

RESEARCH

Ultrasound imaging for lumbar punctures and epidural catheterisations: systematic review and meta-analysis

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Abstract

Objective To determine whether ultrasound imaging can reduce the risk of failed lumbar punctures or epidural catheterisations, when compared with standard palpation methods, and whether ultrasound imaging can reduce traumatic procedures, insertion attempts, and needle redirections.

Design Systematic review and meta-analysis of randomised controlled trials.

Data sources Ovid Medline, Embase, and Cochrane Central Register of Controlled Trials up to May 2012, without restriction by language or publication status.

Review methods Randomised trials that compared ultrasound imaging with standard methods (no imaging) in the performance of a lumbar puncture or epidural catheterisation were identified.

Results 14 studies with a total of 1334 patients were included (674 patients assigned to the ultrasound group, 660 to the control group). Five studies evaluated lumbar punctures and nine evaluated epidural catheterisations. Six of 624 procedures conducted in the ultrasound group failed; 44 of 610 procedures in the control group failed. Ultrasound imaging reduced the risk of failed procedures (risk ratio 0.21 (95% confidence interval 0.10 to 0.43), $P<0.001$). Risk reduction was similar when subgroup analysis was performed for lumbar punctures (risk ratio 0.19 (0.07 to 0.56), $P=0.002$) or epidural catheterisations (0.23 (0.09 to 0.60), $P=0.003$). Ultrasound imaging also significantly reduced the risk of traumatic procedures (risk ratio 0.27 (0.11 to 0.67), $P=0.005$), the number of insertion attempts (mean difference -0.44 (-0.64 to -0.24), $P<0.001$), and the number of needle redirections (mean difference -1.00 (-1.24 to -0.75), $P<0.001$).

Conclusions Ultrasound imaging can reduce the risk of failed or traumatic lumbar punctures and epidural catheterisations, as well as the

number of needle insertions and redirections. Ultrasound may be a useful adjunct for these procedures.

Introduction

Lumbar punctures and epidural catheterisations are common procedures used to access the subarachnoid and epidural spaces. Lumbar punctures are used for diagnostic sampling of the cerebrospinal fluid to evaluate for suspected infections of the central nervous system, haemorrhage, neoplasm, or inflammatory disorders, as well as for delivering therapeutic agents to the intrathecal space.¹ Epidural catheterisations provide regional anaesthesia and analgesia during childbirth or surgical procedures.² A national audit project estimated that over 293 000 epidurals and 325 000 subarachnoid blocks are performed each year in the United Kingdom.³

A failure to obtain diagnostic samples or to achieve correct placement can occur. Failed procedures result in the loss of diagnostic information,⁴ inability to deliver treatment, or inadequate analgesia. Traumatic lumbar punctures confound the interpretation of diagnostic tests on cerebrospinal fluid.⁵⁻⁶ In patients with acute lymphoblastic leukaemia, an initial traumatic lumbar puncture with blasts in the cerebrospinal fluid impairs the diagnostic utility of the procedure and is associated with an increased risk of relapse.⁷⁻¹⁰ When procedures are difficult, repeated needle insertions and redirections increase the pain and discomfort experienced by the patient.¹¹

The performance of lumbar punctures and epidural catheterisations relies primarily on the palpation of anatomical landmarks, which might be obscured in the context of obesity, oedema, or anatomical variation. Other important aspects of the procedure, such as the angle of needle progression and the

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Web table: Search strategy

distance from the skin to the target space, cannot be assessed by palpation and rely on the skill of the operator. Similar to the experience with peripheral nerve blocks¹² and central vascular access,^{13 14} it has been hypothesised that the ability to visualise the relevant anatomy of the procedure may aid in its success.^{2 15} Consequently, interest has been growing in the use of ultrasound imaging as an adjunct to lumbar punctures or epidural catheterisations. Pre-procedure ultrasound scanning can identify an intended vertebral interspace level, the midline of the spine, the optimal puncture point, the optimal angle for needle insertion, and the depth to the spinal canal.^{16 17} Real time or dynamic scanning can visualise the progression of the needle and the injected drug entering the desired space.¹⁸ Ultrasound is relatively cheap, readily available at the point of care, compact, and involves no radiation.

