 min *prn*). During the study period (48 hr), these authors reported no differences in static and dynamic pain

scores, ropivacaine consumption, and requests for supplemental non-steroidal, anti-inflammatory drugs (metimazol) or opioids (piritramide). Furthermore, procedural pain and performance time were also similar. However, complete motor block was achieved ten minutes sooner with stimulating catheters (10 *vs* 20 min; $P = 0.02$); onset of sensory block did not differ between the two groups. At six months, patients who received a stimulating catheter displayed a greater improvement in shoulder function when assessed with the Constant Murley Score (34.5 *vs* 4; $P < 0.01$), but not when assessed with the Disability of the Arm, Shoulder and Hand criteria.

Femoral block (FB)
Four RCTs have compared stimulating and non stimulating femoral catheters in healthy volunteers undergoing total knee replacement (TKR) and anterior cruciate ligament (ACL) repair. In 20 healthy volunteers, Salinas *et al.*[24] placed bilateral femoral catheters by randomizing one side to a non stimulating catheter and the contralateral side to a stimulating catheter (mean stimulation threshold of the catheter = 0.47 ± 0.05 mA; pulse width = 0.1 msec). Both catheters were bolused with 10 mL of lidocaine 1% and infused with ropivacaine 0.2% infusion (10 mL·hr^{-1} for four hours). These authors detected a clinical difference of 15% in success rate (i.e., loss of sensation to cold and pinprick) (85 *vs* 100% of patients; $P = 0.07$); however, the protocol was only powered to detect a 25% difference. Nonetheless, limbs anesthetized with stimulating catheters displayed a denser femoral nerve block, as evidenced by higher tolerance to transcutaneous electrical stimulation ($P = 0.009$) and depth of motor impairment ($P = 0.03$).

In 41 patients undergoing unilateral TKR, Hayek *et al.*[25] compared blind to stimulating femoral catheters (mean stimulation threshold of the catheter = 0.5 ± 0.2 mA; pulse width unspecified). Both catheters were injected with 25 mL of ropivacaine 0.2% and infused with 6 mL·hr^{-1} of ropivacaine 0.2% for 24–48 hr. For breakthrough pain, both groups were allowed nurse-controlled boluses and increases in the rate of ropivacaine. They also had access to patient-controlled intravenous fentanyl. A single shot SB was not performed. These authors reported similar consumptions of ropivacaine (8.2–8.8 mL·hr^{-1}) and fentanyl (55.0–55.5 μg·hr^{-1}). Furthermore, no differences were found in pain scores, block success rate, physical therapy performance, and side effects.

In 70 patients undergoing ACL repair, Dauri *et al.*[26] compared blind and stimulating femoral catheters (stimulation threshold of the catheter = 0.4–0.5

mA; pulse width = 0.1 msec). Both catheters were inserted preoperatively, and bolused with 25 mL of ropivacaine 0.75% and 50 μg of clonidine. The 36-hr infusion consisted of ropivacaine 0.2% (7 mL·hr^{-1} with 5 mL each 60 min *prn*). A single shot SB (using 20 mL of ropivacaine 0.75% and 50 μg of clonidine) was also performed, to provide analgesia for the posterior aspect of the knee. Stimulating catheters resulted in a quicker sensory block for the femoral nerve (6.4 ± 2.5 *vs* 8.3 ± 2.9 min; $P = 0.006$); however, the success rates of femoral (100%), lateral femoral cutaneous (74.3–88.6%), and obturator nerve blockade (74.2–82.8%) did not differ between the two groups. Furthermore, the intraoperative requirements of propofol and sufentanyl were also similar. Postoperatively, patients with stimulating catheters consumed less breakthrough ropivacaine (14.6 ± 12.6 *vs* 23.2 ± 13.6 mg; $P = 0.008$) and rescue ketorolac (34.3 ± 35.7 *vs* 54 ± 39.7 mg; $P = 0.033$). This did not translate into a reduced incidence of side effects. Moreover, static and dynamic pain scores were not significantly different.

In 81 patients undergoing TKR ($n = 60$) or ACL repair ($n = 21$), Morin *et al.*[27] compared blind and stimulating femoral catheters (median stimulation threshold of the catheter = 0.2 mA; pulse width = 0.3 msec). Both catheters received a bolus of 20 mL of prilocaine 2% and an infusion of ropivacaine 0.2% (6 mL·hr^{-1} for 48 hr). All patients received a daily dose of rofecoxib and had access to patient-controlled narcotics (piritramide) for breakthrough pain. The authors did not perform a single shot SB. Morin *et al.*[27] found no technical differences pertaining to catheter placement (procedural time, patient satisfaction, and anesthesiologist's evaluation of the difficulty encountered). After the bolus, no differences were noted in the onset of sensory and motor blockade. Postoperatively, static and dynamic pain scores, as well as physiotherapy performance, were similar during the five observational days after surgery. Although a 15% decrease in rescue piritramide consumption was noted during the first 48 hr (44 *vs* 52 mg), this did not achieve statistical significance, as the protocol was only powered to detect a 33% difference.

