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Ultrasound guidance for arterial (other than femoral) catheterisation in adults (Review)

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[Intervention Review]

Ultrasound guidance for arterial (other than femoral) catheterisation in adults

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ABSTRACT

Background

Arterial vascular access is a frequently performed procedure, with a high possibility for adverse events (e.g. pneumothorax, haemothorax, haematoma, amputation, death), and additional techniques such as ultrasound may be useful for improving outcomes. However, ultrasound guidance for arterial access in adults is still under debate.

Objectives

To assess the effects of ultrasound guidance for arterial (other than femoral) catheterisation in adults.

Search methods

We searched CENTRAL, MEDLINE, Embase, LILACS, and CINAHL on 21 May 2021. We also searched IBECS, WHO ICTRP, and ClinicalTrials.gov on 16 June 2021, and we checked the reference lists of retrieved articles.

Selection criteria

Randomised controlled trials (RCTs), including cross-over trials and cluster-RCTs, comparing ultrasound guidance, alone or associated with other forms of guidance, versus other interventions or palpation and landmarks for arterial (other than femoral) guidance in adults.

Data collection and analysis

Two review authors independently performed study selection, extracted data, assessed risk of bias, and assessed the certainty of evidence using GRADE.

Main results

We included 48 studies (7997 participants) that tested palpation and landmarks, Doppler auditory ultrasound assistance (DUA), direct ultrasound guidance with B-mode, or any other modified ultrasound technique for arterial (axillary, dorsalis pedis, and radial) catheterisation in adults.

Radial artery

Real-time B-mode ultrasound versus palpation and landmarks

Real-time B-mode ultrasound guidance may improve first attempt success rate (risk ratio (RR) 1.44, 95% confidence interval (CI) 1.29 to 1.61; 4708 participants, 27 studies; low-certainty evidence) and overall success rate (RR 1.11, 95% CI 1.06 to 1.16; 4955 participants, 28 studies; low-certainty evidence), and may decrease time needed for a successful procedure (mean difference (MD) -0.33 minutes, 95% CI -0.54 to -0.13; 4902 participants, 26 studies; low-certainty evidence) up to one hour compared to palpation and landmarks. Real-time B-mode ultrasound guidance probably decreases major haematomas (RR 0.35, 95% CI 0.23 to 0.56; 2504 participants, 16 studies; moderate-certainty evidence). It is uncertain whether real-time B-mode ultrasound guidance has any effect on pseudoaneurysm, pain, and quality of life (QoL) compared to palpation and landmarks (very low-certainty evidence).

Real-time B-mode ultrasound versus DUA

One study (493 participants) showed that real-time B-mode ultrasound guidance probably improves first attempt success rate (RR 1.35, 95% CI 1.11 to 1.64; moderate-certainty evidence) and time needed for a successful procedure (MD -1.57 minutes, 95% CI -1.78 to -1.36; moderate-certainty evidence) up to 72 hours compared to DUA. Real-time B-mode ultrasound guidance may improve overall success rate (RR 1.13, 95% CI 0.99 to 1.29; low-certainty evidence) up to 72 hours compared to DUA. Pseudoaneurysm, major haematomas, pain, and QoL were not reported.

Real-time B-mode ultrasound versus modified real-time B-mode ultrasound

Real-time B-mode ultrasound guidance may decrease first attempt success rate (RR 0.68, 95% CI 0.55 to 0.84; 153 participants, 2 studies; low-certainty evidence), may decrease overall success rate (RR 0.93, 95% CI 0.86 to 1.01; 153 participants, 2 studies; low-certainty evidence), and may lead to no difference in time needed for a successful procedure (MD 0.04 minutes, 95% CI -0.01 to 0.09; 153 participants, 2 studies; low-certainty evidence) up to one hour compared to modified real-time B-mode ultrasound guidance. It is uncertain whether real-time B-mode ultrasound guidance has any effect on major haematomas compared to modified real-time B-mode ultrasound (very low-certainty evidence). Pseudoaneurysm, pain, and QoL were not reported.

In-plane versus out-of-plane B-mode ultrasound

In-plane real-time B-mode ultrasound guidance may lead to no difference in overall success rate (RR 1.00, 95% CI 0.96 to 1.05; 1051 participants, 8 studies; low-certainty evidence) and in time needed for a successful procedure (MD -0.06 minutes, 95% CI -0.16 to 0.05; 1134 participants, 9 studies; low-certainty evidence) compared to out-of-plane B-mode ultrasound up to one hour. It is uncertain whether in-plane real-time B-mode ultrasound guidance has any effect on first attempt success rate or major haematomas compared to out-of-plane B-mode ultrasound (very low-certainty evidence). Pseudoaneurysm, pain, and QoL were not reported.

DUA versus palpation and landmarks

DUA may lead to no difference in first attempt success rate (RR 1.01, 95% CI 0.90 to 1.14; 666 participants, 2 studies; low-certainty evidence) or overall success rate (RR 0.99, 95% CI 0.92 to 1.07; 666 participants, 2 studies; low-certainty evidence) and probably increases time needed for a successful procedure (MD 0.45 minutes, 95% CI 0.20 to 0.70; 500 participants, 1 study; moderate-certainty evidence) up to 72 hours compared to palpation and landmarks. Pseudoaneurysm, major haematomas, pain, and QoL were not reported.

Oblique-axis versus long-axis in-plane B-mode ultrasound

Oblique-axis in-plane B-mode ultrasound guidance may increase overall success rate (RR 1.27, 95% CI 1.05 to 1.53; 215 participants, 2 studies; low-certainty evidence) up to 72 hours compared to long-axis in-plane B-mode ultrasound. It is uncertain whether oblique-axis in-plane B-mode ultrasound guidance has any effect on first attempt success rate, time needed for a successful procedure, and major haematomas compared to long-axis in-plane B-mode ultrasound. Pseudoaneurysm, pain, and QoL were not reported.

We are uncertain about effects in the following comparisons due to very low-certainty evidence and unreported outcomes: real-time B-mode ultrasound versus palpation and landmarks (axillary and dorsalis pedis arteries), real-time B-mode ultrasound versus near-infrared laser (radial artery), and dynamic versus static out-of-plane B-mode ultrasound (radial artery).

Authors' conclusions

Real-time B-mode ultrasound guidance may improve first attempt success rate, overall success rate, and time needed for a successful procedure for radial artery catheterisation compared to palpation, or DUA. In addition, real-time B-mode ultrasound guidance probably decreases major haematomas compared to palpation. However, we are uncertain about the evidence on major haematomas and pain for other comparisons due to very low-certainty evidence and unreported outcomes. We are also uncertain about the effects on pseudoaneurysm and QoL for axillary and dorsalis pedis arteries catheterisation. Given that first attempt success rate and pseudoaneurysm are the most relevant outcomes for people who underwent arterial catheterisation, future studies must measure both. Future trials must be large enough to detect effects, use validated scales, and report longer-term follow-up.

PLAIN LANGUAGE SUMMARY

Ultrasound to guide arterial (other than femoral) punctures and cannulation in adults

Research question

What is the effectiveness and safety of ultrasound technologies to guide arterial (other than femoral) punctures and cannulation in adults?

Background

Despite the availability of devices that help health professionals to access arteries, unwanted events such as pneumothorax (air outside the lung and inside the thorax), haemothorax (blood outside the lung and inside the thorax), haematoma (blooding in skin and other tissues), amputation, and death may happen. Additional techniques such as ultrasound may be useful for improving these results, but their effects for arterial access in adults remain under debate.

Study characteristics

Review authors identified 48 studies that evaluated the effects of different types of ultrasound guidance for adults who underwent arterial puncture or cannulation. Studies were conducted in hospitals and mainly for diagnostic purposes (smaller devices). Review authors identified the studies included in this review through electronic literature searches conducted up to May 2021.

Key results

Real-time visual ultrasound guidance improved first attempt success rate, overall success rate, and time needed for a successful procedure for up to one month, mainly in radial artery, compared to palpation or non-visual ultrasound guidance. In addition, real-time visual ultrasound guidance probably decreased major haematomas compared to palpation. However, we are uncertain about the effects on major haematomas and on pain for other comparisons due to very low-certainty evidence and unreported outcomes. We are also uncertain about the effects on pseudoaneurysm and QoL for axillary and dorsalis pedis arteries catheterisation.