Many randomised controlled trials have been performed to evaluate ultrasound imaging for lumbar punctures or epidural catheterisations. However, almost all trials were underpowered to show differences in the most clinically important outcomes, such as failed procedures. Although there have been several qualitative or systematic reviews of ultrasound in the context of regional anaesthesia,^{12 19-21} there is no published meta-analysis of randomised controlled trials evaluating ultrasound imaging for these procedures. We hypothesised that by synthesising all randomised controlled trials, a meta-analysis would provide increased power and more precise estimates of the effect of ultrasound imaging for lumbar punctures and epidural catheterisations. Our primary objective was to determine whether ultrasound imaging reduces the risk of failed lumbar punctures or epidural catheterisations in adults or children undergoing these procedures, by comparison with standard palpation methods. Our secondary objectives were to determine whether ultrasound imaging affects traumatic procedures, the number of insertion attempts, the number of needle redirections, and the time taken to perform the procedure.

Methods

Data sources and searches

We developed a protocol for review and followed PRISMA (preferred reporting items for systematic reviews and meta-analyses) guidelines.²² The study was not registered. We performed comprehensive searches for relevant trials using the Ovid platform in Medline (from 1948 to May 2012), Embase (from 1980 to May 2012), and the Cochrane Central Register of Controlled Trials (to the second quarter of 2011), without restriction by language or publication status. The search strategy included the following medical subject heading terms: “ultrasonography,” “spinal puncture,” “epidural analgesia,” “spinal anaesthesia,” and “obstetrical anaesthesia.” We also included multiple synonyms, abbreviations, and related keywords for each of these terms. The set was limited to clinical trials, observational studies, or diagnostic studies (search strategy available in the web table). We also examined the reference lists of retrieved original and review articles.

Study selection

Randomised or quasi-randomised trials were included if they did all of the following:

- Randomly assigned patients undergoing lumbar punctures or epidural catheterisations in the lumbar region
- Compared ultrasound imaging (as either pre-procedure landmarking or real time scanning) with a non-imaging technique such as palpation or loss of resistance

- Reported at least one of our primary or secondary outcomes.

The loss of resistance technique identifies the epidural space by the sudden change in pressure on the piston of a syringe as the needle enters the space. We excluded studies of procedures involving the peripheral nerves or the caudal, paravertebral, radicular, or plexus regions.

Two investigators (FS and JB) independently screened the titles and abstracts of articles identified by the search strategy. Articles thought to be potentially eligible were obtained in full and each of these articles was assessed for eligibility by both reviewers. Discrepancies were resolved by consensus.

Outcome measures and definitions

Spinal anaesthesia was classified as a lumbar puncture, because it involves accessing the subarachnoid space. Combined spinal and epidural catheterisation was classified as an epidural catheterisation, because the first task of the combined procedure is to identify the epidural space.

The outcomes of interest, in order of importance, were failed procedures, traumatic procedures, number of insertion attempts, number of needle redirections, and time taken to perform the procedure. We defined these outcomes a priori, but used each study’s definitions if they were reasonable and similar to ours. In general, a failed lumbar puncture was defined as one without the return of cerebrospinal fluid. A failed epidural catheterisation was defined as inability to place the catheter, a requirement for additional intraoperative analgesia, or a requirement to replace the epidural catheter. In short, a procedure was considered to have failed if the intended objective of the procedure, whether to collect a diagnostic sample or to provide analgesia, could not be fulfilled. A traumatic lumbar puncture or epidural catheterisation was defined as visible blood aspiration or a red blood cell count in the cerebrospinal fluid above an appropriately defined threshold.

Studies variably defined insertion attempts—as either “redirection” of the needle (without further skin puncture), or “reinsertion” of the needle (a withdrawal and new puncture through the skin). Because a reinsertion implies a greater degree of adjustment needed for correct needle placement, it is a more substantial outcome than a redirection. We attempted to classify, wherever possible, the study’s definition of an “attempt” into either a redirection or a reinsertion. We assumed that each bony contact led to a redirection. If the meaning was unclear, we classified an attempt as a redirection alone, to remain conservative in the estimated benefit of ultrasound imaging.

Data extraction and quality assessment

Two investigators (FS and JB) independently and in duplicate assessed the risk of bias at the study level, using the CLEAR-NPT tool (a checklist to evaluate a report of a non-pharmacological trial).²³ The CLEAR-NPT was created specifically to measure the quality of reports of randomised controlled trials assessing non-pharmacological treatments such as surgeries or devices. Since our outcomes of interest were assessable instantaneously, participant adherence, withdrawals, and intention to treat analysis were not relevant. We thus modified the instrument by reporting the domains meaningful for studies of ultrasound imaging.

