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Ultrasound guidance compared with electrical neurostimulation for peripheral nerve block: a systematic review and meta-analysis of randomized controlled trials

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Background. Despite the growing interest in the use of ultrasound (US) imaging to guide performance of regional anaesthetic procedures such as peripheral nerve blocks, controversy still exists as to whether US is superior to previously developed nerve localization techniques such as the use of a peripheral nerve stimulator (PNS). We sought to clarify this issue by performing a systematic review and meta-analysis of all randomized controlled trials that have compared these two methods of nerve localization.

Methods. We searched Ovid MEDLINE®, the Cochrane Central Register of Controlled Trials®, and Google Scholar databases and also the reference lists of relevant publications for eligible studies. A total of 13 studies met our criteria and were included for analysis. Studies were rated for methodological quality by two reviewers. Data from these studies were abstracted and synthesized using a meta-analysis.

Results. Blocks performed using US guidance were more likely to be successful [risk ratio (RR) for block failure 0.41, 95% confidence interval (CI) 0.26–0.66, $P<0.001$], took less time to perform (mean 1 min less to perform with US, 95% CI 0.4–1.7 min, $P=0.003$), had faster onset (29% shorter onset time, 95% CI 45–12%, $P=0.001$), and had longer duration (mean difference 25% longer, 95% CI 12–38%, $P<0.001$) than those performed with PNS guidance. US guidance also decreased the risk of vascular puncture during block performance (RR 0.16, 95% CI 0.05–0.47, $P=0.001$).

Conclusions. US improves efficacy of peripheral nerve block compared with techniques that utilize PNS for nerve localization. Larger studies are needed to determine whether or not the use of US can decrease the number of complications such as nerve injury or systemic local anaesthetic toxicity.

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With the recent proliferation of ultrasound (US)-guided techniques for performing regional anaesthetic procedures such as peripheral nerve blocks, there has been much debate on the relative merits of US technology in comparison with the earlier methods of nerve localization. The use of a peripheral nerve stimulator (PNS) has been the 'gold standard' for performing peripheral nerve blocks for the last two decades, and has been shown to be a highly effective technique for determining adequate needle placement to produce regional anaesthesia/analgesia.[1–3] Whether or not the use of US can improve practitioners' ability to successfully perform peripheral nerve blocks remains controversial. Several randomized controlled trials (RCTs) have been conducted to compare these two modalities,[4–16] but the number of patients in each study has been too small to conclusively demonstrate superiority of one technique over another. We sought to clarify this issue by performing a meta-analysis of all RCTs that have compared these two techniques.

We hypothesized that the success rate of peripheral nerve blocks would be different when comparing placement with US or PNS guidance. We defined the block

success rate as the percentage of blocks which allowed patients to undergo a surgical procedure without supplementation or conversion to general anaesthesia (GA) or spinal anaesthesia (SA). Other outcomes we examined included: time to perform the block, onset time, duration of block, and complications such as vascular puncture or persistent neurological symptoms.

Methods

Data extraction and quality assessment

In order to find all RCTs that have compared US guidance with the use of a PNS for performing peripheral nerve blocks, we searched Ovid MEDLINE®, the Cochrane Central Register of Controlled Trials®, and Google Scholar databases for keywords: ultrasound with: regional anaesthesia, nerve block, nerve stimulation, and neurostimulation. We performed a two-stage search,[17] using additional keywords in a second-phase search to capture studies not initially identified. Secondary keywords included ultrasound with: interscalene, infraclavicular, axillary, femoral, sciatic, popliteal, and peripheral nerve. Searches were limited to clinical trials and RCTs in humans published between January 1, 1990, and September 1, 2008. Searches were not restricted to the English language. We also searched by hand the archives of relevant journals to identify additional studies that could meet our inclusion criteria. Two of the authors (M.S.A. and M.F.A.) independently examined titles, abstracts, and keywords of citations from electronic databases or journals for eligibility. We obtained the full text of all relevant articles and two of the authors (M.S.A. and M.F.A.) independently assessed whether each met the predefined inclusion criteria (prospective data collection, randomization, and comparison of US and PNS guidance for peripheral nerve blocks in humans). Searching the references of these studies did not yield any additional RCTs comparing US with PNS.

Included studies were then independently rated for methodological quality by two of the authors (M.S.A. and M.F.A.). Any discrepancy in rating was settled by discussion with a third author (J.-L.H.) until consensus was reached. Studies were rated using a nine-item scoring system. The items assessed were:

(1) the method of randomization;
(2) adequate measures taken to conceal allocation;
(3) inclusion and exclusion criteria for patients entered into the study;
(4) adequate description of treatment and control groups at the entry to the study;
(5) if the anaesthetic care was identical between the groups other than the nerve localization technique used for block performance;
(6) equivalent block techniques compared between the groups;
(7) clear definition of the outcome measures in the text;
(8) blinding of the assessors to the treatment group;
(9) statistical analysis on an intention-to-treat basis.