Quality of evidence

We found very low- to moderate-certainty evidence comparing real-time visual ultrasound guidance versus palpation, and comparing one ultrasound guidance type versus another.

Summary of findings 1. [Axillary] B-mode ultrasound guidance compared to palpation and landmarks for arterial (other than femoral) catheterisation in adults

[Axillary] B-mode ultrasound guidance compared to palpation and landmarks for axillary artery catheterisation in adults

Patient or population: adults requiring axillary artery catheterisation
Setting: ICU
Intervention: B-mode ultrasound guidance
Comparison: palpation and landmarks

Outcomes	№. of participants (studies) Follow-up	Certainty of evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects* (95% CI)	
				Risk with palpation and landmarks	Risk difference with [axillary] B-mode ultrasound guidance
First-attempt success rate	not reported				
Pseudoaneurysm	not reported				
Overall success rate Follow-up: end of the procedure (< 1 hour)	33 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,b,c]	RR 1.35 (0.99 to 1.86)	study population 733 per 1000	 257 more per 1000 (7 fewer to 631 more)
Time needed for a successful procedure Follow-up: end of the procedure (< 1 hour)	33 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,b,c]	-	mean time needed for a successful procedure was 9.288 minutes	MD 2.27 lower (7.36 lower to 2.82 higher)
Major haematoma Follow-up: end of the procedure (< 1 hour)	33 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,b,c]	RR 0.83 (0.06 to 12.22)	study population 67 per 1000	 11 fewer per 1000 (63 fewer to 748 more)
Adverse events (pain)	not reported				
Quality of life	not reported				

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the __relative effect__ of the intervention (and its 95% CI).

CI: confidence interval; **ICU:** intensive care unit; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio.

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 due to risk of high risk of performance bias.
[b]Downgraded two levels due to imprecision: few participants, few studies, and 95% CI consistent with possible benefit and possible harm.
[c]Downgraded one level due to indirectness: few participants are not representative of the overall relevant population

Summary of findings 2. [Dorsalis pedis] B-mode ultrasound guidance compared to palpation and landmarks for arterial (other than femoral) catheterisation in adults

[Dorsalis pedis] B-mode ultrasound guidance compared to palpation and landmarks for dorsalis pedis artery catheterisation in adults

Patient or population: adults requiring dorsalis pedis artery catheterisation
Setting: operating room
Intervention: B-mode ultrasound guidance
Comparison: palpation and landmarks

Outcomes	№. of participants (studies) Follow-up	Certainty of evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects* (95% CI)	
				Risk with palpation and landmarks	Risk difference with [dorsalis pedis] B-mode ultrasound guidance
First-attempt success rate Follow-up: end of the procedure (< 1 hour)	60 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,b,c]	RR 1.28 (0.90 to 1.82)	study population 600 per 1000	 168 more per 1000 (60 fewer to 492 more)
Pseudoaneurysm	not reported				
Overall success rate Follow-up: end of the procedure (< 1 hour)	60 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,c,d]	RR 1.00 (0.91 to 1.10)	study population 967 per 1000	 0 fewer per 1000 (87 fewer to 97 more)

Time needed for a successful procedure Follow-up: end of the procedure (< 1 hour)	60 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,b,c]	-	mean time needed for a successful procedure was 0.58 minutes	MD 0.04 lower (0.16 lower to 0.08 higher)
Major haematoma	not reported				
Adverse events (pain)	not reported				
Quality of life	not reported				

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the __relative effect__ of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio.

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 due to risk of high risk of performance bias.
[b]Downgraded two levels due to imprecision: few participants, few studies, and 95% CI consistent with possible benefit and possible harm.
[c]Downgraded one level due to indirectness: few participants are not representative of the overall relevant population.
[d]Downgraded one level due to imprecision: few participants and few studies.

Summary of findings 3. [Radial] B-mode ultrasound guidance compared to palpation and landmarks for arterial (other than femoral) catheterisation in adults

[Radial] B-mode ultrasound guidance compared to palpation and landmarks for radial artery catheterisation in adults

Patient or population: adults requiring radial artery catheterisation
Setting: hospital
Intervention: B-mode ultrasound guidance
Comparison: palpation and landmarks

Outcomes	№. of participants (studies) Follow-up	Certainty of evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects* (95% CI)

				Risk with palpation and landmarks	Risk difference with [radial] B-mode ultrasound guidance
First-attempt success rate Follow-up: from end of the procedure (< 1 hour) to 1 day	4708 (27 RCTs)	⊕⊕⊖⊖ LOW[a,b,c]	RR 1.44 (1.29 to 1.61)	study population	
				542 per 1000	239 more per 1000 (157 more to 331 more)
Pseudomaneurysm Follow-up: up to 1 month	679 (1 RCT)	⊕⊖⊖⊖ VERY LOW[d,e,f]	RR 2.89 (0.12 to 70.63)	study population	
				0 per 333	1 per 346 (absolute risk with B-mode ultrasound guidance)
Overall success rate Follow-up: end of the procedure (< 1 hour) to 1 day	4955 (28 RCTs)	⊕⊕⊖⊖ LOW[a,b,c]	RR 1.11 (1.06 to 1.16)	study population	
				833 per 1000	92 more per 1000 (50 more to 133 more)
Time needed for a successful procedure Follow-up: end of the procedure (< 1 hour) to 1 day	4902 (26 RCTs)	⊕⊕⊖⊖ LOW[a,b,g]	-	mean time needed for a successful procedure was 2.302 minutes	MD 0.33 lower (0.54 lower to 0.13 lower)
Major haematoma Follow-up: end of the procedure (< 1 hour) to 1 month	2504 (16 RCTs)	⊕⊕⊕⊖ MODERATE[h]	RR 0.35 (0.23 to 0.56)	study population	
				122 per 1000	79 fewer per 1000 (94 fewer to 54 fewer)
Adverse events (pain) Assessed with: VAS Scale from 0 to 10 Follow-up: end of the procedure (< 1 hour) to 24 hours	883 (4 RCTs)	⊕⊖⊖⊖ VERY LOW[b,d,f,i]	-	mean number of adverse events (pain) was 1.849	MD 0.81 higher (0.66 lower to 2.28 higher)
Quality of life (satisfaction) Assessed with: VAS Scale from 0 to 10 Follow-up: end of the procedure (< 1 hour)	72 (1 RCT)	⊕⊖⊖⊖ VERY LOW[d,f,j]	-	mean quality of life (satisfaction) was 7	MD 0 (1.07 lower to 1.07 higher)

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio; **VAS:** visual analogue scale.

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 due to high risk of selection, performance, detection, attrition, reporting, and other bias.
[b]Downgraded half a level due to inconsistency: unexplained substantial heterogeneity.
[c]Downgraded half a level due to suspected publication bias: funnel plot asymmetrical and statistical tests compatible with impaired effect size after correction by publication bias.
[d]Downgraded two levels due to imprecision: wide 95% CI consistent with possible benefit and possible harm.
[e]Downgraded one level due to high risk of performance bias.
[f]Downgraded half a level due to suspected publication bias: a large number of included trials did not contribute to this outcome.
[g]Downgraded half a level due to suspected publication bias: funnel plot symmetrical, but statistical tests compatible with impaired effect size after correction by publication bias.
[h]Downgraded one level due to high risk of performance, detection, attrition, reporting, and other bias.
[i]Downgraded one level due to high risk of attrition and reporting bias.
[j]Downgraded one level due to indirectness: few participants are not representative of the overall relevant population.

Summary of findings 4. [Radial] B-mode ultrasound compared to Doppler assistance for arterial (other than femoral) catheterisation in adults

[Radial] B-mode ultrasound compared to Doppler assistance for radial artery catheterisation in adults

Patient or population: adults requiring radial artery catheterisation
Setting: hospital
Intervention: B-mode ultrasound
Comparison: Doppler assistance

Outcomes	№. of participants (studies) Follow-up	Certainty of evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects* (95% CI)	
				Risk with Doppler assistance	Risk difference with [radial] B-mode ultrasound
First-attempt success rate Follow-up: end of the procedure (< 1 hour)	493 (1 RCT)	⊕⊕⊕⊖ MODERATE[a]	RR 1.35 (1.11 to 1.64)	study population	
				393 per 1000	138 more per 1000 (43 more to 252 more)

Pseudoaneurysm	not reported				
Overall success rate Follow-up: end of the procedure (< 1 hour)	493 (1 RCT)	⊕⊕⊖⊖ LOW[a,b]	RR 1.13 (0.99 to 1.29)	study population 602 per 1000	 78 more per 1000 (6 fewer to 175 more)
Time needed for a successful procedure Follow-up: end of the procedure (< 1 hour)	493 (1 RCT)	⊕⊕⊕⊖ MODERATE[a]	-	mean time needed for a successful procedure was 2.138 minutes	MD 1.57 lower (1.78 lower to 1.36 lower)
Major haematoma	not reported				
Adverse events (pain)	not reported				
Quality of life	not reported				

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the __relative effect__ of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio.