We focused on randomisation, allocation concealment, blinding, outcome reporting, details of the intervention, and operator experience or skill. The term “operator” here refers to the person performing the needle procedure, not the person performing the

ultrasound imaging (if not the same individual). We categorised experience and skill as being inadequate if the operators were junior residents within one year of their residency training. If blinding was not used, we also included a domain on whether the same operator was assigned to both groups, which could create a risk for performance bias or an unconscious incentive to show a benefit of ultrasound imaging. The quality of each domain was presented as adequate, inadequate, or unstated or unclear. Disagreements were resolved by consensus.

The same two investigators (FS and JB) independently and in duplicate abstracted data from the trials using a standardised form. They sought the following information from each source article: year of publication, country of study, population and setting, type of procedure (lumbar punctures *v* epidural catheterisation), type of ultrasound imaging (pre-procedure *v* real time), operator characteristics, and type of ultrasound device. If data were not available for validity assessment or outcomes, study authors were contacted to obtain further information.

Data synthesis and analysis

Because of differences in how summary statistics for continuous outcomes were reported, we made the following assumptions to facilitate data synthesis: the mean can be approximated by the median, the range contains six standard deviations, and the interquartile range contains 1.35 standard deviations. When no measure of dispersion was reported, the outcome was not included in the synthesis.

We analysed dichotomous outcome data with the Mantel-Haenszel method and used risk ratio as the effect measure, where a risk ratio less than 1 suggests that ultrasound imaging is better than non-imaging techniques. To account for rare events, we also conducted a sensitivity analysis using the Peto method, where an odds ratio less than 1 suggests that ultrasound imaging is better than non-imaging techniques. We calculated the absolute risk reduction as the difference between the event rates in the control arm and the ultrasound arm, and calculated the number needed to treat as the inverse of the absolute risk reduction. We expressed the effect on continuous outcome variables as the mean difference, where a mean difference less than 0 indicates that ultrasound imaging required fewer needle insertions or redirection attempts than the control procedure.

We summarised the findings using a random effects model, which allows consideration of variations between studies. We looked for heterogeneity among the trials using standard methods and calculated the I^2 index, which describes the percentage of variability in the effect estimates that are due to heterogeneity beyond sampling error.²⁴

We conducted planned subgroup analyses for the effect of ultrasound imaging by type of procedure (lumbar punctures *v* epidural catheterisation), specialty of operator (emergency physician *v* anaesthetist), expected difficulty (studies of patients with a higher expected risk of difficult procedures *v* studies of unselected patients), the experience level of the operator performing the spinal procedure (high *v* low), and whether the same operator was assigned to both groups. Subgroup analyses were conducted for each outcome whenever more than one study with an estimable effect was available per subgroup.

We assessed publication bias by visual inspection of a funnel plot of the effect size (that is, risk ratio) versus its precision (that is, standard error) for each outcome if at least 10 studies were available. We assumed that asymmetry in the lower right hand corner of the funnel plot indicated that small trials with

negative outcomes were not represented in the literature. The potential effect of such missing trials was evaluated using the trim and fill technique.²⁴

Agreement between the two reviewers regarding inclusion of articles and each domain of study validity was examined using the κ statistic. We performed analyses using Review Manager (RevMan 5.1, Cochrane Collaboration) and SAS (version 9.3).

Results

Figure 1 illustrates the flow diagram of trial identification and selection. From a total of 2494 individual records, we identified and included 14 randomised controlled trials of ultrasound imaging in the systematic review.²⁵⁻³⁸ Eleven studies were published as full articles and three published as abstracts.^{29 36 38} The κ score for agreement for study inclusion was 0.94 (95% confidence interval 0.84 to 1.00).

Table 1 lists characteristics of the 14 trials. In total, 1334 patients were randomly assigned to receive ultrasound imaging (674 patients) or to the control group (660 patients). All patients in the control arm received the standard procedure with manual palpation or loss of resistance (or both), but no form of imaging. Seven trials reported outcomes for obstetric epidural anaesthesia, two for surgical epidural anaesthesia, one for spinal anaesthesia, and four for lumbar punctures in the emergency room. Therefore, in total, nine studies used ultrasound imaging for epidural catheterisations and five for lumbar punctures. Eleven studies used a pre-procedure landmarking approach, two studies used real time ultrasound visualisation, and one study used both techniques. There was one paediatric trial.³⁰ In all studies, the ultrasound imaging and landmarking was performed by a study investigator who had adequate expertise in the technique. For the ultrasound groups, the lumbar puncture or epidural catheterisation was subsequently performed by either the same investigator, or by another operator using information obtained by the ultrasound.