Each study could receive a maximum score of 13. The method of randomization and equivalency of block techniques were considered the most important and could score a maximum of three points. All other items could score one point only. Studies with scores of five or less were considered poor quality and would be excluded from the analysis. Those with scores of six to 10 were considered fair quality and those with scores of 11 or higher were considered good quality studies. None of the eligible studies was excluded due to poor methodological quality. Seven of the studies were rated fair quality[5 6 12–16] and six good quality studies.[4 7–11]

We extracted the outcome measures from each study to a spreadsheet. The data included: number of failed blocks, number of rescue or supplemental blocks, number of patients requiring conversion to GA or SA, procedure time, onset time (sensory and motor), complete block at 30 min (sensory and motor), time to readiness for surgery, volume of local anaesthetic injected, number of needle passes required to complete block, number of procedures successfully performed with the first needle pass, procedure-related pain, number of patients reporting paraesthesia during block procedure, number of vascular punctures, number of patients able to tolerate a pneumatic tourniquet during surgery, intraoperative dose of sedative or analgesic medications, postoperative pain or bruising at the block site, persistent neurological symptoms, and block duration.

Statistical analysis

We conducted meta-analyses to obtain more precise estimates comparing US with PNS guidance. For binary outcomes such as block failure, the number of complete sensory or motor blocks at 30 min, vascular puncture, or persistent neurological symptoms, a pooled risk ratio (RR) was estimated using the fixed-effect Mantel–Haenszel method when the between-study heterogeneity was estimated to be zero. Otherwise, the DerSimonian–Laird[18] random effects model was used. For continuous outcomes such as procedure time, onset time, or duration of block, the mean differences (standard errors) between the US-guidance and PNS-guidance methods were calculated from each study and combined using the DerSimonian–Laird[18] random effects model to account for difference among studies.[19] When median time instead of mean time was reported in the study, we used difference in median to approximate mean difference when the distribution of the data was quite symmetric, as in most cases. The standard deviation, if not reported, was calculated based on the reported range.[20] When the reported data showed evidence

of skewness, we calculated standard deviation by assuming the log-transformed data had a normal distribution. Statistical heterogeneity was assessed by Cochran's Q test and I^2 statistic.[21] Publication bias was tested using the funnel plot and Egger's linear regression method.[22] No publication bias was detected by these methods, though the interpretation of results may be limited due to the relative small number of studies in each meta-analysis.[23] All analyses were performed using Stata 10.0 (StataCorp, College Station, TX, USA, 2007).

Results

Patients and studies included

Thirteen studies involving a total of 946 patients receiving peripheral nerve blocks were included. Details of these studies are summarized in Table 1 and Appendix A (Supplementary material available online). A total of 209 studies were identified by our search, of which 184 were excluded because they involved comparisons outside the scope of this review (e.g. US-guided prostate biopsies and neuraxial techniques). The remaining 25 studies were considered for this review and of these 12 were excluded because: they did not compare equivalent blocks (e.g. US-guided infraclavicular and PNS-guided axillary, one study), they compared different US-guided techniques and did not include a PNS group for comparison (three studies), they compared US guidance to landmark-based techniques (five studies), they studied blocks performed using both US and PNS to blocks done with US guidance only (two studies), or they were dose-finding studies which by definition included many failed blocks in both the US and PNS groups (one study). A list of excluded studies can be found in Appendix B (Supplementary material available online).

Outcome measures

Block failure

Two studies[15 16] studied femoral blocks performed to provide analgesia to patients with hip fractures, rather than for surgical anaesthesia. Another study involved blocks performed in children who were under GA.[11] Therefore, these studies were not included in the comparison between US and PNS for this outcome. One other study[13] could not be used for meta-analysis as there were no block failures in either study group. In the remaining nine studies, block failure was defined as a block that did not provide adequate anaesthesia for the planned surgical procedure, required the performance of a rescue or supplemental block procedure, administration of additional analgesic medications, or conversion to GA or SA. The combined RR from each study showed the risk of block failure in the US group was 0.41 that of the PNS group [RR 0.41, 95% confidence interval (CI) 0.26–0.66, $P<0.001$] (Fig. 1). No heterogeneity was detected among studies (Q=3.99, $I^2=0\%$, $P=0.86$).

There was a statistically significant difference in the risk of patients requiring conversion to GA or SA (RR 0.28, 95% CI 0.12–0.63, $P=0.002$) (Fig. 2). However, there was no significant difference between the groups in the need for rescue blocks in the studies that reported the number of supplemental or rescue blocks performed (overall RR 0.52, 95% CI 0.26–1.04, $P=0.63$).

Procedure time

Seven studies compared the time to perform blocks using PNS or US guidance[5–7 9 10 12 14] (Fig. 3). Five of these studies defined procedure time as the time from placement of the US probe to completion of local anaesthetic injection (US groups) and needle insertion to completion of local anaesthetic injection (PNS groups).[5 7 9 12 14] One study[6] defined procedure time as the interval from probe preparation to completion of local anaesthetic injection in the US group and as the interval from palpating landmarks to completion of local anaesthetic injection in the PNS group. One study defined procedure time as the time from needle insertion to successful nerve localization (US and PNS groups).[10] Test of heterogeneity was significant among studies ($Q=22.4$, $I^2=73.5\%$, $P=0.001$), but the direction of mean difference was quite consistent. Overall, US guidance resulted in shorter procedure times (mean 1 min less time to perform with US, 95% CI 0.4–1.7 min, $P=0.003$), though this difference is probably not of clinical significance.