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 due to high risk of reporting and other bias.
[b]Downgraded one level due to imprecision: 95% CI consistent with possible benefit and possible harm.

Summary of findings 5. [Radial] B-mode ultrasound compared to near-infrared laser guidance for arterial (other than femoral) catheterisation in adults

[Radial] B-mode ultrasound compared to near-infrared laser guidance for radial artery catheterisation in adults

Patient or population: adults requiring radial artery catheterisation
Setting: hospital
Intervention: B-mode ultrasound
Comparison: near-infrared laser guidance

Outcomes	№. of participants (studies) Follow-up	Certainty of evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects* (95% CI)	
				Risk with near-infrared laser guidance	Risk difference with [radial] B-mode ultrasound
First-attempt success rate Follow-up: end of the procedure (< 1 hour)	72 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,b,c]	RR 1.33 (0.82 to 2.16)	study population	
				583 per 1000	193 more per 1000 (105 fewer to 677 more)
Pseudoaneurysm	not reported				
Overall success rate Follow-up: end of the procedure (< 1 hour)	72 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,b,c]	RR 1.50 (0.27 to 8.45)	study population	
				944 per 1000	472 more per 1000 (689 fewer to 7.036 more)
Time needed for a successful procedure Follow-up: end of the procedure (< 1 hour)	72 (1 RCT)	⊕⊖⊖⊖ VERY LOW[b,c,d]	-	mean time needed for a successful procedure was 0.189 minutes	MD 0.2 higher (0.09 higher to 0.31 higher)
Major haematoma	not reported				
Adverse events (pain)	not reported				
Quality of life	not reported				

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the __relative effect__ of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio.

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 due to imprecision: few participants and 95% CI consistent with possible benefit and possible harm.
[b]Downgraded one level due to indirectness: few participants are not representative of the overall relevant population.
[c]Downgraded one level due to risk of high risk of performance bias.
[d]Downgraded one level due to imprecision: few participants.

Summary of findings 6. [Radial] B-mode ultrasound compared to modified B-mode ultrasound for arterial (other than femoral) catheterisation in adults

[Radial] B-mode ultrasound compared to modified B-mode ultrasound for radial artery catheterisation in adults

Patient or population: adults requiring radial artery catheterisation
Setting: hospital
Intervention: B-mode ultrasound
Comparison: modified B-mode ultrasound

Outcomes	№. of participants (studies) Follow-up	Certainty of evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects* (95% CI)	
				Risk with modified B-mode ultrasound	Risk difference with [radial] B-mode ultrasound
First-attempt success rate Follow-up: end of the procedure (< 1 hour) to 1 day	153 (2 RCTs)	⊕⊕⊖⊖ LOW[a,b,c]	RR 0.68 (0.55 to 0.84)	study population 831 per 1000	 266 fewer per 1000 (374 fewer to 133 fewer)
Pseudoaneurysm	not reported				
Overall success rate Follow-up: end of the procedure (< 1 hour) to 1 day	153 (2 RCTs)	⊕⊕⊖⊖ LOW[a,b,c]	RR 0.93 (0.86 to 1.01)	study population 974 per 1000	 68 fewer per 1000 (136 fewer to 10 more)
Time needed for a successful procedure Follow-up: end of the procedure (< 1 hour) to 1 day	153 (2 RCTs)	⊕⊕⊖⊖ LOW[a,b,c]	-	mean time needed for a successful procedure was 0.384 minutes	MD 0.04 higher (0.01 lower to 0.09 higher)
Major haematoma Follow-up: end of the procedure (< 1 hour) to 1 day	153 (2 RCTs)	⊕⊖⊖⊖ VERY LOW[a,d]	RR 3.23 (1.37 to 7.60)	study population 78 per 1000	 174 more per 1000 (29 more to 514 more)
Adverse events (pain)	not reported				
Quality of life	not reported				

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio.

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.
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[a]Downgraded one level due to risk of high risk of performance bias.
[b]Downgraded half a level due to inconsistency: unexplained substantial heterogeneity.
[c]Downgraded half a level due to imprecision: few participants.
[d]Downgraded two levels due to imprecision: few participants and 95% CI consistent with possible benefit and possible harm.

Summary of findings 7. [Radial] In-plane B-mode ultrasound compared to out-of-plane B-mode ultrasound for arterial (other than femoral) catheterisation in adults

[Radial] In-plane B-mode ultrasound compared to out-of-plane B-mode ultrasound for radial artery catheterisation in adults

Patient or population: adults requiring radial artery catheterisation
Setting: hospital
Intervention: in-plane B-mode ultrasound
Comparison: out-of-plane B-mode ultrasound

Outcomes	№. of participants (studies) Follow-up	Certainty of evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects* (95% CI)	
				Risk with out-of-plane B-mode ultrasound	Risk difference with [radial] In-plane B-mode ultrasound
First-attempt success rate Follow-up: end of the procedure (< 1 hour)	1051 (8 RCTs)	⊕⊝⊝⊝ VERY LOW[a,b,c]	RR 0.85 (0.65 to 1.12)	study population	
				743 per 1000	111 fewer per 1000 (260 fewer to 89 more)
Pseudoaneurysm	not reported				
Overall success rate Follow-up: end of the procedure (< 1 hour)	1051 (8 RCTs)	⊕⊕⊝⊝ LOW[a,b]	RR 1.00 (0.96 to 1.05)	study population	
				880 per 1000	0 fewer per 1000 (35 fewer to 44 more)

Time needed for a successful procedure Follow-up: end of the procedure (< 1 hour)	1134 (9 RCTs)	⊕⊕⊖⊖ LOW[a,b]	-	mean time needed for a successful procedure was 0.771 minutes	MD 0.06 lower (0.16 lower to 0.05 higher)
Major haematoma Follow-up: end of the procedure (< 1 hour)	1159 (9 RCTs)	⊕⊖⊖⊖ VERY LOW[a,b,c]	RR 0.49 (0.22 to 1.08)	study population 144 per 1000	 73 fewer per 1000 (112 fewer to 11 more)
Adverse events (pain)	not reported				
Quality of life	not reported				

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the __relative effect__ of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio.

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 due to high risk of performance, detection, attrition, reporting, and other bias.
[b]Downgraded one level due to inconsistency: unexplained substantial heterogeneity.
[c]Downgraded one level due to imprecision: 95% CI consistent with possible benefit and possible harm.

Summary of findings 8. [Radial] Doppler assistance compared to palpation and landmarks for arterial (other than femoral) catheterisation in adults

[Radial] Doppler assistance compared to palpation and landmarks for radial artery catheterisation in adults

Patient or population: adults requiring radial artery catheterisation
Setting: hospital
Intervention: Doppler ultrasound assistance
Comparison: palpation and landmarks

Outcomes	№, of participants (studies) Follow-up	Certainty of evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects* (95% CI)

				Risk with palpation and landmarks	Risk difference with [radial] Doppler assistance
First-attempt success rate Follow-up: end of the procedure (< 1 hour)	666 (2 RCTs)	⊕⊕⊖⊖ LOW[a,b]	RR 1.01 (0.90 to 1.14)	study population	
				509 per 1000	5 more per 1000 (51 fewer to 71 more)
Pseudoaneurysm	not reported				
Overall success rate Follow-up: end of the procedure (< 1 hour)	666 (2 RCTs)	⊕⊕⊖⊖ LOW[a,b]	RR 0.99 (0.92 to 1.07)	study population	
				723 per 1000	7 fewer per 1000 (58 fewer to 51 more)
Time needed for a successful procedure Follow-up: end of the procedure (< 1 hour)	500 (1 RCT)	⊕⊕⊕⊖ MODERATE[a]	-	mean time needed for a successful procedure was 1.688 minutes	MD 0.45 higher (0.2 higher to 0.7 higher)
Major haematoma	not reported				
Adverse events (pain)	not reported				
Quality of life	not reported				

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the __relative effect__ of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio.