Summary of the risk of bias is presented in table 2. Only one study was double blinded (both the operator and patients). In this study,³¹ blinding of the operator was achieved by marking sites of insertion determined by ultrasound or palpation with ultraviolet ink visible under a special light. Therefore, only one site was known to the lumbar puncture operators based on their random assignment to either the ultrasound arm or the control arm. No other study blinded either the operator or the patient. Most of the earlier studies were unclear in their description of the methods used for sequence generation or allocation concealment. All of the studies were described as being randomised.

The primary outcome, procedure failure, included data from 12 studies and 1234 randomised patients. Table 3 and figure 2 show that the use of ultrasound imaging reduced the risk of failed procedures (risk ratio 0.21 (95% confidence interval 0.10 to 0.43), $P<0.001$). There were six failed procedures of 624 in the ultrasound group compared with 44 failed procedures of 610 in the control group. The absolute risk reduction in the risk of failed procedures was 0.063, resulting in a number needed to treat of 16 ultrasound guided procedures to reduce one failure.

Table 3 summarises the secondary outcomes. Ultrasound imaging reduced the risk of traumatic procedures with a risk ratio of 0.27 (95% confidence interval 0.11 to 0.67, $P=0.005$), an absolute risk reduction of 0.059 and a number needed to treat of 17. Ultrasound imaging also reduced the number of insertion attempts by a mean difference of -0.44 (-0.64 to -0.24 , $P<0.001$) and the number of needle redirections by a mean

difference of -1.00 per procedure (-1.24 to -0.75 , $P<0.001$). The time taken to perform the ultrasound imaging procedures could not be meta-analysed because the time periods reported were too heterogeneous across studies (for example, studies variably included or excluded preparation time or needle procedure time).

In the sensitivity analysis of dichotomous outcomes using the Peto method, ultrasound imaging reduced the odds of a failed procedure (odds ratio 0.20 (95% confidence interval 0.11 to 0.36), $P<0.001$) and the odds of a traumatic procedure (0.28 (0.13 to 0.61), $P=0.001$).

Table 4¹ presents the subgroup analyses. The effect of ultrasound imaging on reduction of failed lumbar punctures (risk ratio 0.19, 95% confidence interval 0.07 to 0.56, $P=0.002$) and epidural catheterisations (0.23, 95% confidence interval 0.09 to 0.60, $P=0.003$) was similar ($P=0.92$ for interaction). Subgroup analysis showed that the benefit of ultrasound imaging in reducing the mean number of insertion attempts was significantly larger for lumbar punctures than for epidural catheterisations. Another subgroup analysis suggested that the reduction in the mean number of insertion attempts may be larger for patients selected for presumed difficult procedures than for unselected patients, but the effect did not reach statistical significance. For all other subgroup analyses, effect estimates were not significantly different.

A funnel plot of the risk ratio for failed procedures versus standard errors was asymmetric because of the large effect sizes of two studies^{27,33} and suggested that the results of small negative trial(s) may not have been published (plot not shown). To assess the effect of this potential publication bias on our point estimate of the risk ratio, we performed a second analysis that excluded the results of these two studies. The pooled estimate of the risk ratio for the ten remaining studies was 0.24 (95% confidence interval 0.11 to 0.52). After we added back the two studies, together with two hypothetical counterpart studies of equal sizes but opposite effects, the recalculated risk ratio was 0.35 (0.15 to 0.85). Therefore, the possible exclusion of small negative trial(s) from this analysis did not change the conclusion of the primary objective. Funnel plots were not evaluated for secondary objectives because no other outcome had ten or more available studies.

Discussion

Our meta-analysis shows that ultrasound imaging can reduce the risk of failed or traumatic lumbar punctures and epidural catheterisations as well as the number of insertion attempts and needle redirections. The most likely explanation for these findings is that ultrasound visualisation of the relevant anatomy provides the operator with information regarding the midline of the spine, the optimal vertebral level, and the depth to the desired space. Ultrasound thus supplements anatomical information available by palpation. The advantages of ultrasound imaging appeared consistent across multiple subgroup analyses. Ultrasound could therefore be a useful adjunct for lumbar punctures and epidural catheterisations. In particular, clinicians working in settings where these procedures are commonly performed (obstetric anaesthesia and emergency rooms) or where failure is associated with particularly negative consequences (paediatric oncology) should consider utilising ultrasound imaging.