Onset time

Eight studies compared the onset time of sensory block for blocks performed using US or PNS[4 5 7 8 10 13 15 16] (Fig. 4). The other studies did not explicitly measure onset time of the sensory or motor block. Onset time was defined as loss of pinprick or cold sensation in the central sensory area (area proprea) of the blocked nerve in seven of the studies.[4 5 7 8 10 15 16] One study in children defined a visual analogue pain score (VAS) of 1 in the blocked area as the onset of sensory block (all of the subjects in this study were having surgery to treat traumatic injuries).[13] Because the length of onset time was highly variable between studies due to differences in the anatomy and physiology of the nerve(s) blocked and the local anaesthetics used, our analysis was based on the percentage change in mean difference of onset time, rather than the absolute change in mean difference. Significant heterogeneity was detected among studies ($Q=58.1$, $I^2=88.1\%$, and $P<0.001$). Incorporating the heterogeneity into the combined estimate, the overall mean percentage change was 29% faster onset time for the US group when compared with the PNS group (95% CI 45–12%, $P=0.001$).

Five studies measured the number of blocks that produced complete sensory block at 30 min (as defined by

Table 1 Characteristics of studies included for analysis. None of these studies reported any statistically significant difference in the baseline patient characteristics of study participants (e.g. age, weight, height, ASA classification, male:female ratio, and type of surgical procedure) between the US and PNS groups. VAS, visual analogue scale. *$P<0.05$, favours US group. **$P<0.05$, favours PNS group. †Not included in calculations of block failure rate as blocks were performed in patients under GA. ‡Not included in calculations of block failure rates as there were no block failures in either study group. ¶Not included in calculations of block failure rates as blocks were performed for analgesia rather than surgical anaesthesia

First author (year published)	Number of patients (US/PNS), patient population	Block performed	Failed blocks (US/PNS)	Other reported outcomes (US/PNS)	Reported complications (US/PNS)	Quality score
Kapral (2008)	80/80, adult patients undergoing trauma-related surgery of the shoulder or upper arm	Interscalene with ropivacaine 0.75% (20 ml)	1/7*	Mean onset time sensory (min) 10/22*, mean block duration (min): 899/679*	None reported	11
Macaire (2008)	30/29, adult patients undergoing ambulatory endoscopic carpal tunnel release	Median and ulnar with mepivacaine 1.5% (4 ml) each, 1 ml s.c. infiltration of incision site	2/2	Median time to perform block (min): 2.6/3.5, median onset time sensory (min): 6.2/4.1**, median block-related pain (VAS): 4/4, median venipuncture-related pain (VAS): 3/3	None reported	9
Perlas (2008)	37/33, adult patients undergoing elective major foot or ankle surgery	Popliteal sciatic with 30 ml 1:1 mixture bupivacaine 0.5%: lidocaine 2% with 1:200 000 epinephrine	4/13*	Mean time to perform block (min): 8.1/8.3, no. of complete sensory block at 30 min: 33/23*, no. of complete motor block at 30 min: 34/23*	None reported	10
Sauter (2008)	40/40, adult patients undergoing elective ambulatory surgery of the hand or forearm	Lateral saggital infraclavicular with mepivacaine 1.5% (0.6 ml kg^{-1})	2/6	Mean time to perform block (min): 4.1/4.3, mean onset time sensory (min): 13.9/13.7, readiness to surgery (min): 18.1/18.1, median block-related pain (VAS): 1/1, median tourniquet-related pain (VAS): 1/0.5	No. of vascular punctures: 2/13*	11
Casati (2007)	30/29, adult patients undergoing elective forearm, wrist, or hand surgery	Axillary (multiple-injection) with ropivacaine 0.75% (20 ml)	1/2	Readiness to surgery (min): 26/28, mean onset time sensory (min): 14/19*, mean onset time motor (min): 24/25, median block-related pain (VAS): 1/3, patient satisfaction: 100%/93%	None reported	12
Chan (2007)	64/62, adult patients undergoing elective hand surgery	Axillary (multiple-injection) with lidocaine, 2% (42 ml) with 1:200 000 epinephrine	3/9*	No. of rescue blocks: 2/8, no. converted to GA: 1/1, mean time to perform block (min): 9/11*, no. of complete sensory block at 30 min: 53/39*, no. of complete motor block at 30 min: 43/42	No. of paraesthesia during block: 13/13, no. of persistent neurological symptoms: 13/13, no. of postoperative pain at block site: 3/10, no. of bruising at block site: 2/8	11
Domingo-Triadó (2007)	30/31, adult patients undergoing elective foot or ankle surgery	Lateral mid-femoral sciatic with ropivacaine 0.5% (35 ml)	1/3	No. converted to GA/SA: 1/3, median time to perform block (min): 5/5, median onset time sensory (min): 42/40, median onset time motor (min): 38/50, no. of complete sensory block at 30 min: 29/22*, no. of complete motor block at 30 min: 29/22*, median no. of needle passes to locate nerve: 1/2*, no. of successful first needle pass: 23/13*, no. of patients tolerate tourniquet: 28/15*, median block duration (min): 1050/1020	None reported	13
Oberndorfer (2007)	23/23, children having lower-extremity surgery under GA	Femoral with levobupivacaine 0.5% (US: 0.14 ml kg^{-1}, PNS: 0.3 ml kg^{-1}); sciatic with levobupivacaine 0.5% (US: 0.2 ml kg^{-1}, PNS: 0.3 ml kg^{-1})	0/2†	Mean block duration (min): 508/335*	None reported	11
Liu (2005)	30/30, adult patients undergoing elective forearm, wrist, or hand surgery	Axillary (double-injection) with lidocaine 1.5% (0.5 ml kg^{-1}) with 1:200 000 epinephrine	3/3	Mean time to perform block (min); 7/8*, no. of complete sensory block at 30 min: 27/21, no. of complete motor block at 30 min: 22/21, no. of tolerate tourniquet: 29 /28	No. of vascular punctures: 0/3, no. of paraesthesia during block: 0/3, no. of bruising at block site: 0/1	10
Marhofer (2004)	20/20, children having surgery for injuries of the forearm or hand	Infraclavicular with ropivacaine 0.5% (0.5 ml kg^{-1})	0/0‡	Median onset time sensory (min): 9/15*, mean block-related pain (VAS): 3/4, median block duration (min): 384/310*	None reported	10

