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Ultrasound-guided arterial cannulation in the paediatric population (Review)

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Ultrasound-guided arterial cannulation in the paediatric population.
Cochrane Database of Systematic Reviews 2023, Issue 3. Art. No.: CD011364.
DOI: 10.1002/14651858.CD011364.pub3.

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[Intervention Review]

Ultrasound-guided arterial cannulation in the paediatric population

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Editorial group: Cochrane Emergency and Critical Care Group.
Publication status and date: New search for studies and content updated (no change to conclusions), published in Issue 3, 2023.

Citation: Raphael CK, El Hage Chehade NA, Khabsa J, Akl EA, Aouad-Maroun M, Kaddoum R. Ultrasound-guided arterial cannulation in the paediatric population. *Cochrane Database of Systematic Reviews* 2023, Issue 3. Art. No.: CD011364. DOI: 10.1002/14651858.CD011364.pub3.

ABSTRACT

Background

In arterial line cannulation in children and adolescents, traditional methods of locating the artery include palpation and Doppler auditory assistance. It is unclear whether ultrasound guidance is superior to these methods. This is an update of a review originally published in 2016.

Objectives

To evaluate the benefits and harms of ultrasound guidance compared with traditional techniques (palpation, Doppler auditory assistance) for assisting arterial line placement at all potential sites in children and adolescents.

Search methods

We searched CENTRAL, MEDLINE, Embase, and Web of Science from inception to 30 October 2022. We also searched four trials registers for ongoing trials, and we checked the reference lists of included studies and relevant reviews for other potentially eligible trials.

Selection criteria

We included randomised controlled trials (RCTs) comparing ultrasound guidance versus other techniques (palpation or Doppler auditory assistance) to guide arterial line cannulation in children and adolescents (aged under 18 years). We planned to include quasi-RCTs and cluster-RCTs. For RCTs with both adult and paediatric populations, we planned to include only the paediatric population data.

Data collection and analysis

Two review authors independently assessed the risk of bias of included trials and extracted data. We used standard Cochrane meta-analytical procedures, and we applied the GRADE method to assess the certainty of evidence.

Main results

We included nine RCTs reporting 748 arterial cannulations in children and adolescents (under 18 years of age) undergoing different surgical procedures. Eight RCTs compared ultrasound with palpation, and one compared ultrasound with Doppler auditory assistance. Five studies reported the incidence of haematomas. Seven involved radial artery cannulation and two involved femoral artery cannulation.

The people performing arterial cannulation were physicians with different levels of experience. The risk of bias varied across studies, with some studies lacking details of allocation concealment. It was not possible to blind practitioners in any case; this adds a performance bias that is inherent to the type of intervention studied in our review.

Compared to traditional methods, ultrasound guidance probably causes a large increase in first-attempt success rates (risk ratio (RR) 2.01, 95% confidence interval (CI) 1.64 to 2.46; 8 RCTs, 708 participants; moderate-certainty evidence) and probably causes a large reduction in the risk of complications such as haematoma formation (RR 0.26, 95% CI 0.14 to 0.47; 5 RCTs, 420 participants; moderate-certainty evidence). No studies reported data about ischaemic damage. Ultrasound guidance probably improves success rates within two attempts (RR 1.78, 95% CI 1.25 to 2.51; 2 RCTs, 134 participants; moderate-certainty evidence) and overall rate of successful cannulation (RR 1.32, 95% CI 1.10 to 1.59; 6 RCTs, 374 participants; moderate-certainty evidence). In addition, ultrasound guidance probably reduces the number of attempts to successful cannulation (mean difference (MD) −0.99 attempts, 95% CI −1.15 to −0.83; 5 RCTs, 368 participants; moderate-certainty evidence) and duration of the cannulation procedure (MD −98.77 seconds, 95% CI −150.02 to −47.52, 5 RCTs, 402 participants; moderate-certainty evidence).

More studies are needed to confirm whether the improvement in first-attempt success rates is more pronounced in neonates and younger children compared to older children and adolescents.

Authors' conclusions

We identified moderate-certainty evidence that ultrasound guidance for arterial cannulation compared with palpation or Doppler auditory assistance improves first-attempt success rate, second-attempt success rate and overall success rate. We also found moderate-certainty evidence that ultrasound guidance reduces the incidence of complications, the number of attempts to successful cannulation and the duration of the cannulation procedure.

PLAIN LANGUAGE SUMMARY

Ultrasound use for insertion of arterial catheters in children

Background

An arterial catheter is a thin tube that can be inserted into an artery to monitor blood pressure during complex surgeries and during stays in intensive care. Ultrasound (an imaging method that uses sound waves to capture live images of soft tissue) can help doctors to locate the artery and insert the catheter. In children in particular, ultrasound may reduce the need for multiple needle sticks, the occurrence of haematoma (a collection of blood outside the blood vessels) and damage to the artery, compared with other techniques such as palpation of the artery (feeling through the skin for the pulse) or Doppler auditory assistance (listening for a change to a higher pitch at the exact location of the artery).

What did we want to find out?

We aimed to find out whether ultrasound offers any advantages over palpation of the artery or Doppler auditory assistance. Specifically, we wanted to find out if ultrasound improved the following outcomes.

1. How often doctors can successfully insert the catheter on first attempt
2. The occurrence of complications such as haematoma and injury caused by reduced blood flow
3. How often doctors can successfully insert the catheter on the first two attempts
4. How often doctors can successfully insert the catheter after several attempts
5. The average number of attempts needed to insert the catheter
6. How long it takes to insert the catheter

What did we do?

We searched the literature for controlled clinical studies comparing use of ultrasound with traditional ways of placing a catheter into an artery in children under the age of 18 years. We compared and summarised the results of the studies and rated our confidence in the evidence based on factors such as study methods and sizes.

What did we find?

We found nine eligible studies: eight comparing ultrasound with palpation and one comparing ultrasound with Doppler auditory assistance. Seven studies were of radial artery cannulation and two studies were of femoral artery cannulation. Four studies did not mention any funding source and five studies had departmental funds. The studies included children aged from under one month to 18 years.

Main results

We found that ultrasound guidance compared with traditional methods probably increases the rate of successful cannulation on first attempt, within the first two attempts, and after several attempts. Ultrasound guidance probably reduces the occurrence of haematoma, the number of attempts needed to successfully place an arterial catheter, and the time needed to perform successful cannulation. The evidence suggests that ultrasound is probably superior for arterial cannula insertion in children and adolescents, including very young children.

Limitations of the evidence

Our confidence in the evidence is only moderate because it was impossible to mask the doctors performing the cannulation (they knew which children had ultrasound-assisted cannulation), and because the studies included few children and reported few events.

How up to date is the evidence?

The evidence is up to date to October 2022.

SUMMARY OF FINDINGS

Summary of findings 1. Summary of findings table

Ultrasound-guided arterial cannulation compared with palpation or Doppler guidance for children and adolescents

Patient or population: children and adolescents
Setting: various surgical procedures in operating rooms/ICU/emergency departments in university hospital settings in Germany, Japan, Lebanon, Singapore, Thailand, Canada and USA
Intervention: US-guided arterial cannulation
Comparison: other techniques (palpation/Doppler)

Outcomes	Anticipated absolute effects (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Certainty
	Risk with other techniques (palpation/Doppler)	Risk with US-guided arterial cannulation			
First-attempt success rate	**Study population**		**RR 2.01** (1.64 to 2.46)	708 (8 RCTs)	⊕⊕⊕⊖ **Moderate**[a]
	242 per 1000	487 per 1000 (397 to 596)			
Incidence of complications (haematoma)	**Study population**		**RR 0.26** (0.14 to 0.47)	420 (5 RCTs)	⊕⊕⊕⊖ **Moderate**[a]
	218 per 1000	57 per 1000 (31 to 102)			
Successful cannulation within first 2 attempts	**Study population**		**RR 1.78** (1.25 to 2.51)	134 (2 RCTs)	⊕⊕⊕⊖ **Moderate**[a]
	358 per 1000	638 per 1000 (448 to 899)			
Overall successful cannulation after multiple attempts	**Study population**		**RR 1.32** (1.10 to 1.59)	374 (6 RCTs)	⊕⊕⊕⊖ **Moderate**[b]
	606 per 1000	800 per 1000 (667 to 964)			
Number of attempts to successful cannulation	**Study population**		—	368 (5 RCTs)	⊕⊕⊕⊖ **Moderate**[a]
	The mean number of attempts to successful cannulation was 2.12 attempts	MD 0.99 attempts fewer (1.15 fewer to 0.83 fewer)			

Duration of cannulation procedure	**Study population**		—	402 (5 RCTs)	⊕⊕⊕⊖ **Moderate**[c]
	The mean time to successful cannulation was 331.3 seconds	MD 98.77 seconds shorter (150.02 shorter to 47.52 shorter			

CI: confidence interval; **ICU:** intensive care unit; **RCT:** randomised controlled trial; **RR:** risk ratio; **US:** ultrasound.

GRADE Working Group grades of evidence
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.
Moderate certainty: we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.
Very low certainty: we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

[a] Downgraded one level owing to risk of bias concerns (selection bias and performance bias).
[b] Downgraded one level owing to a moderate level of heterogeneity (I^2 = 54%) and risk of bias concerns (selection bias and performance bias).
[c] Downgraded one level owing to potential bias in two studies that set a 10-minute time limit.

BACKGROUND

Description of the condition

Arterial line cannulation is an intervention that is commonly performed during major surgery and in the intensive care unit (ICU) for continuous blood pressure monitoring and arterial blood sampling in children and adolescents. Arterial line cannulation can be more challenging in children and adolescents compared with adults because their arteries are smaller.

Description of the intervention

The most common site for arterial cannulation is the radial artery; other sites include the femoral, axillary, brachial, ulnar, dorsalis pedis, tibial posterior and temporal arteries. There are many possible techniques for arterial cannulation in the paediatric population, including palpation, Doppler auditory assistance and ultrasound guidance (Ueda 2013).

Palpation of the pulse

Pulse palpation to identify a landmark is the traditional approach to inserting an arterial catheter. The site of cannulation is usually selected, positioned and prepped. The physician locates the artery by palpating the pulse before initiating cannulation. Accurate localisation of small arteries is technically difficult, especially in small children and infants (Varga 2013). This may complicate placement and threading of the catheter (Schindler 2005). Dehydration or haemodynamic instability weakens the pulse and makes it difficult to find, further complicating the procedure.

Ultrasound guidance

Ultrasound guidance represents an alternative to the traditional palpation technique for insertion of arterial catheters. It is commonly used for placement of central venous catheters (CVCs). Numerous randomised controlled trials (RCTs) and systematic reviews have found that use of ultrasound reduces complications and increases first-attempt success for CVC placement compared with traditional landmark techniques (Hind 2003; Milling 2005; Randolph 1996).

Doppler auditory assistance

Doppler auditory assistance has been described as another traditional technique for insertion of arterial catheters. The Doppler tone changes to a higher pitch at the exact location of the artery, which may facilitate arterial cannulation. This technique has a reported success rate of 46% (Ueda 2013).

Potential complications

Although rare, devastating complications associated with arterial line cannulation may occur, such as permanent ischaemic damage, sepsis and pseudoaneurysm formation (Scheer 2002). Less serious complications such as arterial occlusion, haematoma and nerve injury are more frequent (King 2008).

How the intervention might work

Intervention

Real-time ultrasound guidance technique

Through an out-of-plane technique, the physician positions the artery in the middle of the screen, holding the probe in their left hand, perpendicular to the skin. With the right hand, the physician introduces a cannula of an appropriate size below the ultrasound probe, and tissue movement is observed on the ultrasound screen. They then redirect the cannula or repeat the manoeuvre until adequate arterial flow allows easy insertion of the guidewire or cannula.

Comparator

Palpation technique

With this approach, the physician uses their non-dominant hand to palpate the artery, while their dominant hand manipulates the intravascular needle or catheter, which they insert at a 30- to 45-degree angle and advance slowly until pulsatile blood flow returns. They then advance the outer cannula into the artery directly from the needle or with the aid of a guidewire.

Doppler auditory assistance

The Doppler probe identifies the artery by locating the area with maximum frequency. During cannulation, the physician uses the Doppler probe to identify the exact position of the artery and to guide needle or cannula insertion.

Why it is important to do this review

The importance of this Cochrane Review stems from the large number of arterial lines placed in children and adolescents undergoing major surgery or hospitalised in an ICU, or both. UK guidelines for placement of CVCs have recommended use of an ultrasound-guided technique, given associated reductions in the rate of failure and in mechanical complications (NICE 2002). The American Society of Anesthesiology Task Force has issued practice guidelines for central venous access, in which they recommended real-time ultrasound guidance for vessel localisation and venipuncture when the internal jugular vein is selected for cannulation (ASA 2012). One systematic review found that ultrasound can offer small gains in safety and quality compared with an anatomical landmark technique when used for subclavian or femoral vein cannulation for central vein catheterisation (Brass 2015). Ultrasound guidance may also significantly reduce the number of haemodialysis catheters successfully inserted on the first attempt, the risk of arterial puncture and haematomas and the time taken for successful venipuncture (Rabindranath 2011). While some studies support the use of ultrasound for arterial line insertion (Schwemmer 2006), others oppose this approach (Ganesh 2009). Ultrasound guidance is a common and broadly used intervention, mainly based on the evidence from adults (Flumignan 2021). No guidelines are available on use of ultrasound for arterial line placement in children and adolescents. Several RCTs have published findings on this topic (Anantasit 2017; Ganesh 2009; Ishii 2013; Min 2019; Salik 2021; Schwemmer 2006; Siddik-Sayyid 2016; Tan 2015; Ueda 2013), but meta-analyses for the paediatric population still include a limited number of studies restricted to radial artery cannulation (Aouad-Maroun 2016; White 2016). This Cochrane Review will provide an objective assessment of the benefits and harms of using ultrasound guidance compared with traditional techniques (palpation, Doppler auditory assistance) for arterial line placement in children and adolescents. This information can help doctors

to make educated choices and reduce potential complications of arterial line placement.

OBJECTIVES

To evaluate the benefits and harms of ultrasound guidance compared with traditional techniques (palpation, Doppler auditory assistance) for assisting arterial line placement at all potential sites in children and adolescents.

METHODS

Criteria for considering studies for this review

Types of studies

We included RCTs.

Types of participants

We limited participants of interest to children and adolescents (under the age of 18 years) undergoing arterial line placement.

Types of interventions

The intervention was ultrasound guidance, and the comparators were pulse palpation and Doppler auditory assistance.

Types of outcome measures

Primary outcomes

1. First-attempt success rate
2. Incidence of complications
   a. Haematoma
   b. Ischaemic damage

Secondary outcomes

1. Successful cannulation within the first two attempts
2. Overall successful cannulation after multiple attempts
3. Number of attempts to successful cannulation
4. Duration of cannulation procedure

Search methods for identification of studies

Electronic searches

We searched the following databases from inception to 30 October 2022.

1. Cochrane Central Register of Controlled Trials (CENTRAL; 2022)
2. MEDLINE (via Ovid)
3. Embase (via Ovid)
4. Web of science

We searched the following trials registries to 30 October 2022.

1. U.S. National Institutes of Health (NIH) ongoing trials register ClinicalTrials.gov (clinialtrials.gov)
2. The ISRCTN registry (www.isrctn.com)
3. The EU Clinical Trials register (www.clinicaltrialsregister.eu)
4. World Health Organization (WHO) International Clinical Trials Registry Platform (trialsearch.who.int)

We also combined the searches (where appropriate) with RCT filters provided in the *Cochrane Handbook for Systematic Reviews of Interventions* (Lefebvre 2021), searched for citations of retrieved included trials, searched for relevant systematic reviews, and checked for errata and retraction notices related to the included studies.

We searched for potentially eligible trials in the following websites.

1. Society for Pediatric Anesthesia (pedsanesthesia.org)
2. American Society of Anesthesiologists (www.asahq.org)

We did not limit our search by language, publication date or publication format.

See Appendix 1, Appendix 2, Appendix 3, and Appendix 4 for details of our searches.

We continuously applied the basic search strategy of the 'My NCBI' (National Center for Biotechnology Information) email alert service of PubMed to identify newly published studies. We performed a completely updated search of all specified databases in October 2022.

Searching other resources

We tried to identify other potentially eligible trials or ancillary publications by searching the reference lists of included trials, related systematic or other reviews and health technology assessment reports.

Data collection and analysis

Selection of studies

We planned to include quasi-RCTs and cluster-RCTs. For RCTs with both adult and paediatric populations, we planned to include only the paediatric population data, if presented separately. Two review authors (CR, NHC) independently assessed every retrieved citation for potential eligibility. We retrieved the full texts for all citations judged potentially eligible by at least one of the two review authors. The two review authors then independently assessed the full texts in duplicate using a standardised and pilot-tested screening form. We compared results and resolved disagreements by consensus, or with the help of a third review author (MAM) when needed. Before starting the selection process, CR and NHC conducted calibration exercises to ensure the validity of the process.

Data extraction and management

Two review authors (CR, NHC) independently extracted relevant data in duplicate, using standard data extraction forms. Abstracted data included characteristics of the population, interventions, controls and outcomes. We also extracted statistical data needed for the meta-analysis. We resolved disagreements by discussion or, if required, by consulting a third review author (MAM). We contacted one study author for clarification and additional data. After completing the data extraction forms, the two review authors (CR, NHC) entered the data into Review Manager Web (RevMan Web 2022).

Dealing with duplicate publications and companion papers

In the event of duplicate publications, companion documents or multiple reports of a primary study, we planned to maximise the yield of information by collating all available data. We planned

to resolve remaining uncertainties by attempting to contact study authors when possible.

Assessment of risk of bias in included studies

Two review authors (CR, NHC) assessed the risk of bias of each included study independently and in duplicate, using the Cochrane risk of bias tool (RoB 1; Higgins 2011). RoB 1 includes the following domains.