Strengths and limitations

The strengths of this review include broad eligibility criteria that did not exclude studies based on publication status or

language. This allowed the review to be representative of the available literature. Furthermore, we hypothesised a priori that ultrasound imaging would have a similar effect in both lumbar punctures and epidural catheterisations and that both types of procedures could be reasonably pooled in a meta-analysis. The resulting data supported this hypothesis. By combining the two types of procedures, we were able to evaluate the effect of ultrasound imaging in both groups and achieved a larger sample size and greater power for synthesis.

Our meta-analysis has several limitations. Similar to many meta-analyses, it is limited by the methodological quality and outcome reporting of its component studies. Only one study fulfilled all seven quality measures that we used to evaluate validity.³¹ This was the only double blind study, and no other study attempted to blind patients. Although blinding the operator in ultrasound imaging trials is logistically difficult, there is little reason that patients cannot be blinded to the assigned treatment by use of a sham ultrasound application. Secondly, in all trials, the individuals performing the ultrasound imaging were study investigators who generally had high levels of experience and special interest in the technique. Many of the studies (seven of 14) were in the setting of obstetric anaesthesia, and thus included a patient population composed of young, collaborating, healthy women. These features might limit the external validity of our findings. Thirdly, other important complications of these procedures, such as postdural puncture headaches or pain during the procedure, were not often reported and could not be synthesised. Time taken to perform the procedure, one of our intended secondary outcomes, was defined and measured differently across studies and thus could not be meta-analysed. None of the studies included a cost effectiveness analysis.

Comparison with other studies

Some previous narrative reviews and systematic qualitative reviews have suggested a potential benefit for ultrasound imaging in the context of regional anaesthesia of the spine,^{12,19-21} but none performed a quantitative synthesis. A guideline by the National Institute for Health and Clinical Excellence on ultrasound guided epidural catheterisation similarly concluded that ultrasound might be helpful in achieving correct epidural placement, but that evidence was limited.³⁹ Our meta-analysis is the first study to quantitatively evaluate the effect on failed procedures, which is the most clinically significant outcome. Nearly all the component randomised controlled trials were underpowered for this outcome and could not show a significant beneficial effect. Many studies individually concluded that ultrasound had no effect on the rate of failed procedures. However, when pooled together in meta-analysis, a clinically and statistically significant effect clearly emerged.

Another imaging technique, fluoroscopy, is often used as a rescue modality after failed lumbar punctures.^{40,41} However, ultrasound has important advantages compared with fluoroscopy. Fluoroscopy is expensive, not readily available or portable, requires multiple operators, and involves radiation exposure.^{42,43} Consequently, we believe that a focus is warranted on ultrasound imaging rather than fluoroscopy for these procedures.

Implications for practice and research

Future studies should determine the optimal way to incorporate ultrasound imaging for lumbar punctures and epidural catheterisations into clinical practice. Because the baseline rate of failed procedures was low even when ultrasound was not used, it is unclear whether ultrasound imaging should be used for all lumbar punctures and epidural catheterisations. Perhaps

it will be best used in a risk directed manner for patients anticipated to have difficult procedures, or as a rescue modality after failed procedures. This question should be further investigated. The best approach will probably vary across different settings depending on the volume of procedures, baseline rate of failure, availability of proficiency in the ultrasound technique, and cost of obtaining the required training and equipment. Additional pragmatic randomised controlled trials of high methodological quality would be of benefit in further validating these results.

Future research should also focus on the cost effectiveness of using ultrasound imaging for these procedures.¹⁵ The cost includes the expense of purchasing and maintaining the equipment and obtaining training. In smaller institutions, equipment can be shared among different departments. Point-of-care ultrasound is already used to provide image guidance across a wide range of other medical and surgical procedures.¹⁵ Furthermore, the cost of ultrasound imaging is likely to rapidly decline in the future, as ultrasound technology becomes less expensive and more compact, and proficiency with ultrasound becomes more ubiquitous among clinicians. Some medical schools now include ultrasound education within their curriculums and provide students with portable machines to be used during their rotations.⁴⁴⁻⁴⁶ If such trends continue, both ultrasound skills and equipment will become increasingly available in routine clinical settings. Based on the results of this meta-analysis, lumbar punctures and epidural catheterisations can be added to the growing list of medical procedures that could benefit from ultrasound imaging.