Sciatic block (SB)
Three RCTs have compared stimulating and non stimulating, posterior popliteal sciatic catheters in the setting of hallux valgus surgery. In all three studies, a single shot femoral or saphenous nerve block was also performed, to cover the medial aspect of the lower limb. Patients also received regular doses of propacetamol or ketorolac. In 98 subjects, after bolusing the

popliteal catheters with 25 mL of mepivacaine 1.5% and infusing them with ropivacaine 0.2% (3 mL·hr^{-1} with 5 mL each 20 min *prn* to a maximum of two hourly doses), Casati *et al.*[28] observed that stimulating catheters (mean stimulation threshold of the catheter = 0.39 ± 0.17 mA; pulse width = 0.15 msec) were associated with a shorter onset of sensory (15 *vs* 20 min for tibial nerve; 10 *vs* 15 min for common peroneal nerve; both $P \leq 0.02$) and motor blockade (20 *vs* 30 min; $P = 0.004$), as well as a decrease in ropivacaine consumption (239 *vs* 322 mL; $P = 0.002$) and need for rescue opioid (tramadol) analgesia (25 *vs* 58% of patients; $P = 0.002$). However, during the study period (48 hr), this did not translate into a difference in the evolution sensory and motor blockade, the static and dynamic pain scores, or the incidence of side effects. Moreover, patient satisfaction was also similar. Interestingly, the catheter insertion time was not different between the two groups (5–7 ± 2 min). The following year, Casati *et al.*[29] repeated the same protocol in another 76 patients. Again, during the study period (24 hr), stimulating catheters (stimulation threshold not specified) were associated with a decrease in ropivacaine consumption (120 *vs* 153 mL; $P = 0.04$). Administration of breakthrough tramadol was also decreased (21 *vs* 60% of patients; $P = 0.001$). Despite yielding a marginally higher level of patient satisfaction (90 *vs* 80 on a 0–100 mm scale; $P = 0.013$), this altered neither the static and dynamic pain scores, nor the incidence of side effects. However, the authors were able to calculate that the reduction in ropivacaine resulted in decreased costs in LA (21 *vs* 42 ε; $P < 0.001$), if 100-mL bags of ropivacaine were used. These savings covered the additional cost of the stimulating catheter so that, in the end, there were no differences in analgesia-related expenditures between the two groups. When using 200-mL bags, the LA sparing effect did not occur; thus, a 40% increase in analgesia-related costs was seen with stimulating catheters (75 *vs* 55 ε; $P < 0.001$).

Rodriguez *et al.*[30] randomized 48 patients to blind catheters using levobupivacaine 0.125% infusion, stimulating catheters using levobupivacaine 0.0625% infusion (median stimulatory threshold of the catheter = 0.52 mA; pulse width = 0.1 msec), and stimulating catheters using levobupivacaine 0.125% infusion (median stimulatory threshold of the catheter = 0.42 mA; pulse width = 0.1 msec). All infusions were run at a basal rate of 3 mL·hr^{-1}, with the possibility of one additional bolus of 3 mL every hour. These authors reported that the stimulating catheter-levobupivacaine 0.125% group consistently displayed lower pain scores at six to eight hours (5 *vs* 60–70 on a 0–100 scale;

$P < 0.05$) and required less rescue opioid (tramadol) analgesia at 24 hr (0 *vs* 31–44% of patients; $P < 0.05$). However, motor block of the ankle occurred more frequently at six to eight hours (88 *vs* 25–31% of patients; $P < 0.05$).

Interpretation

Compared to their blind counterparts, stimulating catheters can provide faster and denser nerve blocks. Although statistically significant, the shorter onset of sensory blockade (for instance, 6.4 ± 2.5 *vs* 8.3 ± 2.9 min for FB) may not be clinically relevant. Furthermore, these advantages do not seem to offer many practical benefits, because of their minimal impact on patient satisfaction, procedural pain, performance time, success rate of the block, static/ dynamic pain scores, and physiotherapy performance. Stimulating catheters can also provide a reduction in LA and opioid consumption. Unfortunately, this sparing effect is not associated with a decrease in the incidence of side effects. Furthermore, at best, the decrease in LA consumption may only serve to cover the cost of the stimulating catheter itself; total analgesia-related expenditures remain similar between stimulating and non stimulating catheters.