1. Random sequence generation (selection bias)
2. Allocation concealment (selection bias)
3. Blinding of participants, providers, data collectors, outcome adjudicators and data analysts (performance bias and detection bias)
4. Incomplete outcome data (attrition bias)
5. Selective outcome reporting (outcome reporting bias)
6. Other bias

We assessed outcome reporting bias by comparing outcomes listed in a trial protocol, at registration and in the methods section versus outcomes for which data were reported in the results section (Kirkham 2010). We judged trials as having 'low risk', 'high risk' or 'unclear risk' of bias and evaluated individual bias items as described in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011). For blinding of participants and personnel (performance bias), blinding of outcome assessors (detection bias) and incomplete outcome data (attrition bias), we intended to evaluate risk of bias separately for subjective and objective outcomes (Hróbjartsson 2013). We planned to consider the implications of missing outcome data for individual participants.

Measures of treatment effect

We planned to express dichotomous data as risk ratios (RRs) or hazard ratios (HRs) with 95% confidence intervals (CIs). We planned to express continuous data as mean differences (MDs) with 95% CIs when all studies reported the outcome using the same scale, and as standardised mean differences (SMDs) when studies reported the outcome using different scales.

If included studies had reported rate data (i.e. counts measured for each participant along with observation time), we would have pooled rate ratios.

When studies reported median and interquartile range (IQR), we assumed the median was representative of the mean, and we used guidance in the *Cochrane Handbook for Systematic Reviews of Interventions* to calculate standard deviations (SDs; Higgins 2021).

Unit of analysis issues

When studies randomised individual participants, we considered the participant as the unit of analysis. For cluster-RCTs or trials with multiple catheters per person, we planned to use estimates from the included studies adjusted for correlation. Whenever this was not reported, we treated the trial as a parallel group trial. For studies with multiple intervention arms, we omitted groups that were irrelevant to our comparison of interest.

Dealing with missing data

We planned to use a complete case approach in the main analysis and to conduct sensitivity analyses using plausible assumptions about the outcomes of participants with missing outcome data to test the robustness of our findings, as outlined in Akl 2013 and Ebrahim 2013. However, there were no missing data.

Assessment of heterogeneity

We assessed statistical heterogeneity (inconsistency) by visually inspecting the forest plots and by using a standard Chi^2 test with a significance level of 0.1. In view of the low power of this test, we also considered the I^2 statistic, which quantifies inconsistency across studies, to assess the impact of heterogeneity on the meta-analysis (Higgins 2002; Higgins 2003). We considered an I^2 statistic of 50% or more as indicative of a considerable level of statistical heterogeneity (Higgins 2021).

We planned to conduct subgroup analyses to explore whether any clinical or methodological factor could explain cases of considerable statistical heterogeneity (see Subgroup analysis and investigation of heterogeneity). If the subgroup analysis identified a subgroup effect (i.e. statistical heterogeneity was explained), we planned to present results stratified by relevant subgroups. If the subgroup analysis did not identify a subgroup effect (i.e. statistical heterogeneity remained unexplained), we planned to refrain from meta-analysis of studies.

We expected the following characteristics to introduce clinical heterogeneity.

1. Expertise of the physician
2. Academic versus non-academic setting
3. Age group of participants (infants versus older children versus adolescents)
4. Site of cannulation (radial or other arteries)
5. Experience of the physician with ultrasound
6. Studies at low versus high risk of bias

We made a post-hoc decision to conduct subgroup analyses that we judged clinically relevant even in the absence of statistical heterogeneity.

Assessment of reporting biases

We planned to examine funnel plots to assess the potential for publication bias if we found 10 or more studies reporting on a particular outcome (Sterne 2011); however, we included only nine studies in total.

Data synthesis

We synthesised and analysed data using RevMan Web (RevMan Web 2022). We calculated agreement between the two independent review authors for assessment of full-text eligibility using the kappa statistic. For categorical data, we calculated RRs separately for each study for the event rate of outcomes by treatment arm, then pooled the results of different studies using a random-effects model. For continuous data, we pooled data from different studies using a random-effects model. For both types of data, we used a fixed-effect model when meta-analysing two studies.

Subgroup analysis and investigation of heterogeneity

We planned to investigate potential reasons for heterogeneity by conducting subgroup analyses. We planned to investigate interactions by conducting subgroup analyses based on the following characteristics.

1. Expertise of the physician
2. Academic versus non-academic setting
3. Age group of participants (neonates versus infants versus children versus adolescents)
4. Site of cannulation (radial or other arteries)
5. Experience of the physician with ultrasound

However, there were insufficient data for some characteristics: expertise of the physicians varied widely among the included studies and all studies were performed in university hospitals. Therefore, we analysed data according to age groups of participants (though we could not obtain these data for one study), site of cannulation and experience with ultrasound.

Sensitivity analysis

We planned to perform sensitivity analyses to explore the influence of the following factors (when applicable) on effect size.

1. Restricting the analysis to published studies.
2. Restricting the analysis to studies with low risk of bias.
3. Making plausible assumptions about the outcomes of participants with missing data.

Summary of findings and assessment of the certainty of the evidence

Using the GRADE approach, we classified the certainty of the evidence for each outcome into one of four possible categories: high, moderate, low and very low (Guyatt 2011a). This approach takes into account the study design, as well as risk of bias, imprecision, inconsistency, indirectness, publication bias, large effect size, dose-response effect and confounding. We used the principles of the GRADE system to assess the certainty of the body of evidence associated with the following specific outcomes in our review.

1. First-attempt success rate
2. Incidence of complications
   a. Haematoma
   b. Ischaemic damage
3. Successful cannulation within the first two attempts
4. Overall successful cannulation after multiple attempts
5. Number of attempts to successful cannulation
6. Duration of cannulation procedure

We used GRADE software to construct a summary of findings table (GRADEpro GDT). The GRADE approach appraises the certainty of a body of evidence according to the extent to which one can be confident that an estimate of effect or association reflects the item being assessed.

RESULTS

Description of studies

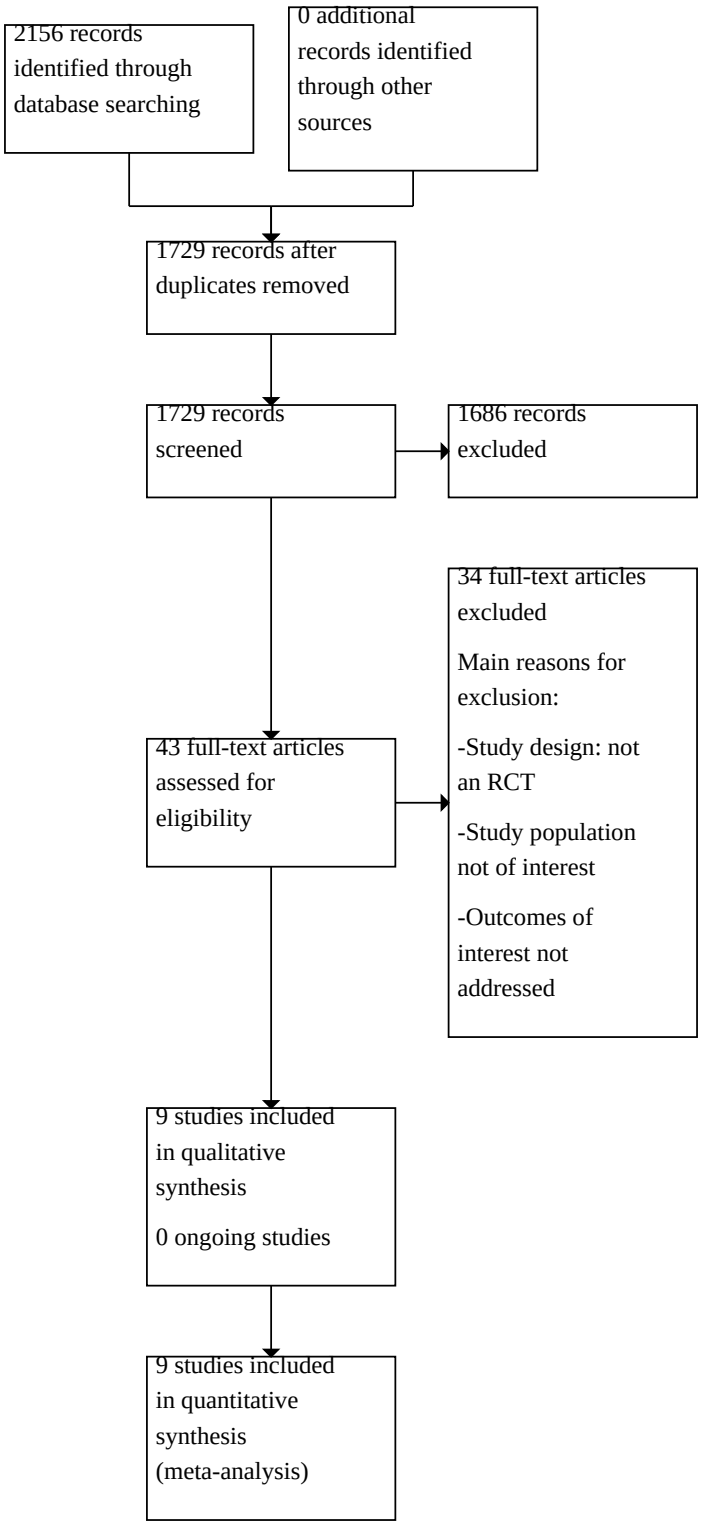
See Characteristics of included studies table.

Results of the search

Of the 1729 records identified through database searching (excluding duplicates), we retrieved 43 full-text articles that we considered potentially eligible. Of these 43 titles, nine met our eligibility criteria (Anantasit 2017; Ganesh 2009; Ishii 2013; Min 2019; Salik 2021; Schwemmer 2006; Siddik-Sayyid 2016; Tan 2015; Ueda 2013). We excluded 34 studies (Abdelbaser 2021; Aouad-Maroun 2016; Bhattacharjee 2018; Bobbia 2013; Chi 2015; Gu 2014; Guan 2016; Ijiri 2016; Jung 2021; Kiberenge 2018; Lee 2016; Liu 2019; Nakayama 2014; Oulego-Erroz 2019; Polat 2019; Quan 2019; Schults 2020; Selldén 1987; Sethi 2017; Seto 2010; Seto 2013; Shiloh 2010; Sobolev 2015; Song 2016; Sorrentino 2020; Staudt 2019; Takeshita 2015; Takeshita 2021; Varga 2013; White 2016; Ye 2020; Zhang 2020; Zhefeng 2019; Zhou 2016). We found no ongoing studies or studies awaiting classification.

We have further illustrated these findings in the study flow diagram (Figure 1; Liberati 2009).

Figure 1. Study flow diagram.



Included studies

We included nine studies published between 2006 and 2021, all in English. The studies involved a total of 748 participants, including 369 ultrasound-assisted arterial catheterisations, 327 palpation-assisted catheterisations and 52 Doppler-assisted catheterisations.

Seven RCTs studied radial artery cannulation (Anantasit 2017; Ganesh 2009; Ishii 2013; Min 2019; Schwemmer 2006; Tan 2015; Ueda 2013), while two studied femoral artery cannulation (Salik 2021; Siddik-Sayyid 2016). Eight studies randomised participants, while Ishii 2013 randomised multiple arteries (right and left) of the same participants.

Eight RCTs evaluated ultrasound-guided arterial catheterisation versus palpation-guided arterial catheterisation, and Ueda 2013 evaluated ultrasound-guided arterial catheterisation versus Doppler-guided arterial catheterisation. The median sample size across studies was 94 (IQR 84 to 104). These studies took place in university hospital settings in Germany, Japan, Lebanon, Thailand, Singapore, Turkey, the USA and Canada. All studies included participants of both sexes, with ages ranging from under one month to 18 years.

The exclusion criteria were as follows.

1. Skin erosion or haematoma, a visible recent catheterisation scar or an arterial puncture site from one month earlier (Anantasit 2017; Ishii 2013; Ueda 2013)
2. Signs of skin infection near the puncture site (Min 2019)
3. Absence of an amplitude of radial or femoral pulsation (Anantasit 2017; Salik 2021)
4. Prominent differences in arterial pressure between left and right arms (Ishii 2013)
5. Diagnosed vascular abnormality or variation (Min 2019)
6. Anticipated circulatory instability after anaesthesia induction, such as pulmonary hypertension or severe heart failure (Min 2019; Salik 2021; Siddik-Sayyid 2016; Tan 2015)
7. Allergy to ultrasound gel (Salik 2021)

Types of surgery included elective cardiac surgeries (Ishii 2013; Min 2019; Salik 2021; Siddik-Sayyid 2016), major neurosurgery (Schwemmer 2006), and other major surgeries (Ueda 2013). Two studies were performed in the paediatric intensive critical care unit (Anantasit 2017; Tan 2015).

The people performing cannulation were medical doctors with different levels of expertise, including inexperienced anaesthesiology fellows (Anantasit 2017; Tan 2015), paediatric subspecialty trainee anaesthesiologists with a minimum of two years (Ueda 2013) or three years of training in anaesthesia (Ganesh 2009; Ishii 2013; Siddik-Sayyid 2016), a mix of consultant paediatric anaesthesiologist and trainees (Ganesh 2009), cardiac anaesthesia fellows (Ueda 2013) and a specialist with at least three years of experience in paediatric cardiac anaesthesia (Salik 2021).

Some physicians had minimal experience with ultrasound (Anantasit 2017; Ganesh 2009; Siddik-Sayyid 2016; Tan 2015; Ueda 2013), while others were advanced users (Ishii 2013; Min 2019; Salik 2021; Schwemmer 2006).

Four studies did not mention any funding source (Anantasit 2017; Ishii 2013; Salik 2021; Schwemmer 2006), and five studies had departmental funding (Ganesh 2009; Min 2019; Siddik-Sayyid 2016; Tan 2015; Ueda 2013).

Excluded studies

We excluded 34 studies. The main reasons for exclusion were related to the type of study design (not an RCT), the age group (adults) and the outcomes.

Ongoing studies

We identified no ongoing studies.

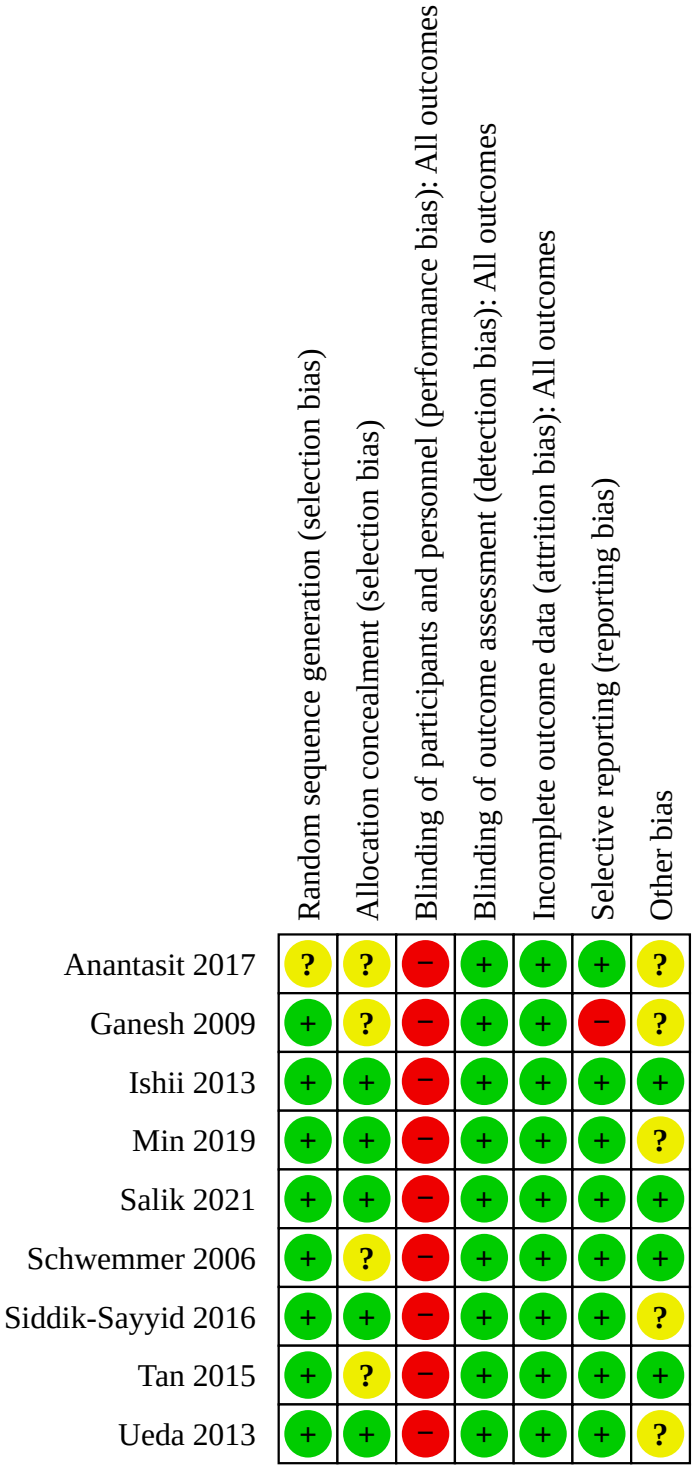
Awaiting classification

We identified no studies awaiting classification.

Risk of bias in included studies

Figure 2 shows the risk of bias summary, which reflects judgements about each risk of bias item for each included study.

Figure 2. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.



Allocation

The included studies used different methods of random sequence generation.