Williams (2003)	40/40, adult patients undergoing forearm, wrist, or hand surgery	Supraclavicular with 0.5 ml kg^{-1}, 1:1 mixture bupivacaine 0.55%: lidocaine 2% with 1:200 000 epinephrine	5/9	No. of rescue blocks: 5/9, no. converted to GA: 0/3, mean time to perform block (min): 5/10*, no. of complete sensory block at 30 min: 38/32*, no. of complete motor block at 30 min: 22/26, mean block duration (min): 846/652	No. of persistent neurological symptoms: 1/2	7
Marhofer (1998)	20/40, adult patients with hip fractures (blocks for pain control)	Three-in-one with bupivacaine 0.5% (20 ml) (PNS group had two subgroups, 20 patients received 20 ml LA, 20 patients received 30 ml LA)	1/8[¶]	Mean sensory onset time (min): 13/27*	No. of vascular punctures: 0/4	8
Marhofer (1997)	20/20, adult patients with hip fractures (blocks for pain control)	Three-in-one with, bupivacaine 0.5% (20 ml)	1/2[¶]	Mean sensory onset time (min): 16/27*	No. of vascular punctures: 0/3	8

complete loss of sensation in all nerve distributions involved in the block performed).[6 9 10 12 14] In four of these studies, the US group showed a greater proportion of complete sensory block in all involved nerve territories.[6 9 10 14] The overall RR for complete block at 30 min was 1.23 comparing US with PNS (95% CI 1.07–1.41, P=0.004). Five studies measured the number of blocks that produced total motor block at 30 min for all involved nerves.[6 9 10 12 14] The pooled estimate from these studies did not show a statistically significant difference in the proportion of motor block between the US and PNS groups (RR 1.14, 95% CI 0.93–1.39, P=0.198).

Duration

Five studies examined the relationship between nerve localization technique and block duration[4 10 11 13 14] (Fig. 5). Block duration was defined as the interval between block performance and the first dose of analgesic medication. As the duration of block was quite variable between studies due to specificities of the blocks performed and local anaesthetics used, our analysis was based on the percentage change in mean difference of block duration, rather than the absolute change in mean difference. Significant heterogeneity was detected among studies (Q=11.3, I^2=64.6%, and P=0.023), but the direction of percentage change in mean difference was quite consistent. Overall, the US group had longer block duration than the PNS group, with a combined mean difference of 25% increased block duration (95% CI 12–38%, P<0.001).

Complications

Only some of the studies compared the relative risk of complications between the US and PNS groups.[7 9 12 14–16] Complications specifically assessed were vascular puncture, postoperative bruising at the site of the block, and persistent neurological symptoms in the distribution(s) of the blocked nerve(s). No major complications such as pneumothorax, systemic local anaesthetic toxicity, or permanent neurological damage were reported by any of the studies. Four studies[7 12 15 16] reported the incidence of vascular puncture and the combined estimate showed a significant difference between the US and PNS groups (RR 0.16, 95% CI 0.05–0.47, P=0.001) (Fig. 6). There were no statistically significant differences between the US and PNS groups in the incidence of paraesthesia during block placement or persistent neurological symptoms after the block's resolution.