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 due to high risk of reporting and other bias.
[b]Downgraded one level due to imprecision: 95% CI consistent with possible benefit and possible harm.

Summary of findings 9. [Radial] Dynamic out-of-plane B-mode ultrasound compared to static out-of-plane B-mode ultrasound for arterial (other than femoral) catheterisation in adults

[Radial] Dynamic out-of-plane B-mode ultrasound compared to static out-of-plane B-mode ultrasound for radial artery catheterisation in adults

Patient or population: adults requiring radial artery catheterisation
Setting: hospital
Intervention: dynamic out-of-plane B-mode ultrasound
Comparison: static out-of-plane B-mode ultrasound

Outcomes	№. of participants (studies) Follow-up	Certainty of evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects* (95% CI)	
				Risk with static out-of-plane B-mode ultrasound	Risk difference with [radial] dynamic out-of-plane B-mode ultrasound
First-attempt success rate Follow-up: end of the procedure (< 1 hour)	131 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,b,c]	RR 0.91 (0.67 to 1.23)	study population	
				591 per 1000	53 fewer per 1000 (195 fewer to 136 more)
Pseudoaneurysm	not reported				
Overall success rate Follow-up: end of the procedure (< 1 hour)	131 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,c,d]	RR 1.07 (0.92 to 1.25)	study population	
				803 per 1000	56 more per 1000 (64 fewer to 201 more)
Time needed for a successful procedure Follow-up: end of the procedure (< 1 hour)	131 (1 RCT)	⊕⊖⊖⊖ VERY LOW[a,c,d]	-	mean time needed for a successful procedure was 0.981 minutes	MD 0.37 higher (0.07 higher to 0.66 higher)
Major haematoma	not reported				
Adverse events (pain)	not reported				
Quality of life	not reported				

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the __relative effect__ of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio.

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 due to risk of high risk of performance bias.
[b]Downgraded two levels due to imprecision: few participants, few studies, and 95% CI consistent with possible benefit and possible harm.
[c]Downgraded one level due to indirectness: few participants are not representative of the overall relevant population.
[d]Downgraded one level due to imprecision: few participants.

Summary of findings 10. [Radial] Oblique-axis in-plane B-mode ultrasound compared to long-axis in-plane B-mode ultrasound for arterial (other than femoral) catheterisation in adults

[Radial] Oblique-axis in-plane B-mode ultrasound compared to long-axis in-plane B-mode ultrasound for radial artery catheterisation in adults

Patient or population: adults requiring radial artery catheterisation
Setting: hospital
Intervention: oblique-axis in-plane B-mode ultrasound
Comparison: long-axis in-plane B-mode ultrasound

Outcomes	№. of participants (studies) Follow-up	Certainty of evidence (GRADE)	Relative effect (95% CI)	Anticipated absolute effects* (95% CI)	
				Risk with long-axis in-plane B-mode ultrasound	Risk difference with [radial] oblique-axis in-plane B-mode ultrasound
First-attempt success rate Follow-up: end of the procedure (< 1 hour) to 72 hours	275 (3 RCTs)	⊕⊖⊖⊖ VERY LOW[a,b,c]	RR 1.11 (0.44 to 2.79)	study population	
				326 per 1000	36 more per 1000 (183 fewer to 583 more)
Pseudoaneurysm	not reported				
Overall success rate Follow-up: up to 72 hours	215 (2 RCTs)	⊕⊕⊖⊖ LOW[d,e]	RR 1.27 (1.05 to 1.53)	study population	
				571 per 1000	154 more per 1000 (29 more to 303 more)
Time needed for a successful procedure	275 (3 RCTs)	⊕⊖⊖⊖ VERY LOW[a,c,e]	-	mean time needed for a successful procedure was 0.634 minutes	MD 0.35 lower (0.95 lower to 0.25 higher)

Follow-up: end of the procedure (< 1 hour) to 72 hours					
Major haematoma Follow-up: up to 72 hours	215 (2 RCTs)	⊕⊖⊖⊖ VERY LOW[b,d]	RR 0.68 (0.32 to 1.47)	Study population	
				133 per 1000	43 fewer per 1000 (91 fewer to 63 more)
Adverse events (pain)	not reported				
Quality of life	not reported				

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the __relative effect__ of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio.

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 due to risk of high risk of performance, detection, attrition, and reporting bias.
[b]Downgraded two levels due to imprecision: few participants, few studies, and 95% CI consistent with possible benefit and possible harm.
[c]Downgraded one level due to inconsistency: unexplained substantial heterogeneity.
[d]Downgraded one level due to risk of high risk of performance, detection, and attrition bias.
[e]Downgraded one level due to imprecision: few participants.

BACKGROUND

See Appendix 1 for a glossary of terms.

Description of the condition

In all medical specialties that encounter critically ill patients requiring invasive blood pressure measurements - for instance, in the intensive care unit (ICU), emergency room, or surgical theatre; and for some diagnostic and therapeutic procedures, such as arterial catheterisation for cardiac angiography or percutaneous coronary intervention (PCI) - arterial cannulation is the primary pathway for intravascular access. Arterial access for cardiovascular procedures, such as arterial blood sampling and blood pressure monitoring, may be performed using almost all peripheral arteries. The puncture site is commonly selected based on the diameter of devices to be used in the procedure and characteristics of the patient's body (e.g. obesity, previous surgery, arterial stenosis, occlusion). In the vascular catheterisation setting, clinicians constantly seek to attain lower puncture injury rates and to reduce any other possible setbacks for better safety rates in diagnostic angiography, percutaneous intervention, or arterial monitoring (Sandoval 2017).

The transfemoral approach can be used for artery access, mainly when the devices used present wider diameters, such as for transcatheter aortic valve implantation (Pascual 2017). A randomised controlled trial (RCT) showed that ultrasound-guided cannulation of the femoral artery improved access in patients with a weak arterial pulse and a hostile groin (Dudeck 2004). Investigators in the FAUST trial achieved better results with ultrasound-guided femoral artery access in comparison with fluoroscopic access (Seto 2010). The same result was found when devices with wider diameters were necessary for endovascular placement of stent grafts (20 French or wider) (Arthurs 2008). There is a Cochrane registered title that aims to study the differences between ultrasound-guided femoral artery access and landmark access (Strauss 2021).

The femoral artery approach presents complications such as bleeding, pseudoaneurysm, and dissection, among others (Flumignan 2018). These complications contribute to high costs and significant morbidity and mortality. A Cochrane Review compared transfemoral and transradial approaches for the diagnosis and treatment of cardiac disease. Kolkailah 2018 found that transradial access, although associated with increased radiation exposure and technique difficulties, demonstrated fewer access complications and less bleeding and death in the first 30 days.

Femoral access is still used for arterial access procedures because it allows for the use of devices of all sizes and it is an easily accessible site (one of the first sites used for arterial procedures such as angioplasties). Non-femoral vascular access - such as via the radial artery - is common for PCI, however, and may be related to lower adverse event rates (Aboyans 2018; Attie 2019; Feldman 2013).

The radial artery is the most-used site of arterial access for invasive blood pressure monitoring and for arterial blood gas sampling. Transradial access is preferable for patients with peripheral artery disease (PAD) in the lower limbs, as this access route appears to be safer for this patient population, with lower rates of vascular complications, including significant bleeding; it also allows patients to be mobile immediately following the procedure in contrast to transfemoral access (Aboyans 2018; Brueck 2009; Jolly 2009). Regarding cardiac procedures in the USA, however, it has been shown that less than 1.5% of PCIs were performed by the transradial access route between 2004 and 2007 (Rao 2008), with a slight increase between 2007 and 2012, and one PCI via radial access was used for every six procedures performed (Feldman 2013). Data are available regarding the feasibility of this access for non-cardiac procedures, such as endovascular treatment of carotid disease (Jaroenngarmsamer 2019). Some factors have influenced study results for radial access. The permeability of the radioulnar arch, for instance, is still open to debate, mainly after release of results of the RADAR study (predictive value of Allen's test result in elective patients undergoing coronary catheterisation by radial approach), which reported no major ischaemic complications for patients with an incomplete palmar arch (Valgimigli 2014). Seto 2015 reported that ultrasound guidance may be better than palpation alone for radial artery cannulation in adults, but this is still under debate. Aouad-Maroun 2016 found "moderate-quality evidence suggesting that ultrasound guidance for radial artery cannulation improves first and second attempt success rates and decreases the rate of complications as compared with palpation or Doppler auditory assistance" in paediatric patients, but no similarly robust evidence is available for adults.