Ganesh 2009, Min 2019 and Tan 2015 used computer-generated random number sequence for assignment to one of two groups, whereas Ishii 2013 and Salik 2021 utilised the envelope method. Schwemmer 2006 tossed a coin and allocated 'heads' to the ultrasound technique and 'tails' to the palpation technique. Siddik-Sayyid 2016 and Ueda 2013 assigned participants by randomised block design to the control group or the ultrasound-guided technique group. Anantasit 2017 did not clearly describe the randomisation method. Ishii 2013, Min 2019, Salik 2021, Siddik-Sayyid 2016, and Ueda 2013 ensured allocation concealment via the envelope method, whereby assignments were contained in prepared opaque envelopes that were opened just before cannulation. However, Anantasit 2017, Ganesh 2009, Schwemmer 2006 and Tan 2015 did not mention the method of concealment. For random sequence generation, all studies were judged to be at low risk of bias except Anantasit 2017 (unclear risk). Regarding allocation concealment, we judged Ishii 2013, Min 2019, Salik 2021, Siddik-Sayyid 2016 and Ueda 2013 at low risk, and Anantasit 2017, Ganesh 2009, Schwemmer 2006 and Tan 2015 at unclear risk.

Blinding

Risk of performance bias for participants in all nine included studies was low because all participants underwent induction of general anaesthesia before catheter insertion. However, risk of performance bias was high for the anaesthesiologist, who cannot be blinded during the intervention and is aware of the allocated technique before performing arterial catheterisation. Since the outcomes depend on the operator, we judged all studies to be at high risk of performance bias.

Ganesh 2009, Min 2019 and Salik 2021 considered aspiration of blood from the distal end of the arterial cannula as the endpoint, and Ishii 2013, Siddik-Sayyid 2016 and Ueda 2013 deemed the procedure successful when the artery was cannulated and an arterial waveform was recorded. Tan 2015 classified the procedure as successful when the artery was cannulated. Schwemmer 2006 mentioned only that in the ultrasound technique, when the cannula appeared to be within the vessel, the transducer was removed and catheterisation was considered successful, but the study did not describe the endpoint for the palpation technique. All these endpoints are unequivocal, so we considered the studies at low risk of detection bias.

Incomplete outcome data

Risk of attrition bias was low in six studies because outcome data were complete and no participants withdrew or were lost to follow-up (Ganesh 2009; Ishii 2013; Min 2019; Schwemmer 2006; Tan 2015). Salik 2021, Siddik-Sayyid 2016, and Ueda 2013 were at low risk of attrition bias because only a few participants were excluded from the analysis. In Ueda 2013, two cases were withdrawn and were counted as failures in the intention-to-treat analysis. The first of these occurred because an unintentional femoral arterial cannulation was performed on a participant who had been allocated to the ultrasound-guided technique; in the second case, a participant in the Doppler-assisted group dropped out because the operator who would have performed the procedure was unavailable. In Siddik-Sayyid 2016, two participants from each group were excluded because the residents were unavailable to perform the procedures, and in Salik 2021, three participants were removed after randomisation because they had haematomas at the selected site of cannulation due to previous interventions.

Selective reporting

Regarding our primary outcomes, eight studies reported first-attempt success rate (Anantasit 2017; Ganesh 2009; Ishii 2013; Min 2019; Salik 2021; Schwemmer 2006; Siddik-Sayyid 2016; Ueda 2013), and five of those studies also reported incidence of complications (Anantasit 2017; Ishii 2013; Min 2019; Salik 2021; Ueda 2013). We judged them at low risk of reporting bias. Although the methods of Ganesh 2009 included stratification according to age group (younger than two years, two to five years, older than five years), investigators did not report results according to this stratification, so we judged the study at high risk of reporting bias. The primary endpoint for Tan 2015 was time to successful cannulation using the primary randomisation method, and the secondary endpoints were number of attempted sites, number of attempts by practitioner and estimated cost of the procedure. We judged Tan 2015 at low risk of reporting bias.

Other potential sources of bias

Differences in the definitions of outcome measures among the included studies may be another source of bias. All studies except Ganesh 2009 defined a specific duration of procedure or number of attempts that would represent an unsuccessful cannulation. Ueda 2013 had two other potential sources of bias: firstly, haemodynamic manipulation of the size of a radial artery (by volume load or vasopressor effect) could improve the success rate of cannulation; and secondly, the investigated terminated the trial after recruiting only 50% of the original sample size.

Min 2019 and Siddik-Sayyid 2016 set a time limit of 10 minutes for successful cannulation, which might have affected the outcome duration of cannulation. In Min 2019, the participants' age and height were significantly different between the two groups, which could have affected all outcomes.

In Anantasit 2017, the operators included seven fellows with different levels of experience. Although the study authors performed a multiple logistic regression analysis to reduce bias related to operators' experience, a potential source of bias cannot be ruled out.

Effects of interventions

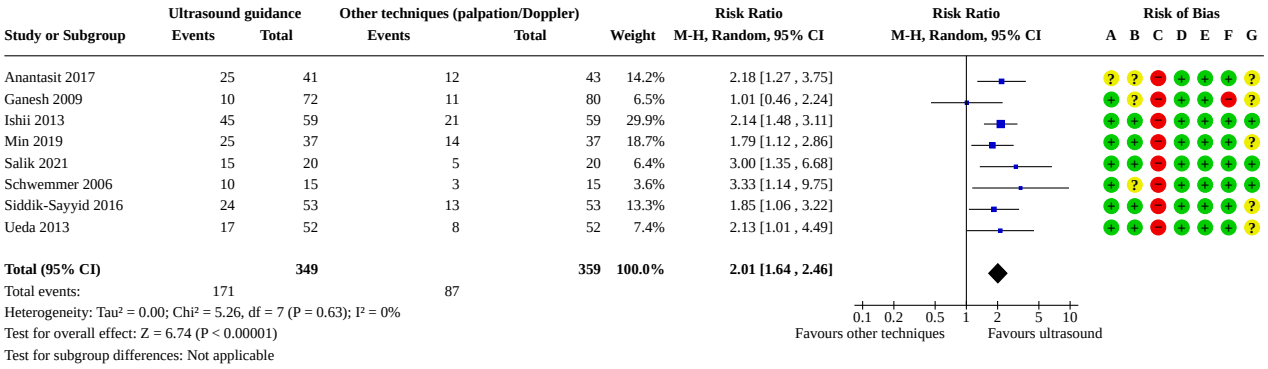
See: **Summary of findings 1** Summary of findings table

Primary outcomes

1. First-attempt success rate

Eight studies reported first-attempt success rate (Anantasit 2017; Ganesh 2009; Ishii 2013; Min 2019; Salik 2021; Schwemmer 2006; Siddik-Sayyid 2016; Ueda 2013). Meta-analysis of their results showed that ultrasound guidance compared with palpation or Doppler probably causes a large increase in the first-attempt success rate of cannulation in children and adolescents (RR 2.01, 95% CI 1.64 to 2.46; P < 0.001; 8 RCTs, 708 participants; Analysis 1.1; Figure 3). We judged the certainty of evidence as moderate owing to small sample sizes and risk of bias concerns, mainly selection bias and performance bias (Summary of findings 1).

Figure 3.

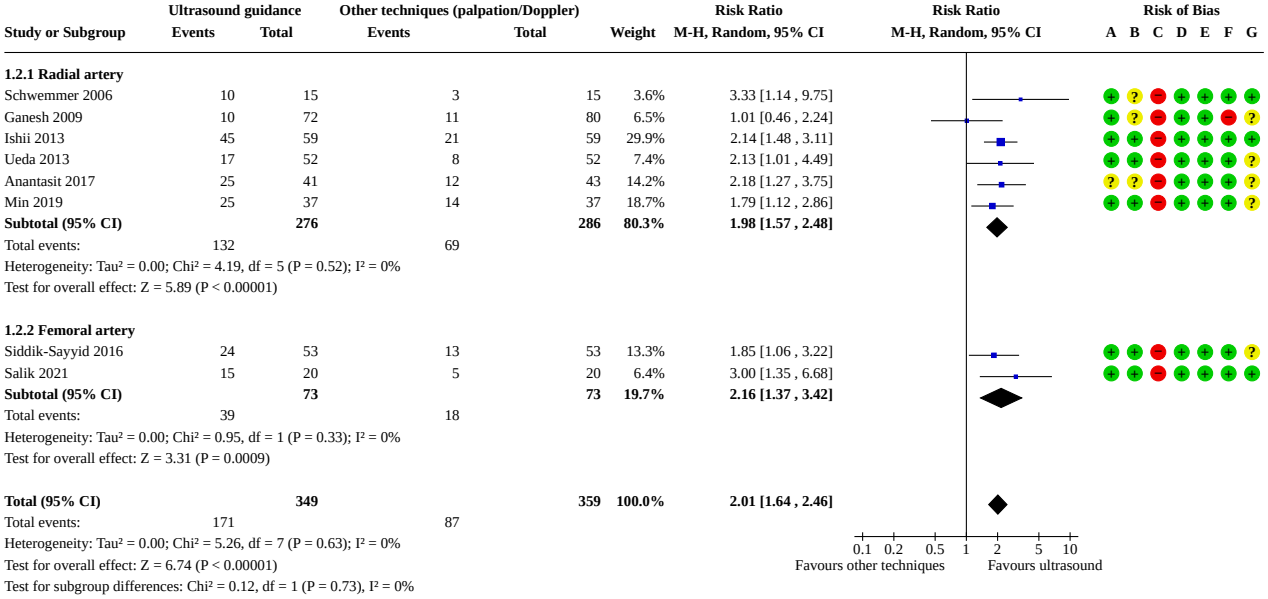


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Subgroup analysis based on artery site

We conducted a subgroup analysis based on artery site (radial/femoral; Figure 4).

Figure 4.



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(F) Selective reporting (reporting bias)
(G) Other bias

Six studies that reported first-attempt success rate provided data for radial artery cannulation (Anantasit 2017; Ganesh 2009; Ishii 2013; Min 2019; Schwemmer 2006; Ueda 2013), while Salik

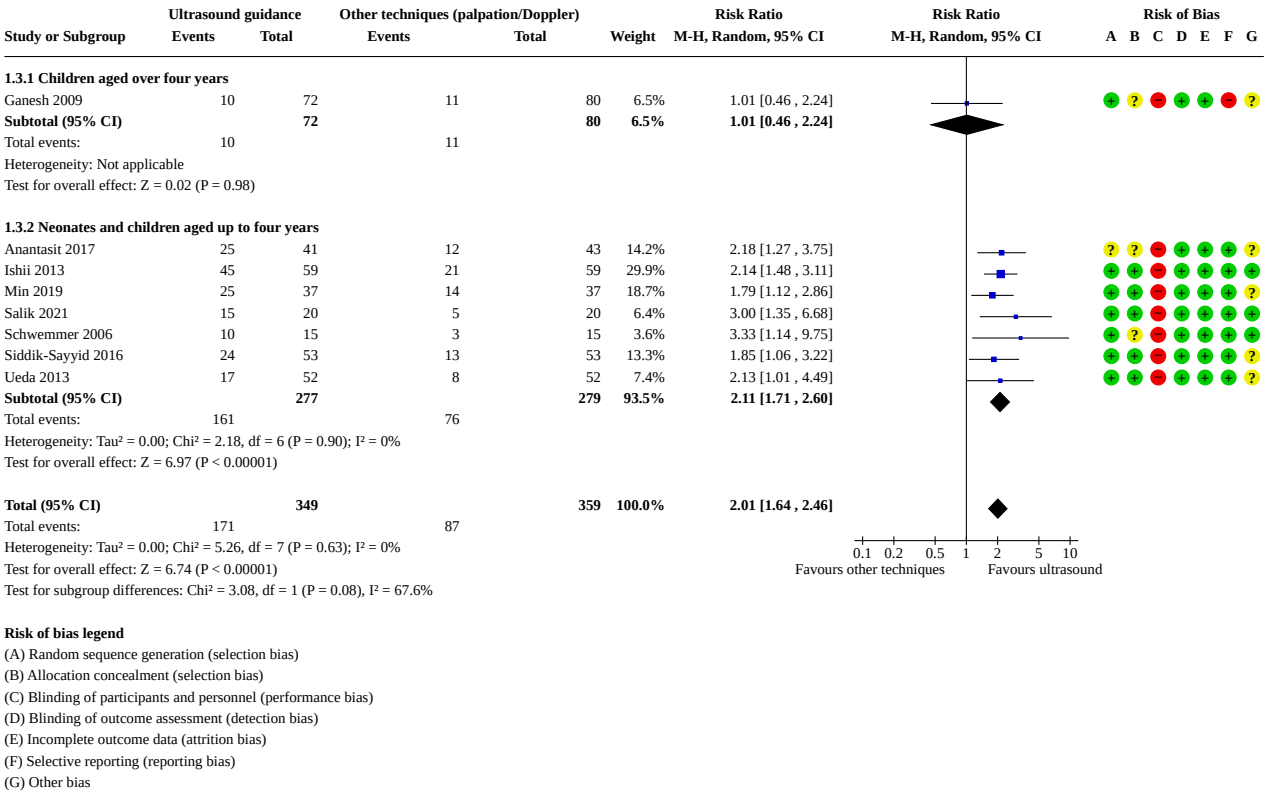
2021 and Siddik-Sayyid 2016 provided data for femoral artery cannulation.

We found that the superior performance of ultrasound guidance applied to both the radial site (RR 1.98, 95% CI 1.57 to 2.48; P < 0.001; 6 RCTs, 562 participants) and the femoral site (RR 2.16, 95% CI 1.37 to 3.42; P = 0.001; 2 RCTs, 146 participants). The test of subgroup difference was not statistically significant (P = 0.73).

Subgroup analysis based on age

We conducted a subgroup analysis based on age (Figure 5).

Figure 5.



Ganesh 2009 included children from a wide age group, but most were older children, with a mean age of 99 months. This study showed no difference between the use of ultrasound and palpation.

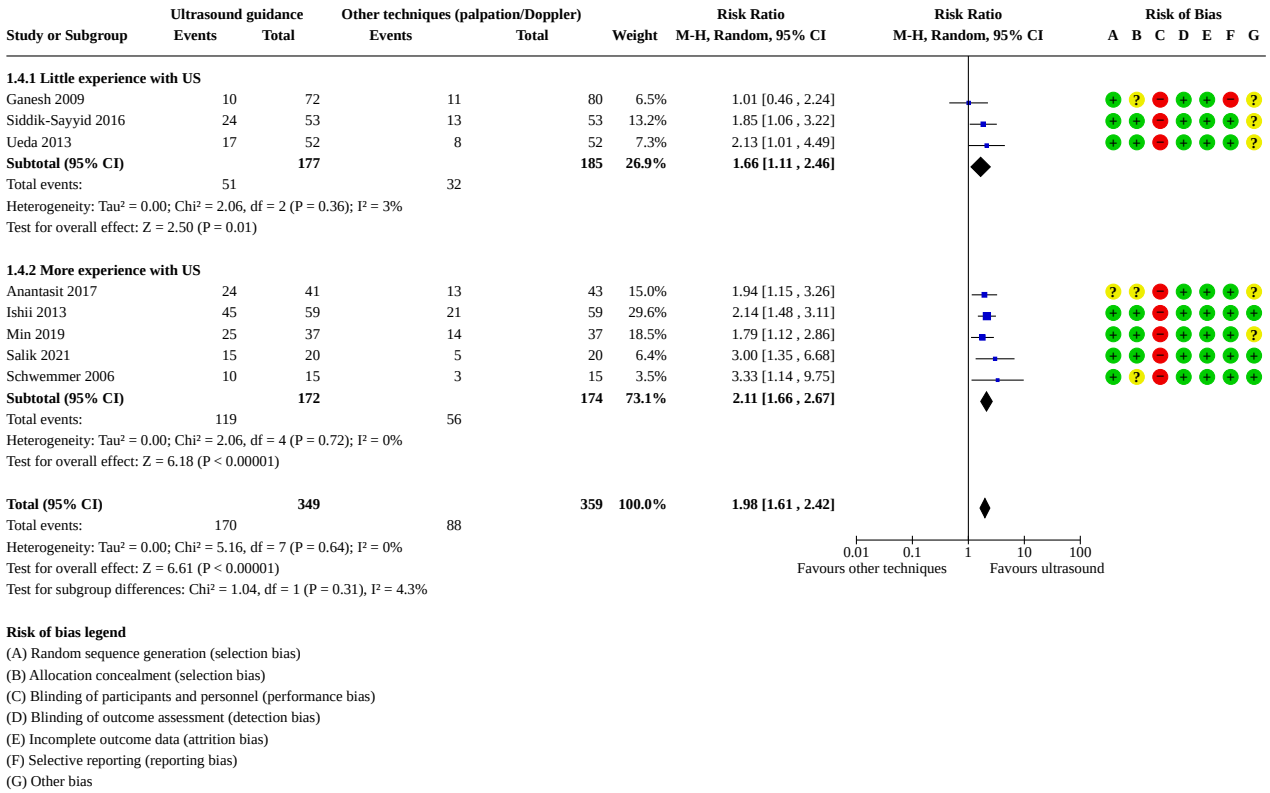
Seven studies reported data on neonates and children aged up to four years, with a mean age under 48 months (Anantasit 2017; Ishii 2013; Min 2019; Salik 2021; Schwemmer 2006; Siddik-Sayyid 2016; Ueda 2013). When we meta-analysed their results, we found a clear difference in first-attempt success rate in favour of ultrasound guidance (RR 2.11, CI 95% 1.71 to 2.60; P < 0.001; 7 RCTs, 556 participants).

The difference between ultrasound guidance and traditional techniques appears to be greater in children aged up to four years compared with older children; however, the test for subgroup differences was not statistically significant (P = 0.08).

Subgroup analysis based on the operator's experience with ultrasound

We conducted a subgroup analysis based on the experience of the operator performing the arterial cannulation in ultrasound use (Figure 6).

Figure 6.