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What is already known on this topic

Lumbar punctures and epidural catheterisations are common, and failed procedures result in loss of diagnostic information or inadequate analgesia

Ultrasound imaging can be used to visualise the relevant anatomy of the spine for these procedures

Many randomised trials have compared ultrasound imaging for these procedures with standard palpation methods, but none has shown a significant effect on the ability to reduce failed procedures

What this study adds

Ultrasound imaging can reduce the risk of failed lumbar punctures and epidural catheterisations

Ultrasound imaging can also reduce the risk of traumatic procedures and the number of needle insertions and redirection

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Tables

Table 1 | Characteristics of studies included in the systematic review

Study	Year	Country	N	Population	Setting	Procedure	Ultrasound	Operator	Equipment
Grau ²⁵	2011a	Germany	72	Obstetric patients with presumed or identified difficult EC	LD	EC	Pre-procedure	Staff anaesthetist	Kretz Sonoace 6000, 5 MHz curved probe
Grau ²⁶	2011b	Germany	80	Obstetric patients scheduled for caesarean section	LD	EC (CSE)	Pre-procedure	Staff anaesthetist	Kretz Sonoace 6000, 5 MHz curved probe
Grau ²⁷	2012	Germany	300	Obstetric patients scheduled for vaginal or caesarean delivery	LD	EC	Pre-procedure	Staff anaesthetist	Kretz Sonoace 6000, 5 MHz curved probe
Grau ²⁸	2014	Germany	30	Obstetric patients scheduled for caesarean section	LD	EC (CSE)	Real-time and Pre-Procedure	Staff anaesthetist	GE Logiq 400 system, 7.5 MHz linear probe
Pisupati (abstract) ²⁹	2014	United States	33	Adults	ER	LP	Pre-procedure	ER "physician"	N/A
Willschke ³⁰	2016	Austria and South Africa	64	Children 0-6 years old undergoing major surgery	OR	EC (lumbar or thoracic)	Real-time	Staff anaesthetist	Sonosite 180plus, 5-10 MHz linear probe
Nomura ³¹	2017	United States	46	Adults	ER	LP	Pre-procedure	ER staff or experienced residents	Sonosite Titan or 180plus, multiple probes
Lee ³²	2018	Korea	61	Adults	ER	LP	Pre-procedure	ER residents	Sonosite MicroMaxx, 2-5 MHz curved probe
Cho ³³	2019	Korea	60	Adults >60 years old	ER	LP	Pre-procedure	ER residents	Sonosite MicroMaxx, 2-5 MHz curved probe
Vallejo ³⁴	2010	USA	370	Obstetric patients	LD	EC	Pre-procedure	Junior anaesthesia residents	Sonosite Micromaxx, 2-5 MHz curved probe
Kawaguchi ^{37*}	2011	Japan	24	Adults undergoing total hip arthroplasty	OR	EC (deliberate ipsilateral)	Pre-procedure	Two staff anaesthetists	GE Logiq Book XP, 2-5 MHz curved probe
Chin ³⁵	2011	Canada	120	Adults undergoing orthopaedic surgery with difficult surface landmarks	OR	LP (spinal anaesthesia)	Pre-procedure	Anaesthesia staff or fellows	Sonosite M-Turbo, 2-5 MHz curved probe
Gnaho (abstract) ³⁶	2011	France	20	Obese obstetric patients	LD	EC	Real-time	Anaesthesia "physicians"	Logiq book xpro GE Solingen, 5 MHz curved probe
Fogel (abstract) ^{38*}	2011	United States	54	Obstetric patients	LD	EC	Pre-procedure	Anaesthesia staff, residents, and CRNAs	Sonosite M-Turbo, 2-5 MHz curved probe

CRNA=certified registered nurse anaesthetist; CSE=combined spinal-epidural anaesthesia; EC=epidural catheterisations; ER=emergency room; LD=labour and delivery suite; LP=lumbar puncture; MHz=megahertz; N=no of patients; N/A=not available; OR=operating room.

*Additional information provided by authors.