Discussion

These results suggest that US improves efficacy of peripheral nerve block compared with PNS for nerve localization. The data for the US groups consistently showed higher success rates, shorter procedure and onset times, and longer block duration. Other variables examined by

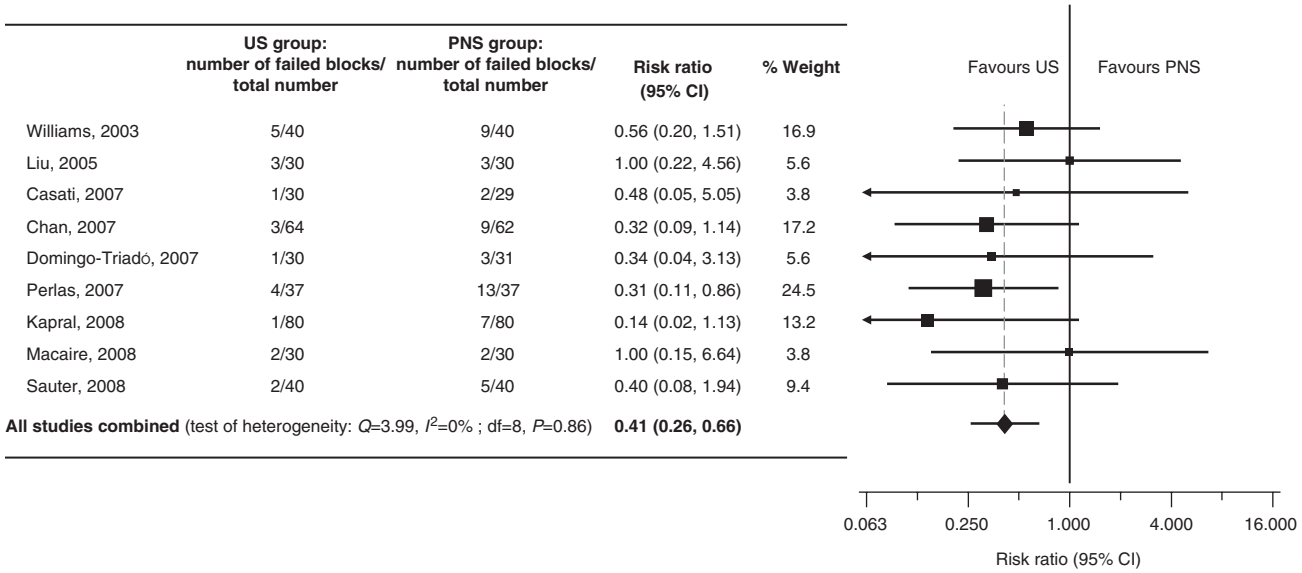

Fig 1 Block failure rate by study and overall. The number of failed blocks is listed for both study groups, along with the RR, 95% CI, and percentage of weight assigned to each study in the analysis of overall RR for block failure. In the forest plot on the right, the vertical line indicates no difference between the groups, with points to the left of the line indicating lower rates of block failure in the US group and points to the right indicating lower rates of block failure in the PNS group.

the studies included in this review such as the volume of local anaesthetic needed to produce a block,[11 15] pain during block performance,[5 7 8 13] number of needle passes required to complete block,[8 10] percentage of procedures successfully performed on the first attempt,[10] percentage of patients able to tolerate a tourniquet,[7 10 12] and patient satisfaction[8] all favoured US in their individual analyses, though too few of these studies looked at each of these outcomes to combine data in a meta-analysis. US guidance also appears to reduce the risk of inadvertent vascular puncture during block performance. There were no differences in the rates of other reported complications.

Our analysis was based on all currently available RCTs which compare US with PNS guidance for peripheral nerve blocks. However, at the time of this analysis, relatively few studies have been published. Since all of these estimates are based on a small number of studies, careful interpretation of the results is warranted. It is possible that our findings will be supported or refuted as more evidence accumulates. However, it seems more likely at this point that further studies will strengthen our findings, as none of