Caution should be exercised when interpreting the data available in the literature. So far, only a limited number of surgical procedures (shoulder, TKR, ACL, and hallux valgus surgery), in the setting of a limited array of perineural catheters (interscalene, femoral, and posterior popliteal), have been studied. To date, no RCT has compared blind and stimulating catheters for other orthopedic procedures and other types of nerve blocks (cervical paravertebral, thoracic paravertebral, SCB, ICB, AXB, lumbar plexus, transgluteal/ subgluteal/ lateral midfemoral/ lateral popliteal SB). Moreover, no study has formally compared the equipment available for stimulating catheter insertion. RCTs have used alternately different kits: the Arrow StimuCath Continuous Nerve Block Set (Arrow International, Reading, PA, USA);[23–25,27] an 18G, 85-mm long needle, oversheathed with a plastic introducer set (Multiplex, Vygon, France);[28,29] a 50-mm, 18G needle with a stimulating catheter (Polymedic C-50 K +);[26] or a 22G, stimulating catheter with a 19.5G, 100-mm needle set (Stimulong Plus, Pajunk, Geisingen, Germany).[30] Further studies are required to compare the electrical properties of these kits.

Limitations

For practical reasons, a decision was taken not to include ambulatory pumps in this narrative review. Although outpatient perineural LA infusions have

TABLE III   Elements of adjunctive ultrasonography and stimulating perineural catheters warranting further investigation

Adjunctive Ultrasonography	• Comparison of NS and US for: CPVB, ISB, SCB, ICB, brachial canal block, LPB, SB using approaches other than the subgluteal and posterior popliteal approaches • Comparison of NS and US for perineural catheter insertion • Comparison of palpation- and US-guided epidural blocks
Stimulating Perineural Catheters	• Comparison of blind and stimulating catheters for orthopedic surgical procedures other than shoulder surgery, TKR, ACL repair and hallux valgus correction • Comparison of blind and stimulating catheters for CPVB, TPVB, SCB, ICB, AXB, LPB and SB using approaches other than the posterior popliteal approach • Comparison of the different commercially available kits for stimulating perineural catheter insertion

ACL = anterior cruciate ligament; AXB = axillary block; CPVB = cervical paravertebral block; ICB = infraclavicular block; ISB = interscalene block; LPB = lumbar plexus block; NS = neurostimulation; SB = sciatic block; SCB = supraclavicular block; TPVB = thoracic paravertebral block; TKR = total knee replacement; US = ultrasonography.

revolutionized the practice of ambulatory anesthesia, the data derived from the eight RCTs dealing with this topic would have been difficult to interpret.[31–38] While five RCTs discharged patients on the day of surgery,[32,34–37] three studies involved patient admission to hospital for the first night following surgery.[31,33,38] Presumably, in these subjects, such a decision had an impact on the quality of data recording. While most RCT protocols examined ropivacaine 0.2% infusions, one study evaluated bupivacaine 0.25%.[36] More importantly, a total of six different types of ambulatory pumps were used in these eight RCTs. Ilfeld *et al.*[39–41] have repeatedly demonstrated that infusion rate accuracy differed significantly among various pumps, exhibiting flow rates within 15% of their expected rate for 18–100% of the infusion duration.

For this review, no attempt was made to perform a meta-analysis. In our view, heterogeneity would have been far too great to have supported such a systematic pooling of data.

Conclusions
For axillary blocks, US guidance yields a higher success rate than a double-injection, transarterial and a triple-stimulation technique. Compared to a quadruple-stimulation technique, no differences were found. The addition of NS to US guidance offers no clear benefits for AXB. For femoral blocks, compared to

neurostimulation, echoguidance is associated with a LA sparing effect (up to 42%). In children, US guidance yields a LA sparing effect and a longer duration of action for lower extremity nerve blocks.

Compared to their blind counterparts, stimulating perineural catheters seem to provide limited clinical benefits because of their minimal impact on patient satisfaction, procedural pain, performance time, success rate of the block, static/dynamic pain scores, and physiotherapy performance. The use of stimulating catheters is associated with a marked reduction in LA and opioid consumption. However, the benefits of this sparing effect remain uncertain, as they are not associated with a decrease in side effects or with analgesia-related costs.

A critical survey of the available RCTs can provide an effective tool to establish recommendations pertaining to the use of adjunctive US and stimulating perineural catheters. However, caution should be exercised when interpreting the limited data available in the literature. Despite current best evidence, many issues regarding these recent advances in regional anesthesia remain unresolved and, thus, warrant further elucidation through well-designed and meticulously conducted RCTs (Table III).

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