Table 2| Risk of bias summary

Study	Sequence generation	Concealment	Blinding	Outcome reporting	Intervention details	Experience and skill	Different operators in each group
Grau 2001a ²⁵	Unclear	Adequate	Inadequate	Adequate	Adequate	Adequate	Inadequate
Grau 2001b ²⁶	Unclear	Adequate	Inadequate	Adequate	Adequate	Adequate	Inadequate
Grau 2002 ²⁷	Unclear	Adequate	Inadequate	Adequate	Adequate	Adequate	Inadequate
Grau 2004 ²⁸	Unclear	Adequate	Inadequate	Adequate	Adequate	Adequate	Inadequate
Pisupati 2004 ²⁹	Unclear	Adequate	Inadequate	Adequate	Adequate	Adequate	Unclear
Willschke 2006 ³⁰	Adequate	Adequate	Inadequate	Adequate	Adequate	Adequate	Unclear
Nomura 2007 ³¹	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
Lee 2008 ³²	Unclear	Adequate	Inadequate	Inadequate	Adequate	Inadequate	Unclear
Cho 2009 ³³	Unclear	Adequate	Inadequate	Adequate	Adequate	Inadequate	Unclear
Vallejo 2010 ³⁴	Adequate	Adequate	Inadequate	Adequate	Adequate	Inadequate	Adequate
Kawaguchi 2011 ³⁷	Adequate	Adequate	Inadequate	Adequate	Adequate	Adequate	Inadequate
Chin 2011 ³⁵	Adequate	Adequate	Inadequate	Adequate	Adequate	Adequate	Adequate
Gnaho 2011 ³⁶	Unclear	Unclear	Unclear	Adequate	Unclear	Unclear	Unclear
Fogel 2011 ³⁸	Adequate	Adequate	Inadequate	Adequate	Adequate	Adequate	Inadequate
κ (95% CI)	0.55 (0.11 to 0.99)	0.76 (0.32 to 1.00)	1.0 (1.0 to 1.0)	0.63 (0.0 to 1.0)	0.76 (0.32 to 1.0)	0.70 (0.32 to 1.0)	0.76 (0.32 to 1.0)

Data indicate adequate, unclear, or inadequate fulfilment of quality measure in that domain.

Table 3| Summary of outcomes for ultrasound imaging groups versus control groups

	Effect (95% CI)	P	I ² (%)
No of failed procedures (12 studies)			
Risk ratio	0.21 (0.10 to 0.43)	<0.001	0
Absolute risk reduction	0.063 (0.041 to 0.084)	—	—
Number needed to treat	16 (12 to 25)	—	—
No of traumatic procedures (5 studies)			
Risk ratio	0.27 (0.11 to 0.67)	0.005	0
Absolute risk reduction	0.059 (0.023 to 0.095)	—	—
Number needed to treat	17 (11 to 44)	—	—
No of insertion attempts (8 studies)			
Mean difference	-0.44 (-0.64 to -0.24)	<0.001	73
No of needle redirections (8 studies)			
Mean difference	-1.00 (-1.24 to -0.75)	<0.001	69

Table 4 | Subgroup analyses

Outcome	Subgroup 1		Subgroup 2		P for interaction
	No of studies	Effect (95% CI)	No of studies	Effect (95% CI)	
Lumbar punctures v epidural catheterisations					
Failed procedures	5	RR 0.19 (0.07 to 0.56), ARR 0.12, NNT 9	7	RR 0.23 (0.09 to 0.60), ARR 0.04, NNT 25	0.92
Traumatic procedures	2	RR 0.24 (0.05 to 1.08), ARR 0.11, NNT 9	3	RR 0.28 (0.09 to 0.92), ARR 0.04, NNT 24	0.99
Insertion attempts	3	MD -1.01 (-1.56 to -0.45)	5	MD -0.23 (-0.33 to 0.13)	0.007
Procedure performed by emergency physician v anaesthetist					
Failed procedures	4	RR 0.15 (0.05 to 0.50), ARR 0.17, NNT 6	8	RR 0.25 (0.10 to 0.62), ARR 0.04, NNT 25	0.51
Traumatic procedures	2	RR 0.24 (0.05 to 1.08), ARR 0.11, NNT 10	3	RR 0.28 (0.09 to 0.92), ARR 0.04, NNT 24	0.86
Insertion attempts	2	MD -1.22 (-2.29 to -0.14)	6	MD -0.33 (-0.49 to -0.17)	0.11
Treatment groups had same operator or unclear information v different operators or adequate blinding					
Failed procedures	9	RR 0.16 (0.06 to 0.45), ARR 0.07, NNT 14	3	RR 0.27 (0.10 to 0.73), ARR 0.05, NNT 20	0.46
Redirection attempts	6	MD -0.95 (-1.19 to -0.70)	2	MD -3.74 (-9.60 to 2.12)	0.35
Low v high experience of operators					
Failed procedures	3	RR 0.22 (0.08 to 0.61), ARR 0.07, NNT 14	9	RR 0.20 (0.07 to 0.55), ARR 0.06, NNT 17	0.88
Traumatic procedures	2	RR 0.24 (0.05 to 1.08), ARR 0.11, NNT 9	3	RR 0.28 (0.09 to 0.92), ARR 0.04, NNT 24	0.99
Insertion attempts	2	MD -1.22 (-2.29 to -0.14)	6	MD -0.33 (-0.48 to -0.17)	0.11
Patients selected for presumed difficult procedures v unselected patients					
Failed procedures	4	RR 0.22 (0.06 to 0.88), ARR 0.09, NNT 11	8	RR 0.21 (0.09 to 0.48), ARR 0.06, NNT 17	0.92
Insertion attempts	3	MD -0.81 (-1.52 to -0.11)	5	MD -0.27 (-0.41 to -0.13)	0.14
Redirection attempts	2	MD -3.65 (-9.71 to 2.41)	6	MD -0.99 (-1.19 to -0.79)	0.39