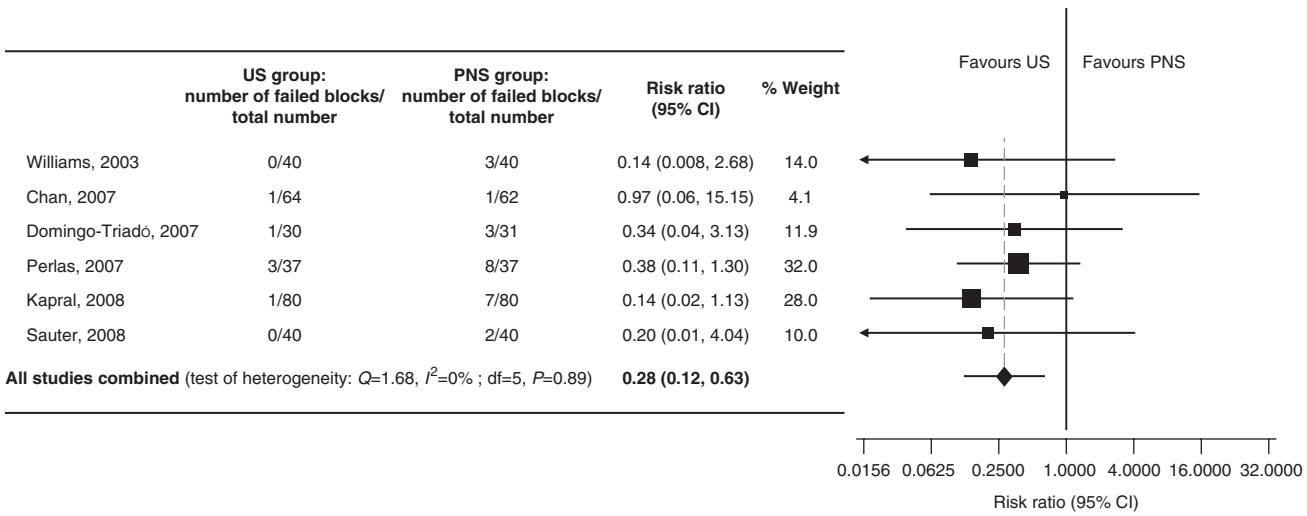

Fig 2 Conversion rate to GA or SA by study and overall. The number of patients converted to GA/SA is listed for both study groups, along with the RR, 95% CI, and percentage of weight assigned to each study in the analysis of overall RR for need to convert to GA/SA. In the forest plot on the right, the vertical line indicates no difference between the groups, with points to the left of the line indicating lower rates of converting to GA/SA in the US group and points to the right indicating lower rates of converting to GA/SA in the PNS group.

	US group: Sample size	Mean (SD)	PNS group: Sample size	Mean (SD)	Weighted mean difference (95% CI)	% Weight
Williams, 2003	40	5.0 (2.4)	40	9.8 (7.5)	–4.8 (–7.2, –2.4)	6.1
Liu, 2005	30	6.7 (1.3)	30	8.2 (1.5)	–1.5 (–2.2, –0.8)	19.1
Chan, 2007	64	9.3 (4.0)	62	11.2 (4.4)	–1.9 (–3.4, –0.4)	11.6
Domingo-Triadó, 2007	30	5.0 (2.5)	31	5.0 (2.6)	0.0 (–1.3, 1.3)	13.5
Perlas, 2007	37	8.1 (3.3)	37	8.3 (5.6)	–0.2 (–2.3, 1.9)	7.6
Macaire, 2008	30	2.6 (0.6)	30	3.5 (1.1)	0.9 (–1.4, –0.4)	21.5
Sauter, 2008	40	4.1 (1.3)	40	4.3 (1.3)	–0.2 (–0.8, 0.4)	20.6
All studies combined (test of heterogeneity: Q=22.4, I^2=73.5% ; df=6, P=0.001)					**–1.1 (–1.7, –0.4)**	

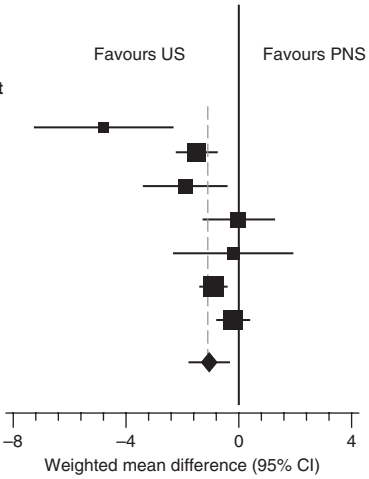

Fig 3 Procedure time (in minutes) by study and overall. In the forest plot on the right, the vertical line indicates no difference between the groups, with points to the left of the line indicating shorter procedure times in the US group and points to the right indicating shorter procedure times in the PNS group.

the trials published to date has demonstrated superiority of PNS compared with US guidance.

A limitation of this meta-analysis is that of the many outcomes, some may be selectively reported in a subset of studies, which may introduce bias to the combined results. However, the consistency in the direction of the difference makes reporting bias less of a concern. Even if different outcomes were reported from different subsets of studies, the combined estimates almost uniformly favoured the US guidance method, showing robustness of the results. It is also possible that there is some publication bias, and that with recent enthusiasm for US guidance, studies that do not show it to be superior to PNS may not be submitted and accepted for publication. This bias does not seem likely though, as the journals that have published these studies have often published an accompanying comment to temper the results by providing an argument in favour of PNS.[24–26] We also did not detect any publication bias using the funnel plots or Egger's method.[22]

The main limitations of this study are those inherent in any meta-analysis. The primary of these is that it is not possible to control for any potential methodological flaws of any of the individual studies that have been selected. Overall, the methodological quality of included studies was fair–good (Table 1). The most common reasons for subtracting points from the studies' quality scores were: poorly described or inadequate methods of randomization or allocation concealment, lack of equivalency between block techniques (discussed below), and statistical analysis not performed on an intent-to-treat basis (Supplementary material online, Appendix A). Though inadequate randomization or allocation concealment may have an impact on the observed effect size between study groups of an RCT,[27] the studies that reported sufficiently rigorous