In Ganesh 2009, anaesthesiologists had experience with fewer than 10 ultrasound-guided arterial cannulations, and in Siddik-Sayyid 2016 and Ueda 2013, anaesthesiologists had experience with fewer than five ultrasound-guided arterial cannulations. Meta-analysis suggested that ultrasound guidance led to increased first-attempt success rates in the paediatric population compared with palpation or the Doppler technique when the operator had minimal experience with ultrasound-guided cannulation (RR 1.66, 95% CI 1.11 to 2.46; P = 0.01; 3 RCTs, 362 participants).

In Ishii 2013, the operators performing arterial cannulation were familiar with the ultrasound-guided technique for central venous catheterisation in adults and children. Fellows who performed the cannulation in Anantasit 2017 assisted a vascular access course and had experience with more than 10 paediatric ultrasound-guided arterial cannulation procedures prior to the study. Anaesthesiologists in Min 2019, Salik 2021 and Schwemmer 2006 had experience with more than 20 paediatric ultrasound-guided arterial cannulation procedures. Meta-analysis suggested that ultrasound guidance led to increased first-attempt success rates in the paediatric population compared with palpation when the operator was more experienced in performing ultrasound-guided radial artery cannulation (RR 2.11, 95% CI 1.66 to 2.67; P < 0.001; 5 RCTs, 346 participants).

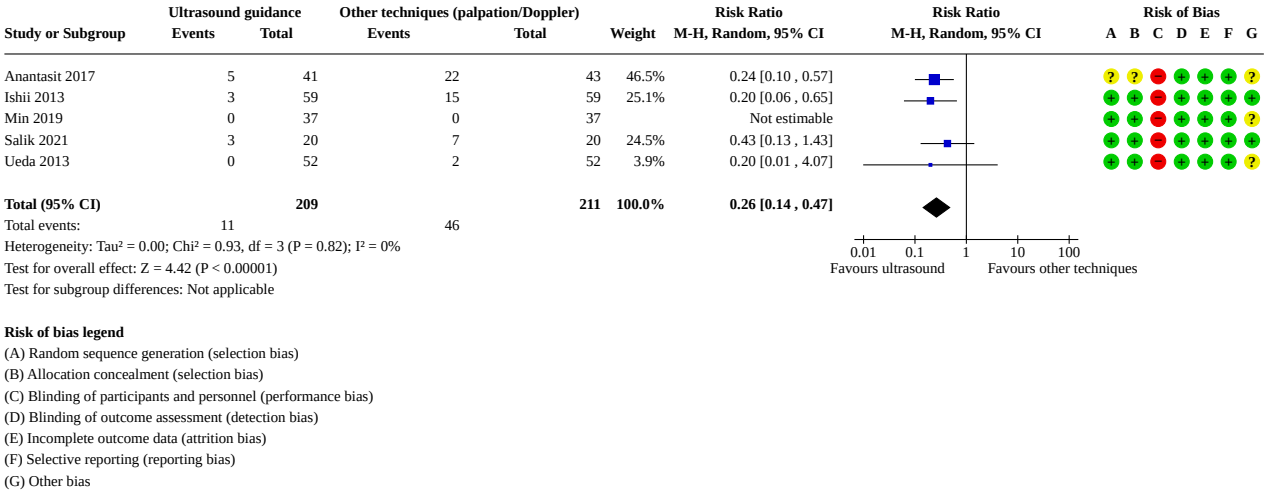
The test of subgroup effects showed that ultrasound guidance compared to traditional techniques leads to a similar increase in first-time success rates regardless of the operators' experience with ultrasound (P = 0.31).

2. Incidence of complications (haematoma or ischaemia)

Five studies reported incidence of haematoma (Anantasit 2017; Ishii 2013; Min 2019; Salik 2021; Ueda 2013).

Meta-analysis of their results showed that ultrasound guidance compared with palpation or the Doppler technique probably causes a large reduction in the rate of haematoma during arterial cannulation in the paediatric population (RR 0.26, 95% CI 0.14 to 0.47; P < 0.001; 5 RCTs, 420 participants; Figure 7). We judged the certainty of evidence as moderate owing to imprecision and risk of bias concerns, mainly regarding selection bias and performance bias (Summary of findings 1).

Figure 7.



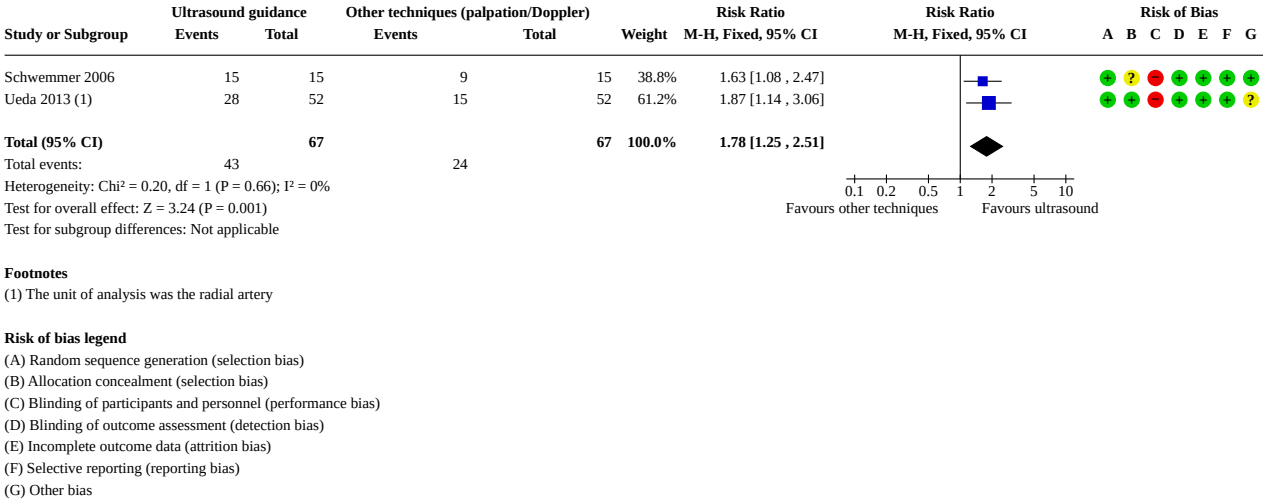
No studies reported ischaemia as an outcome.

Secondary outcomes

1. Successful cannulation within the first two attempts

Two studies reported successful cannulation within the first two attempts (Schwemmer 2006; Ueda 2013). Meta-analyses of their results showed that ultrasound guidance compared with palpation or the Doppler technique probably increases the rate of successful radial artery cannulation within the first two attempts in the paediatric population (RR 1.78, 95% CI 1.25 to 2.51; P = 0.001; 2 RCTs, 134 participants). We judged the certainty of evidence as moderate owing to imprecision and risk of bias concerns, mainly regarding selection bias and performance bias (Summary of findings 1, Figure 8).

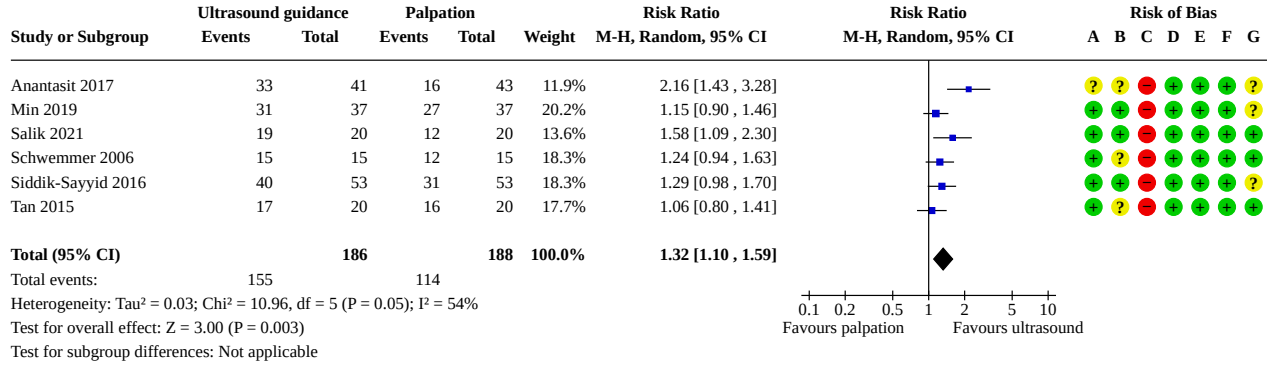
Figure 8.



2.Overall successful cannulation after multiple attempts

Six studies reported overall successful cannulation after multiple attempts (Anantasit 2017; Min 2019; Salik 2021; Schwemmer 2006; Siddik-Sayyid 2016; Tan 2015). Meta-analysis of their results showed that ultrasound guidance compared with palpation probably increases overall successful cannulation in the paediatric population (RR 1.32, 95% CI 1.10 to 1.59; P = 0.003; 6 RCTs, 374 participants; Figure 9). We judged the certainty of evidence as moderate owing to imprecision and risk of bias concerns, mainly regarding selection bias and performance bias (Summary of findings 1).

Figure 9.



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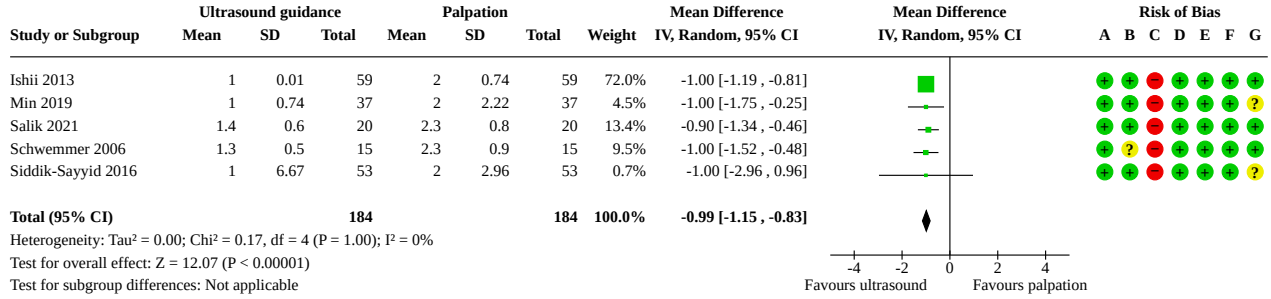
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

3. Number of attempts to successful cannulation

Five studies reported the number of attempts to successful cannulation as a secondary outcome (Ishii 2013; Min 2019; Salik 2021; Schwemmer 2006; Siddik-Sayyid 2016). We found that ultrasound-guided arterial cannulation compared with palpation in the paediatric population probably reduces the number of attempts to successful cannulation (MD −0.99 attempts, 95% CI −1.15 to −0.83; P < 0.001; 5 RCTs, 368 participants; Figure 10). We judged the certainty of evidence as moderate owing to small sample sizes and risk of bias concerns, mainly regarding selection bias and performance bias (Summary of findings 1).

Figure 10.



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(G) Other bias

4. Duration of cannulation procedure

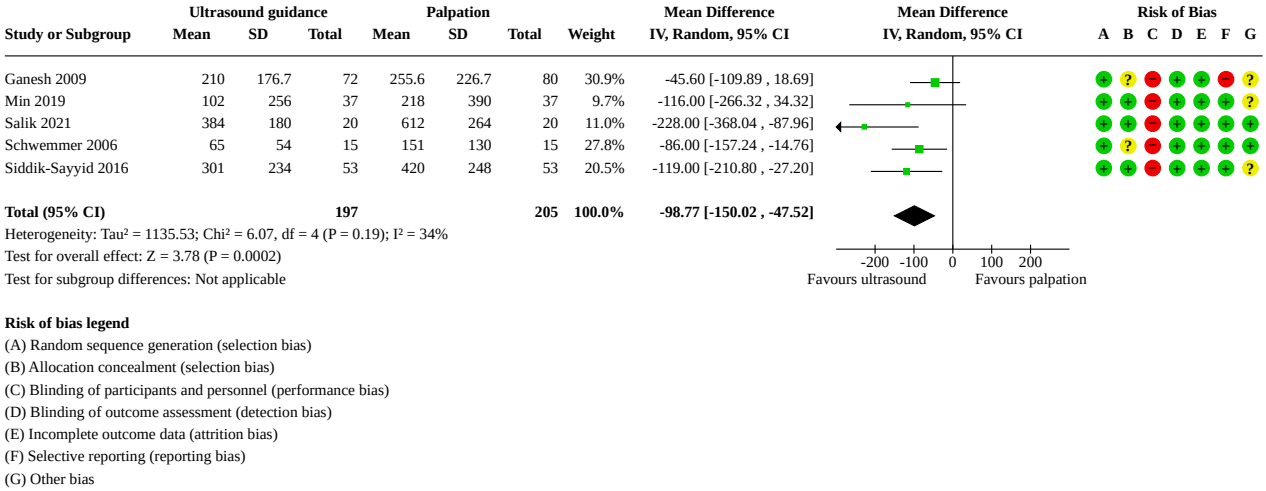
Seven studies reported time to successful cannulation (Anantasit 2017; Ganesh 2009; Min 2019; Salik 2021; Schwemmer 2006; Siddik-Sayyid 2016; Tan 2015); however, we could not include Anantasit 2017 or Tan 2015 in the meta-analysis owing to missing data.

Anantasit 2017 reported that the median time to success was significantly shorter in the ultrasound-guided group than in the palpation group (3.3 minutes versus 10.4 minutes; P < 0.001; 84 participants); no SDs were provided. Tan 2015 (40 participants) reported a mean of 7.8 minutes for the ultrasound group and 12.7 minutes for the palpation group but provided no SDs or P values.

When we meta-analysed data from the remaining five studies, we found that ultrasound-guided radial artery catheterisation probably reduces mean time to success (MD −98.77 seconds, 95% CI −150.02 to −47.52; P = 0.001; 5 RCTs, 402 participants; Figure 11). We judged the certainty of evidence as moderate owing to

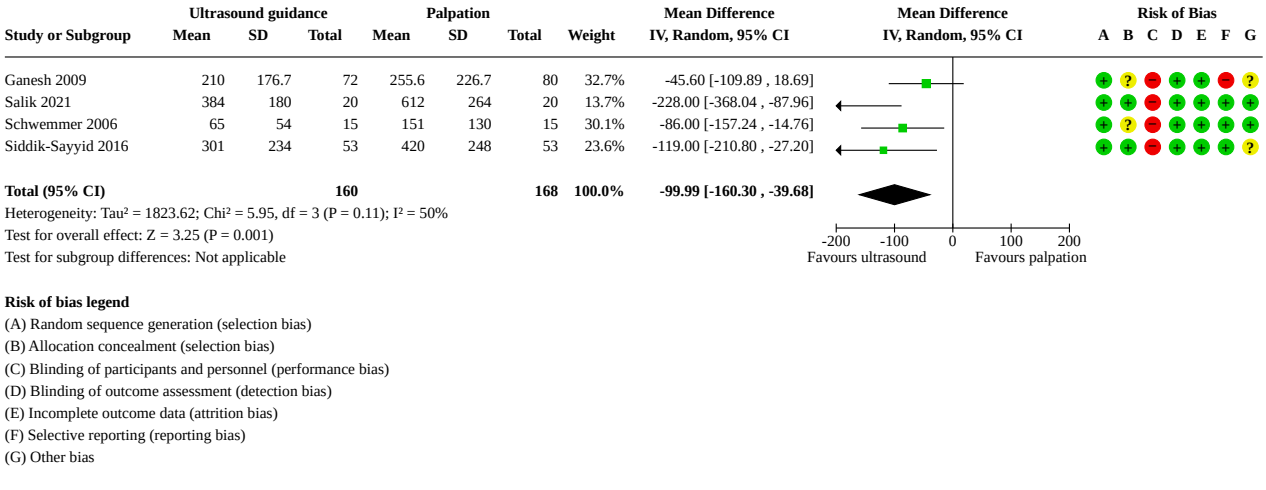
imprecision and risk of bias concerns, mainly regarding selection bias and performance bias (Summary of findings 1).

Figure 11.



Min 2019 reported the median (IQR) "procedural time(s) until successful catheterization", which we converted to mean and SD. A sensitivity analysis excluding Min 2019 did not change the results of the analysis (Figure 12).

Figure 12.



DISCUSSION

Summary of main results

The results of our review indicate that ultrasound usage for arterial cannulation probably causes a large increase in the first-attempt success rate and a moderate increase in the success rate after two attempts, compared with traditional techniques (palpation or Doppler auditory assistance). Moreover, ultrasound guidance probably causes a large reduction in haematoma formation, which was the only reported complication. We found that ultrasound probably improves the overall rate of successful cannulation. although definitions of this outcome varied among studies. What is more relevant than the success rate is the number of attempts and time needed to secure successful cannulation, both of which are probably lower with ultrasound-guided cannulation.

A subgroup analysis per age group included only one study with children aged over four years (Ganesh 2009), and seven studies in which participants were neonates and smaller children aged up to four years (Anantasit 2017; Ishii 2013; Min 2019; Salik 2021; Schwemmer 2006; Siddik-Sayyid 2016; Ueda 2013). More studies are needed to confirm whether ultrasound guidance is more beneficial in younger children versus older children (P = 0.08).

Overall completeness and applicability of evidence

We identified moderate-certainty evidence suggesting that ultrasound guidance for arterial cannulation improves first-attempt success rates, success rates within two attempts, and overall

success rates compared with palpation or Doppler auditory assistance. We also found moderate-certainty evidence suggesting that ultrasound guidance for arterial cannulation probably reduces the incidence of complications, the number of attempts to successful cannulation and the duration of the cannulation procedure.

The evidence suggests that ultrasound guidance is preferable to traditional techniques even when operators have little experience with ultrasound. However, an ultrasound device might not be present or readily available in the operating room in all institutions, which may limit the applicability of our evidence.