Current data show that brachial access is uncommon for arterial procedures. Parviz 2015 reported that in the UK, only 0.44% of all 26,602 procedures between 2005 and 2014 were performed via brachial access. Brachial access is an effective artery-access option, primarily for treatment of lower-limb PAD when femoral access cannot be used (e.g. graft or occlusion in a femoral path) because it is a more favourable entry route for procedures in caudal-oriented visceral arteries, and because the brachial artery allows the use of larger-diameter devices than can be used for the radial artery. The complication rate associated with brachial access is similar to that associated with femoral access and may be minimised via ultrasound-guided puncture (Franz 2017; Lee 2015).

Percutaneous access through the axillary artery is a strategy used for more difficult endovascular interventions or in the absence of other feasible arterial access, mainly due to the particular location of this artery. As this artery is in close proximity to local nerves and the axillary vein, and has a relatively deep location, the use of ultrasonography to aid its catheterisation may be beneficial, reducing the risk of local iatrogenic lesions (Harris 2018).

Other less common sites - direct aortic, carotid, or subclavian accesses - for transcatheter aortic valve implantation (TAVI) and for popliteal or tibial arteries, mainly in critical arterial lesions of the lower limbs, also have utility. However, available evidence on the benefits and the best ways to perform these punctures remains under debate (Aboyans 2018; Conte 2019).

Description of the intervention

To cannulate an artery, healthcare providers primarily use the Seldinger technique, which consists of puncturing the anterior artery wall, passing a guidewire, removing the needle, and finally cannulating the artery through this guidewire with any medical device. Use of the anterior arterial wall puncture seems to be a good choice compared to total arterial transfixation because many patients who undergo an arterial puncture have critical illnesses, such as coagulopathy, or have been advised to use anticoagulants

or antiplatelet agents (or both). These illnesses or medicines may cause any puncture to become a site of possible complications, such as bleeding or a pseudoaneurysm. Transfixation of the target artery can add some risk of inadvertent bleeding or even puncture of other nearby structures. Moreover, some 'catheter-over-needle' devices allow introduction of the guidewire initially through a catheter instead of initially through a needle (original Seldinger technique), and this may provide some advantages in simplifying the process, mainly in reduced calibre vessels. All subsequent interventions will be added to the Seldinger technique for a complete arterial catheterisation (Aboyans 2018; Flumignan 2018; Gopalasingam 2017; Hansen 2014; Higgs 2005; Kendall 2014; Seldinger 1953; Song 2016; Song 2018).

Palpation and landmarks

Anatomical marks are used as a guide for catheterisation, with or without a scope, in most procedures performed. To identify a reference point, pulse palpation is the most commonly used approach for insertion of an arterial catheter. The artery is localised using palpation for the subsequent puncture and cannulation attempt. However, haemodynamic instability, hypotension, or other shock-causing conditions may hamper the palpation technique, as these make the pulse weaker and more difficult to find. Also, because of underlying diseases such as atherosclerosis, the pulse may not be present in a determined region, making it impossible to use this technique for puncture. Palpation of deeper arteries (e.g. axillary artery) and pulse palpation in patients with a higher body mass index (BMI) can be other challenges, mainly during the learning curve of the practitioner who will perform the procedure (AIUM 2013; Soverow 2016).

Doppler auditory ultrasound assistance

Doppler auditory ultrasound assistance (DUA) has been described as an alternative to the traditional palpation technique for arterial catheter insertion. A change in the Doppler tone to a higher tone suggests that the target artery has been located. Loss of Doppler sound is expected during the procedure, when the artery is compressed by the puncture (Ueda 2013).

Indirect ultrasound guidance

Indirect ultrasound guidance (IUG), or ultrasound-assisted arterial cannulation, is defined as vessel imaging used to confirm location and patency, followed by arterial cannulation, without real-time needle guidance. Commonly, IUG is performed by looking for the vessel using B-mode ultrasound and marking the puncture site on the skin. Subsequently, the healthcare provider punctures the artery and performs the catheterisation without any sonographic guidance. IUG is coupled with arterial cannulation to facilitate locating the arteries and nearby structures (e.g. nerves, veins) and to help make the procedure safer, faster, as complication-free as possible, and successful more often (Attie 2019; Lamperti 2012).

Direct ultrasound guidance

Direct ultrasound guidance (DUG), or ultrasound-guided arterial cannulation, is defined as real-time needle guidance via B-mode ultrasound for vessel puncture and cannulation (Lamperti 2012). DUG is performed by a sterile technique, with the ultrasound probe inside a sterile cover, and is aided by sterile ultrasound gel (AIUM 2013).

During passage of the needle into the vessel, the artery can be seen by a transverse (short artery axis) view or a longitudinal (long artery axis) view. Benefits of the transverse artery view include a shorter learning curve and easier visualisation of small vessels. However, the transverse approach allows only a cross-section of the artery to be visualised by DUG and may lead to errors in direction perception of the needle. Regarding needle visualisation, vessel access via DUG can be performed through two different techniques: in-plane puncture technique; and out-of-plane technique. For the in-plane puncture technique, the ultrasound plane and the longitudinal needle axis are in the same virtual plane. The in-plane puncture allows continuous visualisation of the needle along its trajectory until it reaches the vessel. In contrast, for the out-of-plane technique, the ultrasound plane and the longitudinal needle axis are not in the same virtual plane (Lamperti 2012). The American College of Emergency Physicians has recommended the longitudinal needle view (i.e. in-plane approach) because it permits the operator to trace the entire path and angle of the needle starting from the entry site at the skin (Kendall 2014).

How the intervention might work

When used for arterial puncture, the different ultrasound modes (i.e. DUA, IUG, and DUG) aim to improve correct identification of the target vessel location; to identify possible cannulation obstacles (e.g. artery obstruction or occlusion); and to avoid adverse events (e.g. inadvertent vein puncture, nerve lesion, blood leaks by multiple unnecessary artery punctures). Additional resources for better artery localisation may be beneficial in some special situations, such as for patients with a high body mass index (BMI), anatomical variations, or arterial obstruction or occlusion; or for critically ill patients and those in need of multiple punctures when palpation and landmarks are insufficient (Kendall 2014; Lamperti 2012). Without direct visualisation, the risk of complications is increased: these complications include bleeding, inadvertent nerve or venous injury, and pseudoaneurysm and puncture failure, among others (AIUM 2013; Soverow 2016).

Regarding first-attempt punctures for radial artery access in adults, low-certainty evidence suggests there is no difference between DUA and palpation; however, success rates of 46% were achieved in small children using this type of access (Gu 2016; Ueda 2013). IUG is coupled to arterial catheterisation to facilitate locating arteries and nearby structures (e.g. nerves, veins). IUG can result in procedures that are safer and faster, have fewer complications, and are more often successful. Then again, because the ultrasound evaluation is not conducted at the same time as the puncture, its real benefits are not clear (Attie 2019; Lamperti 2012).

For arterial access, DUG can reduce possible bleeding and other complications associated with this procedure. For radial and femoral arterial access, Nguyen 2019 reported that DUG increased success rates with shorter procedure times and a reduced number of puncture attempts, and it allowed for fewer difficult accesses or inadvertent venipunctures. However, the clinical effects regarding DUG for all arterial access procedures are still under discussion (Attie 2019; Gu 2016; Lamperti 2012). Although it is more challenging, Lamperti 2012 supports the in-plane technique for all DUG procedures because it is related to higher precision and fewer complications. The longitudinal artery view allows better visualisation of the advancing needle tip, which may reduce perforation of the posterior vessel wall (Kendall 2014). It is recommended that the external diameter of the catheter should

not exceed one-third the internal diameter of the vein to avoid the risk of thrombosis, but similar evidence for arterial access is sparse. Additional benefits of DUG include the ability to change position before puncture and to measure the diameter of the artery during the procedure (Lamperti 2012).