	US group: Sample size	Mean (SD)	PNS group: Sample size	Mean (SD)	Per cent change in mean difference (95% CI)	% Weight
Marhofer, 1997	20	16.0 (14.0)	20	27.0 (16.0)	–40.7 (–68.2, –13.3)	11.8
Marhofer, 1998	20	13.0 (16.0)	40	27.0 (12.0)	–51.9 (–78.7, –25.1)	12.0
Marhofer, 2004	20	9.0 (2.8)	20	15.0 (7.4)	–40.0 (–55.4, –24.6)	15.1
Casati, 2007	30	14.0 (6.0)	29	23.0 (6.0)	–39.1 (–50.1, –28.2)	16.2
Domingo-Triadó, 2007	30	41.7 (38.9)	31	40.0 (37.3)	4.3 (–44.6, 53.1)	6.9
Kapral, 2008	80	10.0 (2.1)	80	22.0 (5.8)	–54.6 (–57.9, –51.2)	17.3
Macaire, 2008	30	6.2 (1.6)	30	4.1 (0.7)	51.2 (1.7, 100.8)	6.8
Sauter, 2008	40	13.9 (5.8)	40	13.7 (6.6)	1.5 (–18.6, 21.5)	13.9
All studies combined (test of heterogeneity: Q=58.8, I^2=88.1% ; df=7, P=0.000)					**–28.9 (–45.4, –12.3)**	

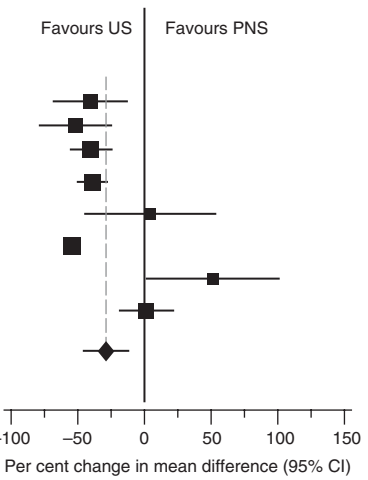

Fig 4 Sensory onset time of blocks by study and overall. Data are expressed as the percentage difference in mean time rather the absolute difference in mean time to account for heterogeneity of data. In the forest plot on the right, the vertical line indicates no difference between the groups, with points to the left of the line indicating shorter onset times in the US group and points to the right indicating shorter onset times in the PNS group.

	US group: Sample size	US group: Mean (SD)	PNS group: Sample size	PNS group: Mean (SD)	Per cent change in mean difference (95% CI)	% Weight
Williams, 2003	40	846 (531)	40	652 (473)	29.8 (–8.8, 68.3)	8.7
Marhofer, 2004	20	384 (54)	20	310 (56)	23.9 (11.4, 36.3)	27.5
Domingo-Triadó, 2007	30	1050 (235)	31	1020 (420)	2.9 (–14.1, 20.0)	22.5
Oberndorfer, 2007	23	508 (178)	23	335 (169)	51.6 (13.6, 89.7)	8.9
Kapral, 2008	80	899 (125)	80	679 (159)	32.4 (24.5, 40.3)	32.4
All studies combined (test of heterogeneity: Q=11.3, I^2=64.6% ; df=4, P=0.023)					**24.9 (11.9, 37.9)**	

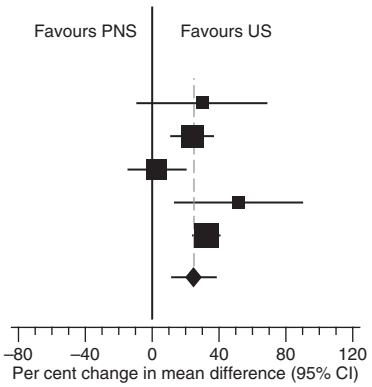

Fig 5 Duration of blocks by study and overall. Data are expressed as the percentage difference in mean time rather the absolute difference in mean time to account for heterogeneity of data. In the forest plot on the right, the vertical line indicates no difference between the groups, with points to the left of the line indicating shorter durations in the US group and points to the right indicating shorter durations in the PNS group.

methods[4 6–11] had similar results. These similar data suggest that these factors did not significantly affect the outcomes of these studies. Many of these studies[5–9 11 14–16] did not analyse data on an intent-to-treat basis. Intent-to-treat analysis could actually strengthen their findings, as the majority of these studies[5–8 11 14–16] excluded patients with failed blocks in the PNS group from further analysis.

One problem with all of these studies is that it is difficult to blind patients and providers to the technique being used for block performance. None of the studies could be conducted in a triple-blinded fashion as it is impossible to blind the anaesthetists performing the blocks to the technique they are using. All of the included studies were at least single-blinded as the effects of the blocks were assessed by independent, blinded observers. In two studies,[7 9] the patients in the PNS group had an US probe placed on them with the US machine in the standby mode in an attempt to blind them to their group assignment. In another study,[11] blocks were in children under GA, so they were effectively blinded to group assignment. The results of these three effectively double-blinded studies were consistent with those of the other 10, suggesting that blinding the patients to group assignment would not have significantly altered the outcomes of these studies.