We did not restrict the systematic review to a particular arterial site, but eligible studies included cannulation of the radial and femoral arteries only. Therefore, the results of our review are only directly applicable to cannulation of the radial and femoral arteries, which are the most common sites of arterial cannulation in paediatrics.

We did not limit our comparator to the palpation technique; however, most included studies compared ultrasound with palpation, and only one study compared ultrasound with Doppler assistance. As a result, we could not explore a subgroup effect related to different comparators.

Quality of the evidence

Risk of bias in the included studies varied across assessed factors. Details of allocation concealment were inconsistent across studies. In addition, as it is impossible to blind the anaesthesiologist or the intensivist to the method of arterial line insertion, all studies were at increased risk of performance bias. Another potential bias concerns the lack of a standardised definition of the primary outcome. It is unclear whether a "first pass successful arterial cannulation" includes or excludes redirection of the needle. Moreover, some studies included children with a broad age interval (e.g. Ganesh 2009), and we were unable to obtain additional data from study authors.

We graded the certainty of evidence as moderate for the first-attempt success rate and for the number of attempts to successful cannulation owing to a relatively small number of events and sample sizes for the outcomes. In addition, the incidence of complications, rate of successful cannulation within two attempts, overall rate of success, and the duration of cannulation were graded as moderate certainty, mainly owing to imprecision, relatively small number of events and small sample sizes for these outcomes (Guyatt 2011b).

Potential biases in the review process

We identified one article written in Chinese by cross-checking the reference lists of identified articles. However, we were unable to find or retrieve this article (Liu 2013). One meta-analysis mentioned this article, and its results seem to be consistent with our findings (Zhang 2020). According to the meta-analysis, the study reported a higher first-attempt success rate in the ultrasound group (25/30) than in the palpation group (18/30). Therefore, it is unlikely that its inclusion would have modified our results.

We carried out a thorough search of appropriate electronic databases. We also used citation tracking and searched clinical trials registers. We attempted to contact study authors for additional study details.

Agreements and disagreements with other studies or reviews

This is an update of a review first published in 2016, which was the first to compare real-time ultrasound use versus palpation or Doppler guidance for arterial cannulation exclusively in children (Aouad-Maroun 2016). For this update, we added new data published since 2016.

Our results are consistent with those of previous meta-analyses that gathered data from both adult and paediatric populations and showed an improved first-attempt success rate with the use of ultrasound guidance compared with palpation (Gao 2015; Gu 2014; Shiloh 2011; Tang 2014; White 2016).

AUTHORS' CONCLUSIONS

Implications for practice

Ultrasound guidance for arterial cannulation compared to palpation and Doppler auditory assistance probably improves first-attempt success rate, success rate within two attempts and overall success rate. In addition, ultrasound guidance probably reduces the incidence of hematoma, the number of attempts to successful cannulation and the duration of cannulation.

Implications for research

Future studies could use a standardised definition of each outcome measure and must clearly state whether redirection of the needle within the same entry point is considered an additional attempt. Furthermore, future studies could stratify results by age to confirm differences related to infants and small children. Such studies would include larger numbers of well-defined age groups. Investigators may confirm the contribution of expertise in ultrasound usage to the success of arterial cannulation and highlight the usefulness of ultrasound as a 'rescue technique' following multiple attempts when palpation guidance fails. What is applicable for the radial artery might not be applicable for the larger femoral artery. Therefore, more studies could examine cannulation of arteries of different sites. Moreover, ultrasound might be particularly useful in difficult clinical scenarios, such as the presence of hypotension, oedema or obesity, and in children with congenital cardiac disease who undergo multiple arterial cannulations.

ACKNOWLEDGEMENTS

The following people conducted the editorial process for this review.

1. Sign-off Editor: Harald Herkner, Department of Emergency Medicine, Medical University of Vienna
2. Managing Editor: Naomi Dayan, Herlev Hospital, Denmark
3. Contact Editor: Arash Afshari, Department of Pediatric and Obstetric Anesthesia, University of Copenhagen, Rigshospitalet, Denmark
4. Copy Editor (copy-editing and production): Julia Turner

The following peer reviewers provided comments and recommended an editorial decision.

1. Clinical/content reviewers: Claude Abdallah, MD, MS Associate Professor, Pediatric Anesthesiology, Children's National

Hospital, Washington DC; Ronald Flumignan, Division of Vascular and Endovascular Surgery, Universidade Federal de Sao Paulo, Brazil

2. Consumer reviewer: Janet Wale, independent consumer advocate

The Statistical Editor was Jing Xie, Senior Biostatistician Centre for Biostatistics and Clinical Trials (BaCT), Peter MacCallum Cancer Centre, Victoria, Australia.

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CHARACTERISTICS OF STUDIES

Characteristics of included studies *[ordered by study ID]*

Anantasit 2017

Study characteristics	
Methods	RCT
Participants	**Number:** 84 radial arteries **Number per intervention** 1. Ultrasound: 43 radial arteries 2. Palpation: 41 radial arteries **Inclusion criteria** 1. Critically ill condition 2. Age 1 month–15 years 3. Need for invasive monitoring and frequent blood sampling **Exclusion criteria** 1. Absence of an amplitude of radial pulsation 2. Skin erosions near the insertion site 3. Former cannulation **Surgery/setting:** paediatric ICU **Baseline characteristics** Ultrasound 1. Mean age: 20 months 2. Mean weight: 9 kg 3. Sex ratio (male:female): 25:16 Palpation 1. Mean age: 32 months 2. Mean weight: 11 kg 3. Sex ratio (male:female): 31:12
Interventions	**Randomisation:** stratified block randomisation (blocks of 4, stratified by age < 1 year and > 1 year)

Anantasit 2017 *(Continued)*

	Intervention: ultrasound-guided artery cannulation (short-axis view). Artery was lined up with centre of transducer, needle inserted at centre of transducer in real-time. Single- or double wall technique chosen depending on operator preference (Seldinger technique employed in both cases). **Control:** palpation **Co-intervention:** standard 22- to 24-gauge Jelco intravenous catheter (Smiths Medical International, Ashford, England) percutaneously punctured the radial artery **Experience of operator:** attended course in ultrasound-guided vascular access course; experience of > 10 cases in ultrasound-guided or traditional palpation technique.
Outcomes	**Primary endpoints** 1. First-attempt success rate 2. Total success rate (within 3 attempts; attempts quantified as number of needle tips completely withdrawn from the skin **Secondary endpoints** 1. Time to successful cannulation (from initial needle penetration through skin to removal of needle and flash of arterial blood) 2. Incidence of complications (hand ischaemia, haemorrhage, thrombosis, hematoma)
Notes	No information was provided regarding funding and conflicts of interest.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	RCT with stratified randomisation (children < 1 year and > 1 year). Method of randomisation and stratification not explained.
Allocation concealment (selection bias)	Unclear risk	Method of randomisation and stratification not explained.
Blinding of participants and personnel (performance bias) All outcomes	High risk	The anaesthesiologist was aware of the allocated intervention before performing arterial catheterisation.
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Objective outcomes not affected by lack of blinding.
Incomplete outcome data (attrition bias) All outcomes	Low risk	No missing data.
Selective reporting (reporting bias)	Low risk	All outcomes were addressed.
Other bias	Unclear risk	Quote: "The operators included 7 fellows. The experience of each fellow may have affected the success rate of radial artery cannulation; however, we used a multiple logistic regression analysis, which included the operator to reduce operator bias."

Ganesh 2009

Study characteristics	
Methods	RCT
Participants	**Number:** 152 radial arteries **Number per intervention** 1. Ultrasound: 72 radial arteries 2. Palpation: 80 radial arteries **Inclusion criteria** 1. Age < 18 years 2. Planned radial arterial catheterisation **Exclusion criteria** 1. Not reported **Surgery/setting:** not reported **Baseline characteristics** Ultrasound 1. Mean age: 99.1 (SD 69.3) months 2. Mean weight: 32.2 (SD 22.6) kg 3. Sex ratio (male:female): 36:36 Palpation 1. Mean age: 99.6 (SD 71.6) months 2. Mean weight: 31.3 (SD 22.6) kg 3. Sex ratio (male:female): 38:42
Interventions	**Randomisation:** participants were randomised to US guidance technique (intervention) or palpation (control) for radial artery cannulation. **Intervention:** ultrasound-guided technique: after localisation of the radial artery, using a portable US device (SonoSite 180plus, SonoSite, Bothell, WA, USA) the physician inserted an age appropriate-sized catheter over a needle distal to the transducer and directed it according to the US image. **Control:** palpation (continuous or intermittent) of arterial pulsation. **Co-intervention:** after induction of general anaesthesia and endotracheal intubation, cannulation was performed according to the randomised method. After skin disinfection at the insertion site, the wrist was extended and the hand and forearm were taped. Skin puncture marked the start, and successful cannulation was the endpoint of the procedure. Failure of either technique and use of a crossover technique were determined by the consultant anaesthesiologist assigned to the case. **Experience of operator:** paediatric subspecialty trainee anaesthesiologists who had completed a minimum of 3 years' training in anaesthesia, or consultant paediatric anaesthesiologists. No operator had performed > 10 US-guided arterial cannulations before the study.

Outcomes	**Primary endpoints**
	
	1. Time to successful cannulation by the first operator at the first site of arterial puncture
	   a. Start time: time of initial skin puncture at the first site
	   b. End time: time first operator successfully aspirated blood from the distal end of the inserted cannula

Ganesh 2009 *(Continued)*

	Secondary endpoints 1. Number of attempts at arterial cannulation (each attempt defined as reinsertion following withdrawal) 2. Number of cannulas required for successful catheter insertion 3. Need for additional assistance from another anaesthesiologist 4. Cross-over between techniques or rescue after the first operator was deemed to have failed with the assigned technique 5. Number of sites attempted
Notes	Supported by departmental funds. Study authors disclosed no potential conflicts of interest.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Assignment by a computer-generated random number sequence.
Allocation concealment (selection bias)	Unclear risk	No details were mentioned.
Blinding of participants and personnel (performance bias) All outcomes	High risk	All participants underwent induction of general anaesthesia (low risk of bias). The anaesthesiologist was aware of the allocated intervention before performing arterial catheterisation (high risk of bias).
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Endpoint of procedure was aspiration of blood from the distal end of the inserted cannula (unequivocal endpoint).
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no missing data.
Selective reporting (reporting bias)	High risk	All planned outcomes were reported, but the results were not stratified according to the age groups to which participants were originally randomised (< 2 years, 2–5 years, > 5 years).
Other bias	Unclear risk	Study did not define what constituted lack of success in terms of time or number of attempts.

Ishii 2013

Study characteristics

Methods	RCT
Participants	**Number:** 118 radial arteries **Number per intervention** 1. Ultrasound: 59 radial arteries 2. Palpation: 59 radial arteries **Inclusion criteria**

Ishii 2013 *(Continued)*

1. Infants and small children
2. Weight 3–20 kg

Exclusion criteria

1. Skin erosions or haematomas at or near the insertion site
2. Visible recent catheterisation scars
3. Prominent differences in arterial pressure between left and right arms

Surgery/setting: elective cardiac surgery for congenital heart disease

Baseline characteristics:

1. Median age: 18.4 months (range 7–28)
2. Median weight: 8.1 kg (range 6.04–10.48)
3. Sex ratio: not reported

Interventions	**Randomisation:** right and left radial arteries were randomly assigned to cannulation by the ultrasound-guided technique (ultrasound group) or the usual palpation technique (palpation group) via the envelope method. The ultrasound-guided group included 28 right and 31 left radial arteries, whereas the palpation-guided group included 31 right and 28 left radial arteries. **Intervention:** US usage (SonoSite, Bothell, WA, USA) with a 2- to 7-MHz linear array transducer in real time using short axis. **Control:** palpation using the pulsation of the radial artery. **Co-intervention:** non-invasive electrocardiogram, pulse oximetry and blood pressure monitoring. After induction of general anaesthesia, cannulation was attempted with standard 24-G JELCO cannulas (Smith's Medical, Dublin, OH, USA). A pillow was placed under the wrist to keep the arm slightly extended. The insertion site was disinfected, and no local anaesthetic was used. **Experience of operator:** trainees in anaesthesiology with > 3 years of clinical training and familiar with the ultrasound-guided technique for central venous catheterisation in adults and children.
Outcomes	**Primary study endpoints** 1. Rate of successful cannulation on first attempt 2. Success rate after 3 attempts **Secondary study endpoints** 1. Time to identification of the artery 2. Overall number of cannulation attempts 3. Incidence of complications
Notes	No information was provided regarding funding. Dr Sawa received royalties from The Reagents from the University of California. The remaining study authors disclosed that they had no potential conflicts of interest.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "The right and left radial arteries were randomly assigned to cannulation by the ultrasound-guided technique (ultrasound group) versus the usual palpation technique (palpation group), using the envelope method."

Ishii 2013 *(Continued)*

Allocation concealment (selection bias)	Low risk	Quote: "The right and left radial arteries were randomly assigned to cannulation by the ultrasound-guided technique (ultrasound group) versus the usual palpation technique (palpation group), using the envelope method."
Blinding of participants and personnel (performance bias) All outcomes	High risk	All participants underwent induction of general anaesthesia before arterial line cannulation (low risk of bias). The anaesthesiologist was aware of the allocated intervention before performing arterial catheterisation (high risk of bias).
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "The procedure was classified as successful when the artery was cannulated and an arterial waveform was recorded."
Incomplete outcome data (attrition bias) All outcomes	Low risk	Data available for all randomised participants.
Selective reporting (reporting bias)	Low risk	All outcomes were reported.
Other bias	Low risk	We identified no other sources of bias.

Min 2019

Study characteristics	
Methods	RCT
Participants	**Number:** 74 radial arteries **Number per intervention** 1. Ultrasound: 37 radial arteries 2. Palpation: 37 radial arteries **Inclusion criteria** 1. Age < 12 months 2. Scheduled cardiac surgery **Exclusion criteria:** 1. Signs of skin infection or a recent wound at or near the puncture site 2. Diagnosed abnormal peripheral circulation of the hand 3. Diagnosed vascular abnormality or radial arterial variation 4. Problem at the radial or ulnar artery sites 5. Haemodynamic instability **Surgery/setting:** cardiac surgeries for congenital heart disease **Baseline characteristics** Ultrasound 1. Mean age: 1.7 (SD 2.7) months 2. Mean weight: 4.8 (SD 1.9) kg 3. Sex ratio (male:female): 18:19

Min 2019 *(Continued)*

	Palpation 1. Mean age: 3.5 (SD 3.5) months 2. Mean weight: 5.7 (SD 2.1) kg 3. Sex ratio (male:female): 24:13
Interventions	**Randomisation:** participants were assigned randomly to either a palpation-guided group or an ultrasound-guided group using computer-generated numbers found in sealed envelopes. **Intervention:** a linear ultrasound transducer in the short-axis view was used in the US group. The least depth-of-field setting was 1.5 cm, and a 24-gauge angiocatheter was inserted. The needle was advanced until a bright white dot of the needle tip was observed. The needle was then advanced, targeting the radial artery using an anterior or posterior puncture technique. **Control:** palpation of the radial arterial pulse **Co-intervention**: general anaesthesia with inhaled sevoflurane, intravenous midazolam (0.15 to 0.3 mg/kg) and rocuronium (0.6 to 0.9 mg/kg) **Experience of operator:** all ultrasound recordings and arterial catheterisations were performed by one of two anaesthesiologists (> 2 years of experience in paediatric cardiac anaesthesia and > 50 cases of ultrasound-guided radial arterial catheterisation in paediatric patients).
Outcomes	**Primary endpoints** 1. First-pass success 2. Success within 10 minutes 3. Total number of attempts 4. Total procedural time for successful catheterisation **Secondary endpoints** 1. Complications during the procedures (e.g. haematoma formation, arterial spasm or ischaemic signs)
Notes	Supported by institutional resources. Study authors disclosed no potential conflicts of interest.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "Patients were assigned randomly to either a palpation-guided group or an ultrasound-guided group using computer-generated numbers found in sealed envelopes."
Allocation concealment (selection bias)	Low risk	Quote: "The sealed envelope was opened by a physician just after induction of general anaesthesia."
Blinding of participants and personnel (performance bias) All outcomes	High risk	All participants underwent induction of general anaesthesia prior to arterial catheterisation (low risk of bias). The anaesthesiologist was aware of the allocated intervention before performing arterial catheterisation (high risk of bias).
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Successful arterial cannulation is the endpoint of the procedure for both techniques (unequivocal endpoint).
Incomplete outcome data (attrition bias) All outcomes	Low risk	No missing data.

Min 2019 *(Continued)*

Selective reporting (reporting bias)	Low risk	An investigator recorded all procedures on video for analysis.
Other bias	Unclear risk	Participant age and height were significantly different between the 2 groups. The investigators set a time limit of 10 minutes.