Why it is important to do this review

Vascular access is a frequently performed procedure, with a high possibility of adverse events (e.g. pneumothorax, haemothorax, haematoma, amputation, death), and additional techniques such as ultrasound may be useful for improving outcomes. Arterial catheterisation is an intervention that is commonly performed in several settings, including major surgeries, emergency units, catheterisation laboratories, and ICUs for continuous blood pressure monitoring and arterial blood sampling. Moreover, arterial catheterisation is the main access for endovascular procedures, such as angioplasty and stenting (Sandoval 2017).

Given that the numbers of cardiovascular procedures and intensive antithrombotic therapies are on the rise, complications among patients undergoing endovascular procedures should not be underestimated. Paganin 2018 described a complication rate of almost 9% after puncture, which included minor and major haematomas, as well as stable and unstable bleeding. Therefore, the approaches used to reduce complications at arterial puncture sites may modify the clinical effects. The American Heart Association proposes the radial-first strategy in the USA for patients with acute coronary syndromes and suggests ultrasound guidance, particularly in challenging cases (Mason 2018). For management of coronary disease, various European guidelines recommend radial access as the first choice compared to femoral access but do not mention ultrasound-guided arterial access (Aboyans 2018; Ibanez 2018; NICE 2013). Other recent guidelines regarding management of PAD only superficially address the ultrasound-guided resource for retrograde artery access or do not mention it at all (Conte 2019; NICE 2014; NICE 2018).

Ultrasonography is a widely available method; its use for arterial access guidance seems to improve the first-attempt success rate while reducing the numbers of skin perforations, catheters used, and attempts targeting the vessels (Hansen 2014). However, DUG still is not used frequently (AIUM 2013; Soverow 2016). Soverow 2016 showed that only 13% of interventional cardiologists routinely used ultrasound for arterial access. Although other Cochrane Reviews have shown the benefits of performing venous access in patients of all ages and arterial access in paediatric patients, ultrasound guidance for arterial access in adults remains under debate (Attie 2019). In this setting, a high-quality systematic review is mandatory to provide robust evidence.

OBJECTIVES

To assess the effects of ultrasound guidance for arterial (other than femoral) catheterisation in adults.

METHODS

Criteria for considering studies for this review

Types of studies

We included all randomised controlled trials (RCTs) of parallel (e.g. cluster, individual) or cross-over design. We used only data from the first phase of cross-over studies to avoid the risk of carry-over effects, as described in Section 23.2.4 of the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2019). We included studies reported as full text, those published as abstract only, and unpublished data. We did not consider quasi-randomised trials (i.e. studies in which participants are allocated to intervention groups based on methods that are not truly random, such as hospital number or date of birth).

Types of participants

We included adults (people ≥ 18 years of age) of either gender who require any form of arterial access (other than femoral) for diagnostic or therapeutic purposes. We considered all related arterial procedures such as arterial catheterisation for cardiac angiography, percutaneous coronary intervention (PCI), arterial blood sampling, or blood pressure monitoring. Paediatric patients and adults who underwent femoral arterial puncture are not relevant for our review, and we did not include them, to avoid overlap with other Cochrane Reviews: "Ultrasound-guided versus anatomic landmark-guided percutaneous femoral artery access" and "Ultrasound-guided arterial cannulation for paediatrics" (Aouad-Maroun 2016; Strauss 2021).

If we found studies with mixed populations, and only a subset of participants met our inclusion criteria, we attempted to obtain data for the subgroup of interest from the trialists so we could include the study. For studies with mixed populations for which we cannot get data for the subgroup of interest but at least 50% of the study population is of interest, we planned to include all participants in our analysis. Moreover, we planned to explore the effect of this decision in a sensitivity analysis. Studies in which less than 50% of the population is of interest and data for the subgroup of interest are not available were excluded.

Types of interventions

We considered all types of Seldinger techniques for artery access, such as anterior wall puncture, artery transfixation, 'catheter-over-needle', and other special devices, as the baseline eligible technique for arterial catheterisation. We evaluated possible clinical implications of these differences in the Subgroup analysis and investigation of heterogeneity section.

Many techniques for arterial cannulation guidance in adults have been described, such as palpation and landmarks, two-dimensional ultrasound guidance, and Doppler ultrasound. We considered two-dimensional ultrasound guidance as our intervention of interest. We therefore included trials comparing ultrasound guidance, B-mode, in-plane, or out-of-plane, with vessels accessed in a longitudinal or transversal way versus any other techniques for arterial puncture.

The most commonly accessed site for arterial cannulation in adults within our inclusion criteria is the radial artery, but we considered all other possible sites, such as axillary, brachial, and tibial arteries, each in a separate comparison. We did not include studies regarding femoral access to avoid overlap with the Cochrane Review entitled "Ultrasound-guided versus anatomic landmark-guided percutaneous femoral artery access" (Strauss 2021).

Possible comparisons are as follows.

- B-mode ultrasound guidance versus palpation and landmarks.
- B-mode ultrasound guidance versus Doppler auditory ultrasound assistance.
- Direct ultrasound guidance (real-time) versus indirect ultrasound guidance.
- B-mode ultrasound versus near-infrared laser guidance.
- B-mode ultrasound versus modified B-mode ultrasound.
- In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound.
- Doppler auditory ultrasound assistance versus palpation and landmarks.
- Dynamic out-of-plane B-mode ultrasound versus static out-of-plane B-mode ultrasound.
- Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound.
- Any combination of the above treatments versus any other combination, with or without placebo (sham procedure).

Types of outcome measures

Reporting one or more of the outcomes listed here in the trial was not an inclusion criterion for this review. When a published report did not appear to report one of these outcomes, we accessed the trial protocol and contacted the trial authors to ascertain whether outcomes were measured but not reported. We included in the review, as part of the narrative, relevant trials that measured these outcomes but did not report the data at all, or did not report them in a usable format.

Economic costs were evaluated indirectly by outcomes such as 'First-attempt success rate' and 'Time needed for successful procedure'. Because this is not a cost-effectiveness review, we planned to treat data regarding direct costs in the Discussion section in a narrative form, if these data were available.

We presented outcomes at two different time points following the start of the intervention, if data were available. Our time point of primary interest is early; we therefore intend to produce related 'Summary of findings' tables only for this time point, but we reported long-term outcomes at the longest possible time of follow-up.

- Early outcomes (within 30 days after intervention).
- Long-term outcomes (more than 30 days after intervention).

Primary outcomes

Primary outcomes include the following, ordered according to priority.

- First-attempt success rate (i.e. number of participants for whom the proposed method of catheterisation was successful on the first attempt).
- Pseudoaneurysm: total number of perioperative and postoperative pseudoaneurysms.

Secondary outcomes

Secondary outcomes include the following, ordered according to priority.

- Overall success rate (i.e. number of participants for whom the proposed method of catheterisation was successful).
- Time, in minutes, needed for a successful procedure. We will consider the successful procedure as complete catheter placement or complete blood sample collection.
- Major haematoma, defined as that requiring an intervention (e.g. open surgical or percutaneous drainage) or prolonging duration of hospital stay. We will consider the total number of perioperative and postoperative major haematomas.
- Adverse events. We will consider all possible adverse events separately, as individual outcomes, such as minor haematoma formation defined as neither requiring an intervention (e.g. open surgical or percutaneous drainage) nor prolonging duration of hospital stay; pain; local infection; events requiring prolonged hospitalisation such as artery thrombosis, artery embolism, nerve injury, and amputation; life-threatening events; fatal events.
- Quality of life (QoL): participants' subjective perception of improvement (yes or no) as reported by study authors, or using any validated scoring system such as the Short Form-36 Health Survey (SF-36) (Ware 1992).

Search methods for identification of studies

Electronic searches

We identified trials through systematic searches of the following bibliographic databases on 21 May 2021.

- Cochrane Central Register of Controlled Trials (CENTRAL; 2021, Issue 4 of 12), in the Cochrane Library.
- Epub Ahead of Print, In-Process & Other Non-Indexed Citations, MEDLINE Daily and MEDLINE (Ovid, 1946 to 20 May 2021).
- Embase (Ovid, 1980 to 2021 week 19).
- Cumulative Index to Nursing and Allied Health Literature (CINAHL) (EBSCOHost, 1937 to 21 May 2021).
- Latin American and Caribbean Health Sciences Literature database (LILACS) (Bireme, 1982 to 21 May 2021).
- Indice Bibliográfico Español de Ciencias de la Salud (IBECS, via Virtual Health Library; 2011 to 16 June 2021) (searched 16 June 2021).