Some of the studies have been criticized for high block failure rates in one or both study groups.[24–26] One possible explanation for the high failure rates is that inappropriate endpoints may have been used to determine correct needle placement for the PNS-guidance groups in some of the studies. In two studies,[15 16] a patellar snap at $<$0.5 mA was used as the endpoint for the PNS group. The success rates in the PNS groups may have been higher with a lower stimulating current (e.g. 0.3 mA).[28] In a number of studies,[4 6 9 29–31] the authors accepted a specific motor response as indicating block but a higher success rate may have occurred with a different, more distal motor response. Despite the possibility of suboptimal use of PNS guidance in these studies, the data from the other studies we have included are consistent with their findings and suggestive of an improvement in block success rates with US nerve localization.

	US group: number of punctures/ total number	PNS group: number of punctures/ total number	Risk ratio (95% CI)	% Weight
Marhofer, 1997	0/20	3/20	0.14 (0.008, 2.60)	15.2
Marhofer, 1998	0/20	4/40	0.22 (0.012, 3.84)	13.2
Liu, 2005	0/30	3/30	0.14 (0.008, 2.65)	15.2
Sauter, 2008	2/40	13/40	0.15 (0.037, 0.64)	56.4
All studies combined (test of heterogeneity: Q=0.06, I^2=0% ; df=3, P=0.996)			**0.16 (0.05, 0.47)**	

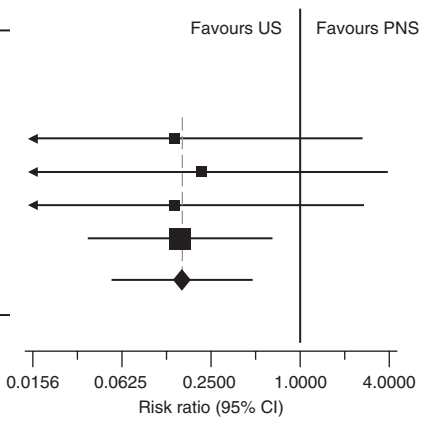

Fig 6 Incidence of inadvertent vascular puncture during block performance by study and overall. In the forest plot on the right, the vertical line indicates no difference between the groups, with points to the left of the line indicating fewer vascular punctures in the US group and points to the right indicating fewer vascular punctures in the PNS group.

Another possible reason for the high failure rates in these studies is the fact that in some of these studies[9 14] blocks were performed by trainees. US may make it easier to supervise trainees performing peripheral nerve blocks as the graphical information provided by US imaging may help the staff to determine and direct any necessary adjustments in needle position more easily than PNS guidance. There is some evidence that trainees may have a steeper learning curve for placing lumbar epidurals, if US is used in addition to traditional landmark-based approaches.[32] Whether the routine use of US in teaching institutions helps or hinders trainees' ability to become proficient at performing peripheral nerve block procedures remains controversial[33 34] and is beyond the scope of this discussion.

However, the majority of studies we have included evaluate only blocks performed by anaesthetists with extensive experience with either technique,[4–8 10–13 15 16] and the pooled data from these demonstrate improved outcomes with US compared with PNS. This is likely because US provides real-time visualization of local anaesthetic spread, and allows the anaesthetist to re-position the needle to achieve optimal distribution of local anaesthetic fluid. Because several trials have demonstrated increased rates of block success using multiple-injection PNS-guided techniques when compared with single-injection PNS-guided techniques,[35–37] it seems logical that multiple-injection US-guided techniques should have higher success rates than single-injection PNS-guided techniques. The studies we have included that compare multiple-injection US-guided with multiple-injection PNS-guided blocks[8 9 12] favour US, perhaps for reasons discussed above. The one study that compared multiple-injection techniques performed by anaesthetists using optimal endpoints for both modalities[8] concluded that US and PNS were essentially equivalent in experienced hands.

It is our opinion that US can improve block success rates, especially for anaesthetists who do not frequently perform peripheral nerve blocks or for those supervising trainees. It is less clear whether or not US substantially improves outcomes for anaesthetists with extensive experience performing peripheral nerve blocks with PNS guidance. Although such practitioners may have excellent success rates using PNS guidance, US may allow them to use more multiple-injection techniques and achieve similar or better success rates with shorter onset times, lower anaesthetic volumes, and longer block durations.[38] Complications such as systemic local anaesthetic toxicity and permanent nerve injury have been reported during US-guided nerve blocks,[39–41] but the ability to visualize nerves, surrounding structures, anatomic variations, needles, and the spread of local anaesthetic fluid in real time may allow experienced practitioners to further decrease their rate of complications. PNS guidance remains an invaluable tool for anaesthetists performing peripheral nerve blocks. Both US and PNS guidance have advantages and limitations.[42 43] Recognition of these can help anaesthetists select the most appropriate techniques (US, PNS, or a combination of the two) for performing specific blocks, making these blocks easier to perform, more effective, and safer.

In conclusion, comparison of the use of PNS and US guidance for nerve localization in this meta-analysis suggests that US guidance for peripheral nerve block produces a higher rate of block success, shorter procedure times, faster onset times, and longer block durations. US guidance also appears to reduce the risk of inadvertent vascular puncture during block performance. Additional studies are needed to demonstrate any safety advantage for US over PNS guidance with regard to major complications such as persistent neurological injury or systemic local anaesthetic toxicity.

Supplementary material

Supplementary material is available at *British Journal of Anaesthesia* online.

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