Salik 2021

Study characteristics	
Methods	RCT
Participants	**Number:** 40 femoral arteries **Number per intervention** 1. Ultrasound: 20 femoral arteries 2. Palpation: 20 femoral arteries **Inclusion criteria** 1. Neonatal age 2. ASA score 3–4 3. Scheduled congenital heart surgery **Exclusion criteria** 1. Parents' refusal to participate in study 2. Undetectable femoral arterial pulse 3. Haemodynamic instability 4. Allergy to US gel 5. Emergency surgery **Surgery/setting:** paediatric cardiac surgery. **Baseline characteristics** Ultrasound 1. Mean age: 21 days 2. Mean weight: 3.5 Kg 3. Sex ratio (male:female): 14:6 4. Mean length: 51.4 cm Palpation 1. Mean age: 18.3 days 2. Mean weight: 3.4 kg 3. Sex ratio (male: female): 14:6 4. Mean length: 51.2 cm
Interventions	**Randomisation:** participants were randomized using the envelope method to the US group or the palpation group. **Intervention:** linear probe (5–12 MHz, Esaote, MyLab Six, the Netherlands) was used in the US group. After the transducer was placed in a sterile sheath, the femoral artery and vein were identified (short axis view). A 20 G needle was used to puncture the artery (out-of-plane technique). After adequate arterial flow was ensured, the guidewire (0.43 mm size and 200 mm length) was placed in the lumen

Salik 2021 *(Continued)*

	of the vessel. The cannula was placed through the guidewire using the Seldinger technique, and the guidewire was removed. **Control:** after palpation of the femoral artery, a 20-G needle was used for arterial puncture. A guidewire (0.43 mm size and 200 mm length) was inserted in the lumen of the vessel. The catheter was sent over the guidewire using the Seldinger technique and the guidewire was removed. **Co-intervention:** induction of anaesthesia using 0.1 mg/kg midazolam, 2 mcg/kg fentanyl, 2–3 mg/kg propofol, and 0.6 mg/kg rocuronium. After orotracheal intubation, a pad under the pelvis in supine position was placed and the legs were positioned in 30-degree abduction, and the knees were bent. Before the procedure, in both groups, the anterior-posterior diameter of the femoral artery was measured at 1–2 cm distal of the ligament by using linear US probe in an out-of-plane technique. A 22-G catheter was used for all cannulation. **Experience of operator:** > 3 years' experience in paediatric cardiac anaesthesia and > 5 years' experience and certification of US use.
Outcomes	1. Time to successful cannulation (from skin puncture to blood aspiration; limited to 15 minutes) 2. Number of attempts (skin puncture considered an attempt; needle redirection not considered an additional attempt) 3. Success on first attempt 4. Success rate (total successful cannulation after multiple attempts) 5. Number of cannulas used 6. Complications (haematoma, pseudoaneurysm, accidental vein puncture) 7. Total cost of the procedure
Notes	The author received no financial support for the research, authorship or publication of the article.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Envelope method.
Allocation concealment (selection bias)	Low risk	Quote: "Assignments were contained in prepared opaque envelopes that were opened just before cannulation."
Blinding of participants and personnel (performance bias) All outcomes	High risk	All participants underwent induction of general anaesthesia prior to arterial catheterisation (low risk of bias). The anaesthesiologist was aware of the allocated intervention before performing arterial catheterisation (high risk of bias).
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Aspiration of blood from the inserted cannula was the endpoint of the procedure in both techniques (unequivocal endpoint).
Incomplete outcome data (attrition bias) All outcomes	Low risk	Low risk of attrition bias because only 3 children were removed after randomisation (because of the presence of hematoma at the site of operation due to previous interventions).
Selective reporting (reporting bias)	Low risk	All outcomes were addressed.
Other bias	Low risk	We identified no other sources of bias.

Schwemmer 2006

Study characteristics	
Methods	RCT

Participants	**Number:** 30 radial arteries
	
	Number per intervention
	
	1. Ultrasound: 15 radial arteries
	2. Palpation: 15 radial arteries
	
	Inclusion criteria
	
	1. Small children
	
	Exclusion criteria
	
	1. Not reported
	
	Surgery/setting: major neurosurgery
	
	Baseline characteristics
	
	1. Age: 6 months–9 years; median age 28 months; mean age 40 (SD 33) months
	   a. Ultrasound group: mean 40.3 (SD 34.9) months
	   b. Palpation group: mean 39.6 (SD 32.5) months
	2. Mean weight: not reported
	3. Sex ratio: not reported

Interventions	**Randomisation:** coin toss **Intervention:** the radial artery was first localised by ultrasound in its short cross-section. The cannula was advanced toward the vessel at an angle of 45 degrees. When the cannula appeared to be within the vessel, the transducer was removed and catheterisation was accomplished. **Control** 1. Palpation technique: the position and course of the artery were identified, the skin was repeatedly disinfected, and the cannula was inserted distally to the fingertip and was directed according to continued palpation. 2. Cross-over to the other technique: after 3 failed cannulation attempts, the initial approach was changed to the alternative method **Co-Intervention:** a normovolaemic status was achieved using crystalloids given the night before the procedure. A linear transducer connected to an ultrasound system (Sonos 5000; Hewlett-Packard, Andover, MA, USA) was used with a focal length positioned 1.8 cm to identify the radial artery. The cross-sectional area of the artery was measured at the head of the radius with and without dorsiflexion of the hand by about 45 degrees. The transducer or the physician's fingertip was applied to the skin, and the radial artery was identified as the pulsating vessel. Following further local disinfection, the vessel was approached with standard 24-G cannulas (Becton Dickinson, Helsinborg, Sweden) via 1 of the 2 techniques. **Expertise of operator:** experienced personnel (> 20 paediatric arterial catheterisations)
Outcomes	1. Cross-sectional area of the radial artery with or without dorsiflexion 2. Cannulation success rates with palpation and ultrasound techniques 3. Cannulation success rate on first attempt 4. Time for successful insertion of the catheter between palpation and ultrasound techniques (interval between skin puncture and successful intra-arterial advancement of the catheter)

Schwemmer 2006 *(Continued)*

5. Total number of attempts at arterial cannulation with palpation and ultrasound techniques
6. Total number of technique switches
7. Rate of complications for palpation and ultrasound techniques

Notes	No information was provided regarding funding, and no conflicts of interest were declared.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "The technique to be used for radial artery puncture and insertion of the catheter was selected by tossing a coin: heads for ultrasound guidance and tails for palpation."
Allocation concealment (selection bias)	Unclear risk	No information.
Blinding of participants and personnel (performance bias) All outcomes	High risk	All participants underwent induction of general anaesthesia prior to arterial catheterisation (low risk of bias). The anaesthesiologist was aware of the allocated intervention before performing arterial catheterisation (high risk of bias).
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "When the cannula appeared to be within the vessel, the transducer was removed and catheterization was accomplished."
Incomplete outcome data (attrition bias) All outcomes	Low risk	No participants withdrawn.
Selective reporting (reporting bias)	Low risk	All outcomes were addressed.
Other bias	Low risk	We identified no other sources of bias.

Siddik-Sayyid 2016

Study characteristics

Methods	RCT
Participants	**Number:** 106 femoral arteries **Number per intervention** 1. Ultrasound: 53 femoral arteries 2. Palpation: 53 femoral arteries **Inclusion criteria** 1. Age < 12 years 2. ASA score 3 or 4 3. Scheduled cardiac surgery **Exclusion criteria** 1. Emergency surgery

Siddik-Sayyid 2016 *(Continued)*

2. Haemodynamic instability
3. Allergy to the ultrasound gel

Surgery/setting: cardiac surgeries

Baseline characteristics

Ultrasound

1. Mean age: 37.9 months
2. Mean weight: 12.4 kg
3. Sex ratio (male:female): 33:20

Palpation

1. Mean age: 30.6 months
2. Mean weight: 10.6 kg
3. Sex ratio (male:female): 29:24

Interventions	**Randomisation:** participants were randomly assigned by randomised block design to femoral arterial catheterisation by the pulse palpation technique (palpation group) or femoral arterial catheterisation using ultrasound guidance (ultrasound group). Results of randomisation were concealed in sealed opaque envelopes and opened after participants' consent. Each operator was randomly assigned procedures in blocks of, where each block was composed of 2 ultrasound-guided and 2 palpation techniques arranged randomly. Each participating operator was required to complete 2 blocks. In both groups, the first site of insertion was the left femoral artery. **Intervention:** the transducer was covered by a sterile sheath. The inguinal area was scanned immediately distal to the inguinal ligament and the femoral artery was identified. Using a short axis and an out-of-plane technique, and after visualisation of the artery, a metallic cannula was introduced and redirected until adequate arterial flow was obtained. The guidewire was introduced, and the catheter was slid over the guidewire. **Control:** palpation technique. A metallic cannula was inserted, and after adequate blood flow a guidewire was inserted followed by the catheter. **Co-intervention:** after induction of anaesthesia, all participants were positioned supine with their legs in neutral position with a pad under the pelvis. In both the groups, the size of the cannula was 24/22 gauge for children weighing < 10 kg and 22 gauge for those weighing 10–40 kg. The study period was limited to 10 minutes. **Expertise of operator:** clinical anaesthesia year 2 or 3 resident with minimal experience in paediatric femoral artery cannulation (no residents had previously performed either US-guided or palpation-guided femoral artery cannulation in paediatric patients > 5 times).
Outcomes	**Primary endpoint:** 1. Time taken for attempted cannulation by the resident at the first site of arterial puncture **Secondary endpoints** 1. Number of attempts at arterial cannulation 2. Number of successful cannulations on first attempt 3. Success rate 4. Number of cannulae required for successful cannula insertion
Notes	The study was supported by the Department of Anesthesiology. No conflicts of interest.

Risk of bias

Bias	Authors' judgement	Support for judgement

Siddik-Sayyid 2016 *(Continued)*

Random sequence generation (selection bias)	Low risk	Quote: "Patients were randomly assigned by randomised block design to one of the two groups. Results of randomization were concealed in sealed opaque envelopes and opened after patients' consent".
Allocation concealment (selection bias)	Low risk	Quote: "To ensure balance between operators in each study procedure, each operator was randomly assigned procedures in blocks of four. Each block was composed of two ultrasound-guided and two palpation techniques were arranged randomly. Once an operator participates, he or she was required to complete two blocks (i.e., each operator performed four ultrasound-guided techniques and four palpation techniques)".
Blinding of participants and personnel (performance bias) All outcomes	High risk	The anaesthesiologist was aware of the allocated intervention before performing arterial catheterisation.
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "Time to arterial cannulation is the primary outcome measured from the time of initial skin puncture until proper placement of the catheter that was confirmed by an arterial waveform seen on the monitor."
Incomplete outcome data (attrition bias) All outcomes	Low risk	2 children excluded because the residents were unavailable to perform the procedures. However, no missing data for the remaining participants.
Selective reporting (reporting bias)	Low risk	All outcomes were addressed.
Other bias	Unclear risk	Investigators set time limit of 10 minutes.

Tan 2015

Study characteristics	
Methods	RCT
Participants	**Number:** 40 radial arteries **Number per intervention** 1. Ultrasound: 20 radial arteries 2. Palpation: 20 radial arteries **Inclusion criteria** 1. Age < 24 months 2. Elective surgical procedure with indication for indwelling arterial catheterisation **Exclusion criteria** 1. Refusal of consent from parents or attending anaesthesiologist 2. Anticipated circulatory instability after anaesthesia induction **Surgery/setting:** not reported **Baseline characteristics** Ultrasound

Tan 2015 *(Continued)*

	1. Mean age: not reported 2. Mean weight: 6.14 kg (95% CI 4.9–7.4) 3. Sex ratio (male:female): not reported Palpation 1. Mean age: not reported 2. Mean weight: 5.5 kg (95% CI 4.1–6.9) 3. Sex ratio (male:female): not reported
Interventions	**Randomisation:** participants were randomised to US guidance technique (intervention) or palpation (control) for radial artery cannulation. **Intervention:** SonoSite M-Turbo (SonoSite, Bothell, WA, USA) SLAX "hockey stick" ultrasound probe. **Control:** palpation **Co-Intervention:** cross-over with another technique was allowed after 3 failed attempts. **Experience of operator:** all catheterisations were performed by anaesthesiology fellows who underwent practice with customised age-specific forearm and femoral phantoms.
Outcomes	**Primary endpoints** 1. Time to successful cannulation within 3 attempts a. Start time: when the palpating finger touches the participant's skin to feel for the arterial pulse (palpation method), or when the gel is applied to the skin (ultrasound) at the first intended cannulation site b. End time: when the arterial cannula was successfully placed **Secondary endpoints** 1. Number of attempts at arterial cannulation 2. Success rate 3. Number of attempted sites 4. Number of cannulas required for successful catheter insertion 5. Estimated cost of the procedure 6. Need for assistance from another anaesthesiologist 7. Cross-over between techniques or rescue after the first operator was deemed to have failed with the assigned technique
Notes	Supported by departmental funds. Study authors disclosed no potential conflicts of interest.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Computer-generated random number sequence.
Allocation concealment (selection bias)	Unclear risk	No information.
Blinding of participants and personnel (performance bias) All outcomes	High risk	All participants underwent induction of general anaesthesia prior to arterial catheterisation (low risk of bias). The anaesthesiologist was aware of the allocated intervention before performing arterial catheterisation (high risk of bias).

Tan 2015 *(Continued)*

Blinding of outcome assessment (detection bias) All outcomes	Low risk	Successful arterial cannulation was the endpoint of the procedure for both techniques (unequivocal endpoint).
Incomplete outcome data (attrition bias) All outcomes	Low risk	No missing data.
Selective reporting (reporting bias)	Low risk	All planned outcomes were reported.
Other bias	Low risk	We identified no other sources of bias.

Ueda 2013

Study characteristics	
Methods	RCT
Participants	**Number:** 104 radial arteries **Number per intervention** 1. Ultrasound: 52 radial arteries 2. Doppler: 52 radial arteries **Inclusion criteria** • Children • Weight 3–12 kg **Exclusion criteria** 1. Signs of skin infection or a wound near the puncture site 2. Abnormal circulation of the hand 3. Arterial puncture within previous month 4. Need for emergency surgery **Surgery/setting** Ultrasound 1. Cardiac: 36 (69%) 2. Non-cardiac: 16 (31%) Doppler 1. Cardiac: 39 (75%) 2. Non-cardiac: 13 (25%) **Baseline characteristics** Ultrasound 1. Median age: 6.0 (range 2.0–9.0) months 2. Mean weight: 7.0 (SD 2.4) kg 3. Sex ratio: not mentioned Doppler

Ueda 2013 *(Continued)*

1. Median age: 5.0 (range 2.0–9.0) months
2. Mean weight: 6.7 (SD 0.4) kg
3. Sex ratio: not mentioned

Interventions	**Randomisation:** randomised block design with opaque envelopes that were opened just before cannulation. Each operator was randomly assigned procedures in blocks of 4. Each block had a random arrangement of 2 US-guided and 2 Doppler-guided techniques. Participating operators had to complete 2 or 3 blocks. **Intervention:** US (HD 11 XE; Andover, MA, USA) via a linear transducer (L15-7io) was utilised to measure 3 times the diameter of the radial artery in the short axis view without dorsiflexion of the wrist. The field was then prepped and draped. A 24 G catheter (Jelco, Smith Medical International Ltd, Rossendale, UK) was advanced at a 15- to 30- degree angle until the tip of the needle was seen on the image and the artery collapsed and re-expanded, or until blood appeared in the hub. The metal stylet was removed, and a wire was inserted through the catheter and was advanced into the artery via the Seldinger technique. If no flash of blood was seen after the stylet was removed, the cannula was withdrawn until blood flow was observed. The catheter was then replaced with a 22 G catheter (Cook Medical Inc., Bloomington, IN, USA) over a guidewire. **Control:** Doppler-assisted technique: the radial artery was located when the area of maximum flow (sound) was found with the Doppler probe (915 BL Doppler Ultrasound, 9 MHz, 1/4-inch diameter, skinny pencil style; Parks, Las Vegas, NV, USA). The technique of cannulation was similar to the US group but using the Doppler-assisted technique. **Co-intervention:** after anaesthetic induction, the participant's hand was secured on an armboard in a neutral position without a wrist roll. **Experience of the operator:** clinical anaesthesia year 2 or 3 resident or cardiac anaesthesia fellow with minimal experience in US-guided or Doppler-assisted radial artery cannulation in paediatric patients (< 5 times).
Outcomes	1. First-attempt success rate (%) 2. Success within 10 minutes (%) 3. Number of attempts (stratified as 1, 2, 3 or more) 4. Adverse events (haematoma and ischaemia)
Notes	Supported by departmental funds. Study authors disclosed no potential conflicts of interest.

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "Participants were assigned by randomised block design to the Doppler-assisted technique group or the US-guided technique group. To ensure balance between operators for each study procedure, each operator was randomly assigned procedures in blocks of 4. Each block had a random arrangement of 2 US-guided and 2 Doppler-guided techniques. Once an operator participated, he or she was required to complete 2 to 3 blocks."
Allocation concealment (selection bias)	Low risk	Quote: "Assignments were contained in prepared opaque envelopes that were opened just before cannulation."
Blinding of participants and personnel (performance bias)	High risk	All participants underwent induction of general anaesthesia prior to arterial catheterisation (low risk of bias). The anaesthesiologist was aware of the al-

Ueda 2013 *(Continued)*

All outcomes		located intervention before performing arterial catheterisation (high risk of bias).
Blinding of outcome assessment (detection bias) All outcomes	Low risk	An arterial waveform is seen on the monitor after the catheter is connected to a transducer (unequivocal endpoint).
Incomplete outcome data (attrition bias) All outcomes	Low risk	Quote: "Two cases were counted as failures according to the intention-to-treat principle: (1) an unintentional femoral arterial cannulation while the faculty was trying the femoral venous cannulation before the radial arterial cannulation was attempted, which was allocated to the US-guided technique, and (2) unavailability of the operator to perform the procedure once the participant had been randomised to the Doppler-assisted group."
Selective reporting (reporting bias)	Low risk	All outcomes were addressed.
Other bias	Unclear risk	Possible effect of confounding variable. Quote: "Further investigation is warranted if any haemodynamic manipulation (i.e. volume load or vasopressor administration) could enlarge the size of a radial artery and thus improve the success rate of cannulation." The trial was prematurely terminated. Quote: "After the first 50% of patients' enrolment (104 patients), the departmental research committee decided to terminate the study because of low accrual."

ASA: American Society of Anesthesiology; CA: clinical anaesthesia; CI: confidence interval; G: gauge; ICU: intensive care unit; RCT: randomised controlled trial; SD: standard deviation; US: ultrasound.

Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Abdelbaser 2021	This study compares 2 ultrasound techniques.
Aouad-Maroun 2016	Previous version of this review.
Bhattacharjee 2018	Meta-analysis of studies in adults.
Bobbia 2013	RCT in adults.
Chi 2015	Full text unavailable.
Gu 2014	Meta-analysis of studies in adults.
Guan 2016	Meta-analysis of studies in adults.
Ijiri 2016	RCT in adults.
Jung 2021	Prospective observational study.
Kiberenge 2018	RCT in adults.
Lee 2016	Participants aged 20-79 years.

Study	Reason for exclusion
Liu 2019	This study combined ultrasound with "modified dynamic needle tip positioning" technique in the ultrasound group.
Nakayama 2014	Comparison of US technique with/without saline injection; depth of artery was point of interest.
Oulego-Erroz 2019	Prospective observational study.
Polat 2019	Comparison between 2 different wires.
Quan 2019	Comparison of regular ultrasound with acoustic shadowing ultrasound.
Schults 2020	Not an RCT.
Selldén 1987	The study is a prospective study and not an RCT.
Sethi 2017	Participants were adults.
Seto 2010	RCT in adults.
Seto 2013	Participants were adults.
Shiloh 2010	Meta-analysis of studies in adults.
Sobolev 2015	Systematic review.
Song 2016	Comparison of 2 ultrasound techniques.
Sorrentino 2020	Meta-analysis, not an RCT.
Staudt 2019	The outcomes of interest were not addressed.
Takeshita 2015	This study concerns venous cannulation and not arterial cannulation.
Takeshita 2021	Ultrasound-guided dynamic needle tip positioning was used.
Varga 2013	The outcomes of interest were not addressed.
White 2016	Meta-analysis, not an RCT.
Ye 2020	Comparison of modified dynamic needle tip positioning versus other techniques.
Zhang 2020	Meta-analysis, not an RCT.
Zhefeng 2019	Does not meet age inclusion criteria and compares 2 ultrasound techniques.
Zhou 2016	The outcomes of interest were not addressed.

RCT: randomised controlled trial.

DATA AND ANALYSES

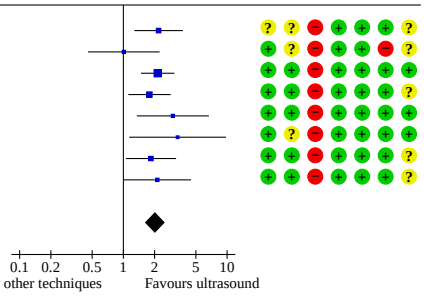
Comparison 1. Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1.1 First-attempt success rate	8	708	Risk Ratio (M-H, Random, 95% CI)	2.01 [1.64, 2.46]
1.2 First-attempt success rate (per artery site)	8	708	Risk Ratio (M-H, Random, 95% CI)	2.01 [1.64, 2.46]
1.2.1 Radial artery	6	562	Risk Ratio (M-H, Random, 95% CI)	1.98 [1.57, 2.48]
1.2.2 Femoral artery	2	146	Risk Ratio (M-H, Random, 95% CI)	2.16 [1.37, 3.42]
1.3 First-attempt success rate (per age group)	8	708	Risk Ratio (M-H, Random, 95% CI)	2.01 [1.64, 2.46]
1.3.1 Children aged over four years	1	152	Risk Ratio (M-H, Random, 95% CI)	1.01 [0.46, 2.24]
1.3.2 Neonates and children aged up to four years	7	556	Risk Ratio (M-H, Random, 95% CI)	2.11 [1.71, 2.60]
1.4 First-attempt success rate (per experience with ultrasound)	8	708	Risk Ratio (M-H, Random, 95% CI)	1.98 [1.61, 2.42]
1.4.1 Little experience with US	3	362	Risk Ratio (M-H, Random, 95% CI)	1.66 [1.11, 2.46]
1.4.2 More experience with US	5	346	Risk Ratio (M-H, Random, 95% CI)	2.11 [1.66, 2.67]
1.5 Incidence of complications (haematoma)	5	420	Risk Ratio (M-H, Random, 95% CI)	0.26 [0.14, 0.47]
1.6 Successful cannulation within first two attempts	2	134	Risk Ratio (M-H, Fixed, 95% CI)	1.78 [1.25, 2.51]
1.7 Overall successful cannulation after multiple attempts	6	374	Risk Ratio (M-H, Random, 95% CI)	1.32 [1.10, 1.59]
1.8 Number of attempts to successful cannulation	5	368	Mean Difference (IV, Random, 95% CI)	-0.99 [-1.15, -0.83]
1.9 Duration of cannulation procedure (seconds)	5	402	Mean Difference (IV, Random, 95% CI)	-98.77 [-150.02, -47.52]
1.10 Duration of the cannulation procedure (seconds) – sensitivity analysis	4	328	Mean Difference (IV, Random, 95% CI)	-99.99 [-160.30, -39.68]

Analysis 1.1. Comparison 1: Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler), Outcome 1: First-attempt success rate

Study or Subgroup	Ultrasound guidance Events	Total	Other techniques (palpation/Doppler) Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Anantasit 2017	25	41	12	43	14.2%	2.18 [1.27 , 3.75]
Ganesh 2009	10	72	11	80	6.5%	1.01 [0.46 , 2.24]
Ishii 2013	45	59	21	59	29.9%	2.14 [1.48 , 3.11]
Min 2019	25	37	14	37	18.7%	1.79 [1.12 , 2.86]
Salik 2021	15	20	5	20	6.4%	3.00 [1.35 , 6.68]
Schwemmer 2006	10	15	3	15	3.6%	3.33 [1.14 , 9.75]
Siddik-Sayyid 2016	24	53	13	53	13.3%	1.85 [1.06 , 3.22]
Ueda 2013	17	52	8	52	7.4%	2.13 [1.01 , 4.49]
Total (95% CI)		**349**		**359**	**100.0%**	**2.01 [1.64 , 2.46]**
Total events:	171		87			

Heterogeneity: Tau² = 0.00; Chi² = 5.26, df = 7 (P = 0.63); I² = 0%
Test for overall effect: Z = 6.74 (P < 0.00001)
Test for subgroup differences: Not applicable



Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.2. Comparison 1: Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler), Outcome 2: First-attempt success rate (per artery site)

Study or Subgroup	Ultrasound guidance Events	Total	Other techniques (palpation/Doppler) Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
1.2.1 Radial artery						
Schwemmer 2006	10	15	3	15	3.6%	3.33 [1.14 , 9.75]
Ganesh 2009	10	72	11	80	6.5%	1.01 [0.46 , 2.24]
Ishii 2013	45	59	21	59	29.9%	2.14 [1.48 , 3.11]
Ueda 2013	17	52	8	52	7.4%	2.13 [1.01 , 4.49]
Anantasit 2017	25	41	12	43	14.2%	2.18 [1.27 , 3.75]
Min 2019	25	37	14	37	18.7%	1.79 [1.12 , 2.86]
Subtotal (95% CI)		**276**		**286**	**80.3%**	**1.98 [1.57 , 2.48]**
Total events:	132		69			

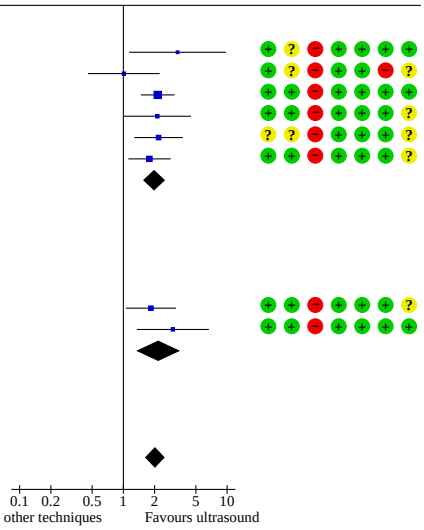
Heterogeneity: Tau² = 0.00; Chi² = 4.19, df = 5 (P = 0.52); I² = 0%
Test for overall effect: Z = 5.89 (P < 0.00001)

1.2.2 Femoral artery						
Siddik-Sayyid 2016	24	53	13	53	13.3%	1.85 [1.06 , 3.22]
Salik 2021	15	20	5	20	6.4%	3.00 [1.35 , 6.68]
Subtotal (95% CI)		**73**		**73**	**19.7%**	**2.16 [1.37 , 3.42]**
Total events:	39		18			

Heterogeneity: Tau² = 0.00; Chi² = 0.95, df = 1 (P = 0.33); I² = 0%
Test for overall effect: Z = 3.31 (P = 0.0009)

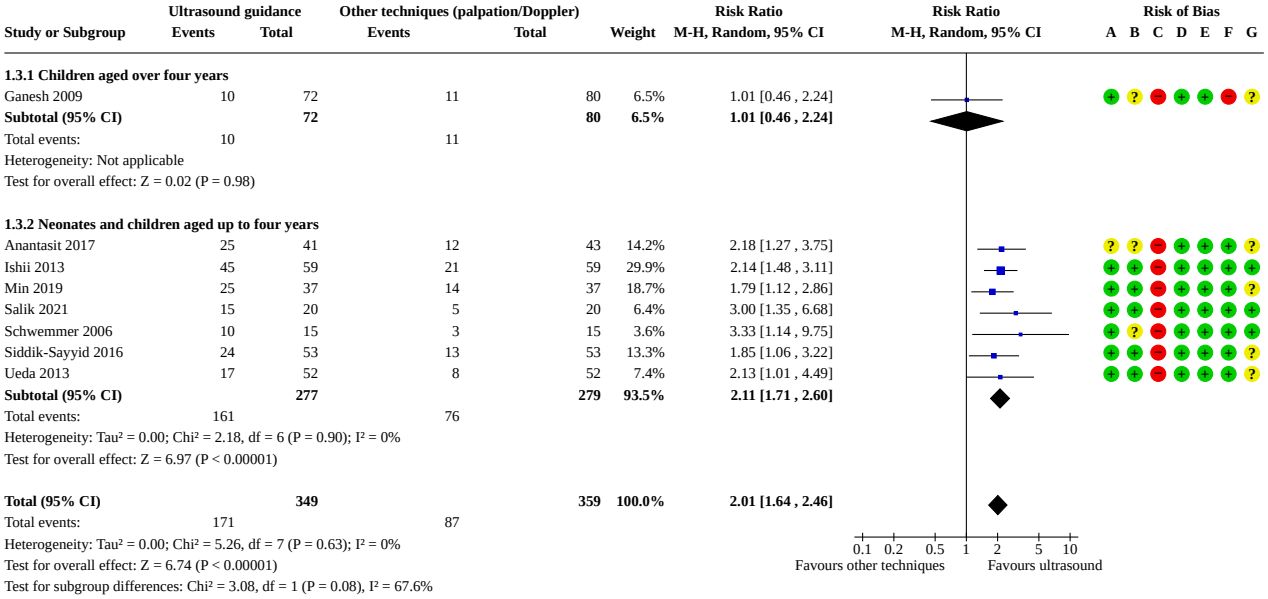
Total (95% CI)		**349**		**359**	**100.0%**	**2.01 [1.64 , 2.46]**
Total events:	171		87			

Heterogeneity: Tau² = 0.00; Chi² = 5.26, df = 7 (P = 0.63); I² = 0%
Test for overall effect: Z = 6.74 (P < 0.00001)
Test for subgroup differences: Chi² = 0.12, df = 1 (P = 0.73), I² = 0%



Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.3. Comparison 1: Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler), Outcome 3: First-attempt success rate (per age group)

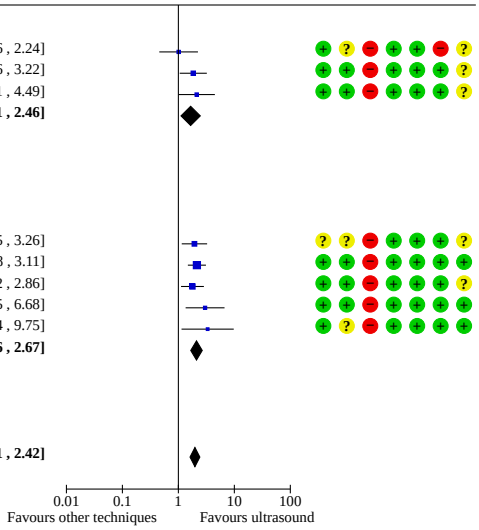


Study or Subgroup	Ultrasound guidance Events	Total	Other techniques (palpation/Doppler) Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
1.3.1 Children aged over four years						
Ganesh 2009	10	72	11	80	6.5%	1.01 [0.46 , 2.24]
Subtotal (95% CI)		**72**		**80**	**6.5%**	**1.01 [0.46 , 2.24]**
Total events:	10		11			
Heterogeneity: Not applicable						
Test for overall effect: Z = 0.02 (P = 0.98)						
1.3.2 Neonates and children aged up to four years						
Anantasit 2017	25	41	12	43	14.2%	2.18 [1.27 , 3.75]
Ishii 2013	45	59	21	59	29.9%	2.14 [1.48 , 3.11]
Min 2019	25	37	14	37	18.7%	1.79 [1.12 , 2.86]
Salik 2021	15	20	5	20	6.4%	3.00 [1.35 , 6.68]
Schwemmer 2006	10	15	3	15	3.6%	3.33 [1.14 , 9.75]
Siddik-Sayyid 2016	24	53	13	53	13.3%	1.85 [1.06 , 3.22]
Ueda 2013	17	52	8	52	7.4%	2.13 [1.01 , 4.49]
Subtotal (95% CI)		**277**		**279**	**93.5%**	**2.11 [1.71 , 2.60]**
Total events:	161		76			
Heterogeneity: Tau² = 0.00; Chi² = 2.18, df = 6 (P = 0.90); I² = 0%						
Test for overall effect: Z = 6.97 (P < 0.00001)						
Total (95% CI)		**349**		**359**	**100.0%**	**2.01 [1.64 , 2.46]**
Total events:	171		87			
Heterogeneity: Tau² = 0.00; Chi² = 5.26, df = 7 (P = 0.63); I² = 0%						
Test for overall effect: Z = 6.74 (P < 0.00001)						
Test for subgroup differences: Chi² = 3.08, df = 1 (P = 0.08), I² = 67.6%						

Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.4. Comparison 1: Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler), Outcome 4: First-attempt success rate (per experience with ultrasound)

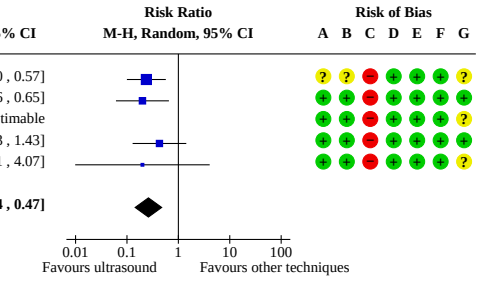
Study or Subgroup	Ultrasound guidance Events	Total	Other techniques (palpation/Doppler) Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
1.4.1 Little experience with US						
Ganesh 2009	10	72	11	80	6.5%	1.01 [0.46 , 2.24]
Siddik-Sayyid 2016	24	53	13	53	13.2%	1.85 [1.06 , 3.22]
Ueda 2013	17	52	8	52	7.3%	2.13 [1.01 , 4.49]
Subtotal (95% CI)		**177**		**185**	**26.9%**	**1.66 [1.11 , 2.46]**
Total events:	51		32			
Heterogeneity: Tau² = 0.00; Chi² = 2.06, df = 2 (P = 0.36); I² = 3%						
Test for overall effect: Z = 2.50 (P = 0.01)						
1.4.2 More experience with US						
Anantasit 2017	24	41	13	43	15.0%	1.94 [1.15 , 3.26]
Ishii 2013	45	59	21	59	29.6%	2.14 [1.48 , 3.11]
Min 2019	25	37	14	37	18.5%	1.79 [1.12 , 2.86]
Salik 2021	15	20	5	20	6.4%	3.00 [1.35 , 6.68]
Schwemmer 2006	10	15	3	15	3.5%	3.33 [1.14 , 9.75]
Subtotal (95% CI)		**172**		**174**	**73.1%**	**2.11 [1.66 , 2.67]**
Total events:	119		56			
Heterogeneity: Tau² = 0.00; Chi² = 2.06, df = 4 (P = 0.72); I² = 0%						
Test for overall effect: Z = 6.18 (P < 0.00001)						
Total (95% CI)		**349**		**359**	**100.0%**	**1.98 [1.61 , 2.42]**
Total events:	170		88			
Heterogeneity: Tau² = 0.00; Chi² = 5.16, df = 7 (P = 0.64); I² = 0%						
Test for overall effect: Z = 6.61 (P < 0.00001)						
Test for subgroup differences: Chi² = 1.04, df = 1 (P = 0.31), I² = 4.3%						



Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.5. Comparison 1: Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler), Outcome 5: Incidence of complications (haematoma)

Study or Subgroup	Ultrasound guidance Events	Total	Other techniques (palpation/Doppler) Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Anantasit 2017	5	41	22	43	46.5%	0.24 [0.10 , 0.57]
Ishii 2013	3	59	15	59	25.1%	0.20 [0.06 , 0.65]
Min 2019	0	37	0	37		Not estimable
Salik 2021	3	20	7	20	24.5%	0.43 [0.13 , 1.43]
Ueda 2013	0	52	2	52	3.9%	0.20 [0.01 , 4.07]
Total (95% CI)		**209**		**211**	**100.0%**	**0.26 [0.14 , 0.47]**
Total events:	11		46			
Heterogeneity: Tau² = 0.00; Chi² = 0.93, df = 3 (P = 0.82); I² = 0%						
Test for overall effect: Z = 4.42 (P < 0.00001)						
Test for subgroup differences: Not applicable						