We adapted the preliminary search strategy for MEDLINE (Ovid) (Appendix 2) for use in the other databases. We applied the Cochrane sensitivity-maximising RCT filter to MEDLINE (Ovid) and adaptations of it to the other databases, except CENTRAL (Lefebvre 2019).

We also conducted a search of ClinicalTrials.gov (www.ClinicalTrials.gov) and the World Health Organization (WHO) International Clinical Trials Registry Platform (ICTRP) Search Portal (ictrptest.azurewebsites.net/Default.aspx) for ongoing or unpublished trials on 16 June 2021.

We searched all databases from their inception to the present, and we imposed no restriction on language of publication nor on publication status. We considered adverse effects described in included studies only.

Searching other resources

We checked reference lists of all included studies and any identified relevant systematic reviews for additional references to trials. We examined any relevant retraction statements and errata for included studies. We contacted the authors of included trials for

any possible unpublished data. Furthermore, we contacted field specialists and searched medical ultrasound company websites (Canon, Fujifilm, GE Healthcare, Mindray, Mobissom, Philips, Samsung, Siemens) to enquire about relevant ongoing and unpublished studies (16 June 2021).

Data collection and analysis

Selection of studies

Two review authors (RLGF, CDQF) independently screened titles and abstracts of all potential studies identified as a result of the search and coded them as 'retrieve' (eligible or potentially eligible/unclear) or 'do not retrieve', using the Covidence tool. If there were any disagreements, we asked a third review author to arbitrate (LCUN). We retrieved the full-text study reports/publications, and two review authors (RLGF, CDQF) independently screened the full text, identified studies for inclusion, and identified ineligible studies and recorded reasons for their exclusion. We resolved any disagreement through discussion, or, if required, we consulted a third person (LCUN). We identified and excluded duplicates and collated multiple reports of the same study, so that each study rather than each report is the unit of interest in the review. We recorded the selection process in sufficient detail to complete a PRISMA flow diagram and Characteristics of excluded studies table (Liberati 2009).

Data extraction and management

We used a data collection form, which has been piloted on at least one study in the review, to record study characteristics and outcome data. One review author (RLGF) extracted the following study characteristics from included studies.

- Methods: study design, total duration of study, number of study centres and locations, study setting, and date of study.
- Participants: N randomised, N lost to follow-up/withdrawn, N analysed, N of interest, mean age, age range, gender, severity of condition, comorbidities, body mass index (BMI), artery of interest characteristics (e.g. access site, diameter), inclusion criteria, and exclusion criteria.
- Interventions: intervention and comparison characteristics, level of experience of the person carrying out the procedure, concomitant medications, and excluded medications.
- Outcomes: primary and secondary outcomes specified and collected, and time points reported.
- Notes: funding for trial, and notable conflicts of interest of trial authors.

Two review authors (RLGF, CDQF) independently extracted outcome data from included studies. We resolved disagreements by reaching consensus or by involving a third person (LCUN). One review author (RLGF) transferred data into the Review Manager 5 (RevMan 5) file (Review Manager 2014). We double-checked that data were entered correctly by comparing data presented in the systematic review with data recorded on the data extraction form. A second review author (CDQF) spot-checked study characteristics for accuracy against the trial report.

When information regarding any of the above was unclear, we attempted to contact authors of the original reports to obtain further details. When data were reported only in graphs, we extracted data of interest such as mean, standard deviation (SD), or standard error (SE) using software such as graphreader.com and RevMan. We identified translators for all foreign languages with which we were unfamiliar (e.g. Chinese, Japanese).

Assessment of risk of bias in included studies

Two review authors (RLGF, CDQF) independently assessed risk of bias for each study using the criteria outlined in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2017). We resolved any disagreements by discussion or by consultation with another review author (LCUN). We assessed risk of bias according to the following domains.

- Random sequence generation.
- Allocation concealment.
- Blinding of participants and personnel.
- Blinding of outcome assessment.
- Incomplete outcome data.
- Selective outcome reporting.
- Other bias.

For cluster-randomised trials, we planned to consider particular biases as recommended in Section 8.15.1.1 of the *Cochrane Handbook for Systematic Reviews of Interventions*: (1) recruitment bias; (2) baseline imbalance; (3) loss of clusters; (4) incorrect analysis; and (5) comparability with individually randomised trials (Higgins 2017). We graded each potential source of bias as high, low, or unclear and provided a quote from the study report, together with a justification for our judgement, in 'Risk of bias' tables, in the Characteristics of included studies section. We summarised risk of bias judgements across different studies for each of the domains listed. When information on risk of bias relates to unpublished data or correspondence with a trialist, we noted this in the 'Risk of bias' table.

When considering treatment effects, we took into account risk of bias for studies that contributed to that outcome. When the protocol text or the trial registry entry was not available, we judged the 'selective outcome reporting' domain by comparing outcomes planned in the methods section (specified) with those described in the results section (collected) of the available report (Higgins 2017).

Assessment of bias in conducting the systematic review

We conducted the review according to this published protocol and report any deviations from it in the Differences between protocol and review section of the systematic review (Flumignan 2020).

Measures of treatment effect

We analysed dichotomous data as risk ratios (RRs) with 95% confidence intervals (CIs), and continuous data as mean differences (MD) with the same scale, and as standardised mean differences (SMDs) with different scales, with 95% CIs. We entered data presented as a scale with a consistent direction of effect.

We estimated the MD using the method reported by Wan 2014 to convert median and interquartile range (IQR) into MD and CI. When this was not possible, we narratively described skewed data reported as medians and interquartile ranges.

We calculated the number needed to treat (NNT) for outcomes with direct implications for practice using RevMan 5 software (Review Manager 2014). As recommended by the *Cochrane*

Handbook for Systematic Reviews of Interventions, we expressed the NNT as 'number needed to treat for an additional beneficial outcome' (NNTB) and as 'number needed to treat for an additional harmful outcome' (NNTH) to indicate direction of effect (Schünemann 2019).

Unit of analysis issues

Individuals were our unit of analysis. If trials included multi-arm interventions, we considered only the arms relevant to the scope of our review.

Cross-over trials

When we identified any cross-over RCTs, we used only data from the first phase of these studies to avoid the risk of carry-over effects, as described in Section 23.2.4 of the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2019).

Cluster-randomised trials

We planned to include cluster-randomised trials in the analyses along with individually randomised trials. We planned to adjust their sample sizes using the methods described in Section 23.1.5 of the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2019), using an estimate of the intra-cluster correlation coefficient (ICC) derived from the trial (if possible), from a similar trial, or from a study of a similar population. If we had used ICCs from other sources, we planned to report this and to conduct sensitivity analyses to investigate effects of variations in the ICC. If we had identified both cluster-randomised trials and individually randomised trials, we planned to synthesise the relevant information. We planned to consider it reasonable to combine the results from both types of trials if we noted little heterogeneity between study designs, and if we considered interaction between effects of intervention and choice of randomisation unit to be unlikely. We also planned to acknowledge heterogeneity in the randomisation unit and to perform a sensitivity analysis to investigate effects of the randomisation unit.

Dealing with missing data

We contacted investigators or study sponsors to verify key study characteristics and to obtain missing numerical outcome data when possible (e.g. when a study was identified as abstract only). When possible, we used the RevMan 5 calculator to calculate missing standard deviations using other data from the trial, such as CIs. We estimated the MD using the method reported by Wan 2014 to convert median and IQR into MD and CI. When data were reported only in graphs, we extracted data of interest such as mean, standard deviation (SD), or standard error (SE) using software such as graphreader.com and RevMan. We identified translators for all foreign languages with which we were unfamiliar (e.g. Chinese, Japanese). When this was not possible, and missing data were thought to introduce serious bias, we planned to explore the impact of including such studies in the overall assessment of results by performing a sensitivity analysis. For all outcomes, we followed intention-to-treat (ITT) principles to the greatest degree possible, that is, we analysed participants in their randomised group regardless of what intervention they actually received. We used available case data for the denominator if ITT data were not available.