ARR=absolute risk reduction; NNT=number needed to treat; RR=risk ratio; MD=mean difference.

Subgroup analyses were performed for outcomes where more than one study with an estimable effect was available per subgroup.

Figures

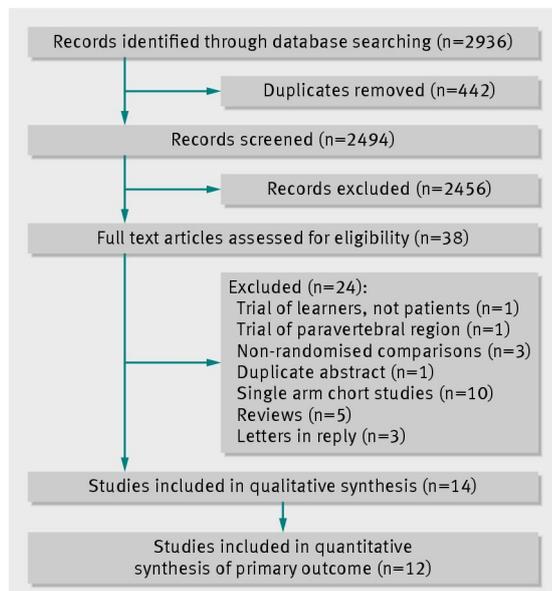


Fig 1 PRISMA flow diagram showing progress of trials

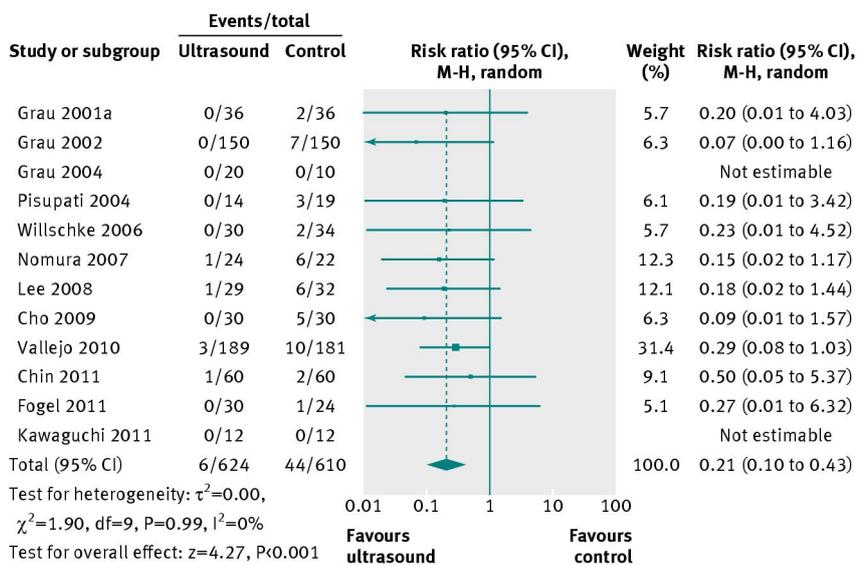


Fig 2 Risk of failed procedures in ultrasound versus control groups. Squares to the left of the vertical line indicate that ultrasound reduced the risk of a failed procedure; horizontal lines=95% confidence intervals; square size=each study's relative weight; diamond=aggregate relative risk (95% confidence interval); M-H=Mantel-Haenszel