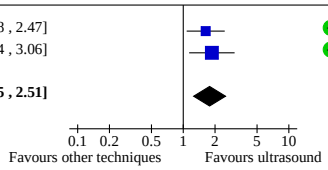


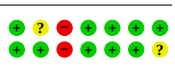
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.6. Comparison 1: Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler), Outcome 6: Successful cannulation within first two attempts

Study or Subgroup	Ultrasound guidance Events	Total	Other techniques (palpation/Doppler) Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Schwemmer 2006	15	15	9	15	38.8%	1.63 [1.08 , 2.47]
Ueda 2013 (1)	28	52	15	52	61.2%	1.87 [1.14 , 3.06]
Total (95% CI)		**67**		**67**	**100.0%**	**1.78 [1.25 , 2.51]**
Total events:	43		24			

Heterogeneity: Chi² = 0.20, df = 1 (P = 0.66); I² = 0%
Test for overall effect: Z = 3.24 (P = 0.001)
Test for subgroup differences: Not applicable





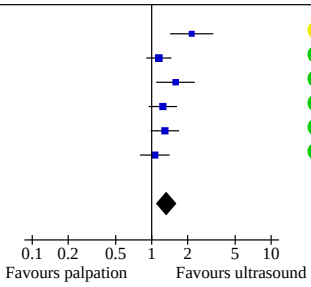
Footnotes
(1) The unit of analysis was the radial artery

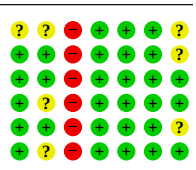
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.7. Comparison 1: Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler), Outcome 7: Overall successful cannulation after multiple attempts

Study or Subgroup	Ultrasound guidance Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Anantasit 2017	33	41	16	43	11.9%	2.16 [1.43 , 3.28]
Min 2019	31	37	27	37	20.2%	1.15 [0.90 , 1.46]
Salik 2021	19	20	12	20	13.6%	1.58 [1.09 , 2.30]
Schwemmer 2006	15	15	12	15	18.3%	1.24 [0.94 , 1.63]
Siddik-Sayyid 2016	40	53	31	53	18.3%	1.29 [0.98 , 1.70]
Tan 2015	17	20	16	20	17.7%	1.06 [0.80 , 1.41]
Total (95% CI)		**186**		**188**	**100.0%**	**1.32 [1.10 , 1.59]**
Total events:	155		114			

Heterogeneity: Tau² = 0.03; Chi² = 10.96, df = 5 (P = 0.05); I² = 54%
Test for overall effect: Z = 3.00 (P = 0.003)
Test for subgroup differences: Not applicable



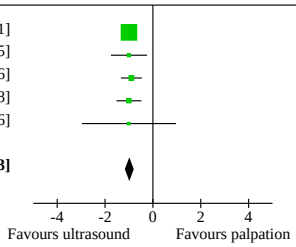


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.8. Comparison 1: Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler), Outcome 8: Number of attempts to successful cannulation

Study or Subgroup	Ultrasound guidance Mean	SD	Total	Palpation Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Risk of Bias A B C D E F G
Ishii 2013	1	0.01	59	2	0.74	59	72.0%	-1.00 [-1.19 , -0.81]	+ + − + + + +
Min 2019	1	0.74	37	2	2.22	37	4.5%	-1.00 [-1.75 , -0.25]	+ + − + + + ?
Salik 2021	1.4	0.6	20	2.3	0.8	20	13.4%	-0.90 [-1.34 , -0.46]	+ + − + + + +
Schwemmer 2006	1.3	0.5	15	2.3	0.9	15	9.5%	-1.00 [-1.52 , -0.48]	+ ? − + + + +
Siddik-Sayyid 2016	1	6.67	53	2	2.96	53	0.7%	-1.00 [-2.96 , 0.96]	+ + − + + + ?
Total (95% CI)			**184**			**184**	**100.0%**	**-0.99 [-1.15 , -0.83]**	

Heterogeneity: Tau² = 0.00; Chi² = 0.17, df = 4 (P = 1.00); I² = 0%
Test for overall effect: Z = 12.07 (P < 0.00001)
Test for subgroup differences: Not applicable

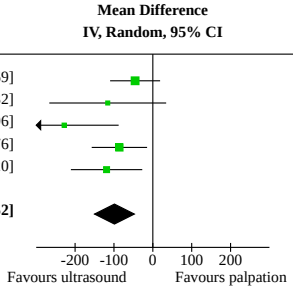


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.9. Comparison 1: Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler), Outcome 9: Duration of cannulation procedure (seconds)

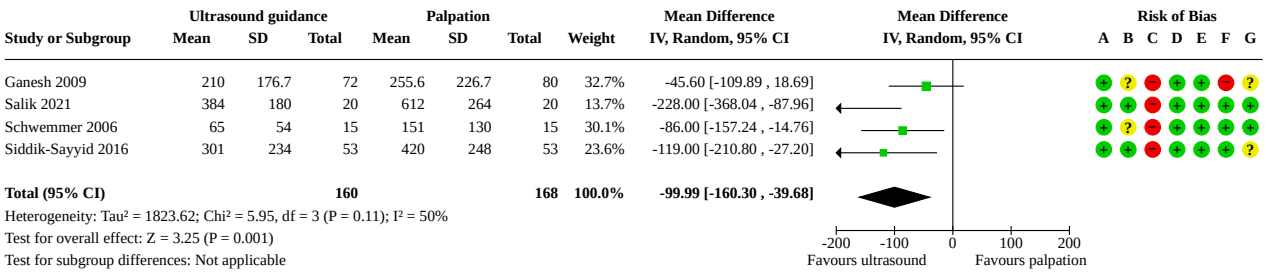
Study or Subgroup	Ultrasound guidance Mean	SD	Total	Palpation Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Risk of Bias A B C D E F G
Ganesh 2009	210	176.7	72	255.6	226.7	80	30.9%	-45.60 [-109.89 , 18.69]	+ ? − + + − ?
Min 2019	102	256	37	218	390	37	9.7%	-116.00 [-266.32 , 34.32]	+ + − + + + ?
Salik 2021	384	180	20	612	264	20	11.0%	-228.00 [-368.04 , -87.96]	+ + − + + + +
Schwemmer 2006	65	54	15	151	130	15	27.8%	-86.00 [-157.24 , -14.76]	+ ? − + + + +
Siddik-Sayyid 2016	301	234	53	420	248	53	20.5%	-119.00 [-210.80 , -27.20]	+ + − + + + ?
Total (95% CI)			**197**			**205**	**100.0%**	**-98.77 [-150.02 , -47.52]**	

Heterogeneity: Tau² = 1135.53; Chi² = 6.07, df = 4 (P = 0.19); I² = 34%
Test for overall effect: Z = 3.78 (P = 0.0002)
Test for subgroup differences: Not applicable



Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.10. Comparison 1: Ultrasound (US)-guided arterial cannulation versus other techniques (palpation/Doppler), Outcome 10: Duration of the cannulation procedure (seconds) – sensitivity analysis



Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

APPENDICES

Appendix 1. CENTRAL (Cochrane Library) search strategy

#1 MeSH descriptor: [Catheterization] explode all trees
#2 MeSH descriptor: [Catheters] explode all trees
#3 #1 or #2
#4 MeSH descriptor: [Arteries] explode all trees
#5 #3 and #4
#6 ((arteria* or artery or arteries) near (canula* or cannula* or catheter* or insert*)):ti,ab,kw
#7 #5 or #6
#8 MeSH descriptor: [Ultrasonography] explode all trees
#9 (ultrasound* or (ultra next sound*) or ultrasonograph* or (ultra next sonograph*) or ultrasonic* or (ultra next sonic*)):ti,ab,kw
#10 #8 or #9
#11 #7 and #10
#12 ((adult* or aged or elderly or (middle next age*)) not (child* or pediat* or paediat* or neonat* or newborn* or infant* or baby* or babies or toddler* or minors* or adolesc* or preteen* or teen* or juvenil* or youth* or preschool* or school* or kindergarten* or kid or kids)):ti,ab,kw
#13 #11 not #12
#14 MeSH descriptor: [Child] explode all trees
#15 MeSH descriptor: [Pediatrics] explode all trees
#16 MeSH descriptor: [Adolescent] explode all trees
#17 MeSH descriptor: [Infant] explode all trees
#18 #14 or #15 or #16 or #17
#19 #11 and #18
#20 #13 or #19
#21 #20 in Trials

Appendix 2. MEDLINE All (OvidSP) search strategy

1 exp Catheterization/

2 exp Catheters/

3 1 or 2

4 exp Arteries/

5 3 and 4

6 ((arteria* or artery or arteries) adj6 (ca?nula* or catheter* or insert*)).mp.

7 5 or 6

8 exp Ultrasonography/

9 (ultrasound* or ultra sound* or ultrasonograph* or ultra sonograph* or ultrasonic* or ultra sonic*).mp.

10 8 or 9

11 7 and 10

12 ((randomized controlled trial or controlled clinical trial).pt. or randomi?ed.ab. or placebo.ab. or drug therapy.fs. or randomly.ab. or trial.ab. or groups.ab.) not (exp animals/ not humans.sh.)

13 11 and 12

14 (exp adult/ or adult*.mp. or elderly.mp. or aged.mp. or middle age*.mp.) not (exp child/ or adolescent/ or exp infant/ or exp Pediatrics/ or child*.mp. or p?ediat*.mp. or neonat*.mp. or newborn*.mp. or infant*.mp. or baby*.mp. or babies.mp. or toddler*.mp. or minors*.mp. or adolesc*.mp. or preteen*.mp. or teen*.mp. or juvenil*.mp. or youth*.mp. or preschool*.mp. or school*.mp. or kindergarten*.mp. or kid.mp. or kids.mp.)

15 13 not 14

Appendix 3. Embase (OvidSP) search strategy

1 exp catheterization/

2 exp artery/

3 1 and 2

4 ((arteria* or artery or arteries) adj6 (ca?nula* or catheter* or insert*)).ti,ab,kw.

5 exp artery catheter/

6 exp artery catheterization/

7 3 or 4 or 5 or 6

8 exp echography/

9 exp ultrasound/

10 (ultrasound* or ultra sound* or ultrasonograph* or ultra sonograph* or ultrasonic* or ultra sonic*).ti,ab,kw.

11 8 or 9 or 10

12 7 and 11

13 (randomized controlled trial/ or controlled clinical study/ or random$.ti,ab. or randomization/ or intermethod comparison/ or placebo.ti,ab. or (compare or compared or comparison).ti. or ((evaluated or evaluate or evaluating or assessed or assess) and (compare or compared or comparing or comparison)).ab. or (open adj label).ti,ab. or ((double or single or doubly or singly) adj (blind or blinded or blindly)).ti,ab. or double blind procedure/ or parallel group$1.ti,ab. or (crossover or cross over).ti,ab. or ((assign$ or match or matched or allocation) adj5 (alternate or group$1 or intervention$1 or patient$1 or subject$1 or participant$1)).ti,ab. or (assigned or allocated).ti,ab. or (controlled adj7 (study or design or trial)).ti,ab. or (volunteer or volunteers).ti,ab. or human experiment/ or trial.ti.) not (((random$ adj sampl$ adj7 (cross section$ or questionnaire$1 or survey$ or database$1)).ti,ab. not (comparative study/ or controlled study/ or randomi?ed controlled.ti,ab. or randomly assigned.ti,ab.)) or (cross-sectional study/ not (randomized controlled trial/ or controlled clinical study/ or controlled study/ or randomi?ed controlled.ti,ab. or control group$1.ti,ab.)) or (((case adj control$) and random$) not randomi?ed controlled).ti,ab. or (Systematic review not (trial or study)).ti. or (nonrandom$ not random$).ti,ab. or Random field$.ti,ab. or (random cluster adj3 sampl$).ti,ab. or ((review.ab. and review.pt.) not trial.ti.) or (we searched.ab. and (review.ti. or review.pt.)) or update review.ab. or (databases adj4 searched).ab. or ((rat or rats or mouse or mice or swine or porcine or murine or sheep or lambs or pigs or piglets or rabbit or rabbits or cat or cats or dog or dogs or cattle or bovine or monkey or monkeys or trout or marmoset$1).ti. and animal experiment/) or (Animal experiment/ not (human experiment/ or human/)))

14 12 and 13

15 (exp adult/ or adult*.mp. or aged.mp. or elderly.mp. or middle age*.mp.) not (exp child/ or exp adolescent/ or exp pediatrics/ or child*.mp. or p?ediat*.mp. or neonat*.mp. or newborn*.mp. or infant*.mp. or baby*.mp. or babies.mp. or toddler*.mp. or minors*.mp. or

adolesc*.mp. or preteen*.mp. or teen*.mp. or juvenil*.mp. or youth*.mp. or preschool*.mp. or school*.mp. or kindergarten*.mp. or kid.mp. or kids.mp.)

16 14 not 15

Appendix 4. Web of science search strategy

#1	TS=((arteria* or artery or arteries) near/6 (canula* or cannula* or catheter* or insert*))
# 2	TS=(ultrasound* or ultra-sound* or ultrasonograph* or ultra-sonograph* or ultrasonic* or ultra-sonic*)
# 3	TS=((control* OR clinical OR comparative) NEAR/3 (trial* or stud*)) OR TS=(trial) OR TS=random* OR TS=placebo* OR TS=((single or double or triple or treble) NEAR/3 (mask* or blind*)) OR TS=(crossover OR crossover) OR TS=(multicenter or multi-center) or TI=(groups)
# 4	#3 AND #2 AND #1
# 5	TS=((adult* or aged or elderly or "middle age*") not (child* or pediat* or paediat* or neonat* or newborn* or infant* or baby* or babies or toddler* or minors* or adolesc* or preteen* or teen* or juvenil* or youth* or preschool* or school* or kindergarten* or kid or kids))
# 6	#4 not #5 *Indexes=SCI-EXPANDED, CPCI-S, ESCI Timespan=All years*

WHAT'S NEW

Date	Event	Description
3 March 2023	New citation required but conclusions have not changed	In this updated review the overall conclusion did not change.
3 March 2023	New search has been performed	Searches updated. We included 4 new trials (Anantasit 2017; Min 2019; Salik 2021; Siddik-Sayyid 2016), and excluded 23 new trials (Abdelbaser 2021; Aouad-Maroun 2016; Bhattacharjee 2018; Guan 2016; Ijiri 2016; Jung 2021; Kiberenge 2018; Lee 2016; Liu 2019; Oulego-Erroz 2019; Polat 2019; Quan 2019; Schults 2020; Sethi 2017; Song 2016; Sorrentino 2020; Staudt 2019; Takeshita 2021; White 2016; Ye 2020; Zhang 2020; Zhefeng 2019; Zhou 2016).

HISTORY

Protocol first published: Issue 11, 2014
Review first published: Issue 9, 2016

Date	Event	Description
18 January 2022	Amended	Updated according to new search and editorial comments
28 January 2021	Amended	Submission first draft of updated meta-analysis
1 July 2020	Amended	Last date of search
3 January 2019	Amended	Editorial team changed to Cochrane Emergency and Critical Care

CONTRIBUTIONS OF AUTHORS

Conceiving the review: EA, MAM
Co-ordinating the review: CR, NHC, JK
Undertaking manual searches: CR, NHC
Screening search results: CR, NHC
Organizing retrieval of papers: CR, NHC
Screening retrieved papers against inclusion criteria: CR, NHC
Appraising quality of papers: CR, NHC
Extracting data from papers: CR, NHC
Writing to authors of papers for additional information: NHC, MAM
Providing additional data about papers: MAM
Obtaining and screening data on unpublished studies: CR, NHC
Managing data for the review: CR, NHC, JK
Entering data into RevMan Web: NHC, JK
Analysing RevMan statistical data: CR, NHC, JK, EA
Performing other statistical analysis not using RevMan: EA
Interpreting data: CR, NHC, JK, EA, MAM, RK
Making statistical inferences: EA
Writing the review: CR, NHC, MAM, RK
Performing previous work that was the foundation of the present study: MAM
Serving as guarantor for the review: MAM
Taking responsibility for reading and checking the review before submission: EA, MAM, RK

DECLARATIONS OF INTEREST

CR: no conflicts of interest
NHC: no conflicts of interest
JK: no conflicts of interest
EA: no conflicts of interest
MAM: no conflicts of interest
RK: no conflicts of interest

SOURCES OF SUPPORT

Internal sources

- Not funded, Lebanon

  No grants received

External sources

- No External source, Other

  No external source

DIFFERENCES BETWEEN PROTOCOL AND REVIEW

Changes between the published protocol (Aouad-Maroun 2014) and the review are as follows.

1. We considered the participant as the unit of analysis. For cluster-RCTs or trials with multiple catheters per person, we planned to use estimates from the included studies adjusted for correlation. Whenever this was not reported, we treated the trial as if it were a parallel group trial. For studies with multiple intervention arms, we omitted groups that were irrelevant to our comparison of interest.
2. In the section Assessment of heterogeneity, we added the following sentence: "We made a post-hoc decision to conduct subgroup analyses that we judged clinically relevant even in the absence of statistical heterogeneity.", because we believed that despite the lack of heterogeneity, it was clinically relevant and important to the reader to conduct subgroup analysis per age group and per expertise in ultrasound usage.
3. We did not include number of cannulas used and need for assistance from another operator (primary operator fails when attempting to insert and asks for help) in the summary of findings table because these outcomes were irrelevant or we had insufficient data to perform the analysis.
4. Conversely, we found the outcome 'successful cannulation after two attempts' to be relevant to our study, so we added it to our secondary outcomes.
5. We also added a subgroup analysis of successful cannulation on first attempt per artery site.
6. We included neonates in this review.
7. We changed the name of the secondary outcome 'time to successful cannulation' to 'duration of cannulation procedure'.
8. We changed the name of the primary outcome 'rate of complications' to 'incidence of complications'.
9. We changed the name of the secondary outcome 'rate of successful cannulation' to 'overall successful cannulation after multiple attempts'.