Assessment of heterogeneity

We inspected forest plots visually to consider the direction and magnitude of effects and the degree of overlap between confidence intervals. We used the I^2 statistic to measure heterogeneity among the trials in each analysis, but we acknowledge that there was substantial uncertainty in the value of I^2 when only a small number of studies were included; we therefore also considered the P value from the Chi^2 test. When we identified substantial heterogeneity, we reported this and explored possible causes by conducting prespecified subgroup analysis.

As strict thresholds for interpretation of I^2 are not recommended, we followed the rough guide to interpretation provided in the *Cochrane Handbook for Systematic Reviews of Interventions* (Deeks 2019).

- 0% to 40%: might not be important.
- 30% to 60%: may represent moderate heterogeneity.
- 50% to 90%: may represent substantial heterogeneity.
- 75% to 100%: considerable heterogeneity.

When I^2 lies in an area of overlap between two categories (e.g. between 50% and 60%), we considered differences in participants and interventions among trials contributing data to the analysis (Deeks 2019).

Assessment of reporting biases

When we were able to pool more than 10 trials, we created and examined a funnel plot to explore possible small-study biases for all available outcomes.

We used R Studio software, version 1.4.1106, for additional tests when we suspected reporting bias (R Studio). First, we re-created all meta-analyses with 10 or more included studies using the package 'meta' version 4.18-0 with the 'metabin' function for dichotomous data and the 'metacont' function for continuous data. Next, we generated funnel plots with the 'funnel' function and used Egger's test to test graph asymmetry with the 'metabias' function, considering $P < 0.05$ a statistically significant value (Egger 1997; Page 2021). Finally, we used the trim-and-fill method with the 'trimfill' function to estimate and adjust for numbers and outcomes of missing studies in funnel graphs that showed asymmetry (Duval 2000; Page 2021).

Data synthesis

We synthesised data using Review Manager 5 (Review Manager 2014). We reported data narratively if it was not appropriate to combine them in a meta-analysis. We undertook meta-analyses only when this was meaningful (i.e. when treatments, participants, and the underlying clinical question were similar enough for pooling to make sense).

We used a fixed-effect model for meta-analysis when included studies were homogenous (considering populations, interventions, comparators, and outcomes characteristics). We used a random-effects model when we identified at least substantial heterogeneity, or when we noted significant clinical differences among included trials regarding patients and interventions (Deeks 2019).

We addressed all outcomes in order as listed in the Types of outcome measures section in the Results portion of the review

under the heading Effects of interventions. In addition, we included a summary of main outcomes in the 'Summary of findings' table. We included results of individual studies and any statistical summary of these in Data and analyses tables.

Subgroup analysis and investigation of heterogeneity

We planned to carry out the following subgroup analyses.

Intervention characteristics

- Experienced versus inexperienced (including residents and fellows) operators
- Additional ultrasound technique (e.g. colour mode, Power Doppler, contrast-enhanced ultrasound)
- Seldinger technique or any possible variation (e.g. anterior wall puncture, artery transfixation, 'catheter-over-needle' puncture, hollow needle puncture)
- Diameter of used devices (e.g. ≤ 20 French versus > 20 French)
- Diagnostic versus therapeutics purpose
- Anterograde versus retrograde access

Participant characteristics

- Age (i.e. young adults (18 years to 24 years), adults (25 years to 64 years), and seniors (65 years and over))
- Gender
- BMI according to Table 1 (WHO 2000)
- Race
- Comorbidities (e.g. critically ill subjects, vasopressors required, elective procedures)
- Vessel diameter

We considered type of vessels in different comparisons. We did not, therefore, consider the different vessels (e.g. radial arteries, brachial arteries) in subgroup analysis.

Because we planned to explore possible causes of substantial heterogeneity through subgroup analysis (Assessment of heterogeneity), we used all outcomes in subgroup analyses if at least 10 included studies contributed to the meta-analysis. A unique possible subgroup analysis was planned to explore the operator's experience (experienced versus inexperienced) for one of the included comparisons (B-mode ultrasound guidance versus palpation and landmarks in the radial artery). When trial authors did not report the level of experience of operators, we were conservative and included this study in the inexperienced operators' subgroup (e.g. Goswami 2020).

We used the formal test for subgroup differences in Review Manager 5 (Review Manager 2014), and we based our interpretation on this.

Sensitivity analysis

We planned to carry out the following sensitivity analyses, to test whether key methodological factors or decisions have affected the main result. These were grouped according to study design (individual, cross-over, or cluster).

- We planned to include only studies with low risk of bias. We considered the overall risk of bias of an included study as low if we noted no high-risk judgement in all four main domains (i.e. random sequence, allocation concealment, incomplete outcome data, and selective reporting).
- We planned to examine both fixed-effect model and random-effects model meta-analyses, and we planned to explore differences between the two estimates. However, when we grouped two or more trials, a random-effects analysis was more suitable due to participant differences.
- We planned to explore the decision to include all participants when at least 50% were of interest in a trial with a mixed population. However, all subgroup of interest participants for our analysis were available, and we did not include any mixed population study in our review.
- We planned to explore the impact of missing data. When we identified studies with missing data that are unobtainable, we repeated analyses by excluding these studies to determine their impact on the primary analyses. However, this was not necessary with the available data.

We also planned to carry out sensitivity analyses while considering cross-over and cluster-RCTs. We planned to investigate effects of variation in the ICC, and we planned to acknowledge heterogeneity in the randomisation unit and to perform a sensitivity analysis to investigate effects of the randomisation unit. We presented these results and compared them with the overall findings.

Summary of findings and assessment of the certainty of the evidence

We created a 'Summary of findings' table for the early time point using the following outcomes: (1) first-attempt success rate; (2) pseudoaneurysm; (3) overall success rate; (4) time needed for a successful procedure; (5) major haematoma; (6) pain; and (7) QoL. We used the five GRADE considerations (study limitations; consistency of effect; imprecision; indirectness; and publication bias) to assess the quality of a body of evidence as it relates to studies that contributed data to the meta-analyses for prespecified outcomes. We used methods and recommendations described in Chapter 12 of the *Cochrane Handbook for Systematic Reviews of Interventions* (Schünemann 2019), along with GRADEpro software (GRADEpro GDT 2015). Each comparison (e.g. B-mode ultrasound guidance versus landmarks; B-mode ultrasound guidance versus palpation; B-mode ultrasound guidance versus Doppler ultrasound guidance; direct ultrasound guidance (real-time) versus indirect ultrasound guidance; any combination of the above treatments versus any other combination, with or without placebo) had a separate 'Summary of findings' table. We justified all decisions to downgrade the quality of studies using footnotes, and we made comments to aid the reader's understanding of the review when necessary.

Judgements about evidence quality were made by two review authors (RLGF, CDQF) working independently, with disagreements resolved by discussion or by consultation with a third review author (LCUN). We justified, documented, and incorporated judgements into reporting of results for each outcome.

We extracted study data, formatted our comparisons in data tables, and prepared a 'Summary of findings' table before writing the results and conclusions of our review.

RESULTS

Description of studies

We have presented the details of studies included in this review in the Characteristics of included studies table, as well as reasons for exclusion in the Characteristics of excluded studies table. We have detailed the status of ongoing trials in the Characteristics of ongoing studies section.

Results of the search

We completed the search in June 2021. We retrieved a total of 12,819 records from electronic databases and identified 197 additional records through other sources. After we excluded 1157 duplicate records, we screened 11,859 unique records. We considered a total of 11,667 records not relevant at this stage and we selected 192 records (147 studies) for full-text reading. We included 48 studies (92 records). Two studies that were included had the same clinical trial registration number but different characteristics (Wang 2017 Wang 2019). Participants were enrolled in separate periods, without any overlap: 1 June 2017 to 27 October 2017 (Wang 2017), and 1 July 2018 to 24 November 2018 (Wang 2019), which avoided double-counting. Besides participants, interventions and comparisons between Wang 2017 and Wang 2019 are significantly different. Therefore, we treated them as separate studies. We excluded 14 studies (15 records) with reasons and assessed another 64 as not relevant at this stage (see Characteristics of excluded studies). Twenty trials are ongoing (see Characteristics of ongoing studies), and one study was tagged as 'awaiting classification' due to the fact that essential information about the artery of interest was lacking and our attempts to contact trial authors were unsuccessful (Flores-Arévalo 2016). The flowchart for results of the search is presented in Figure 1.

Figure 1. Study flow diagram.

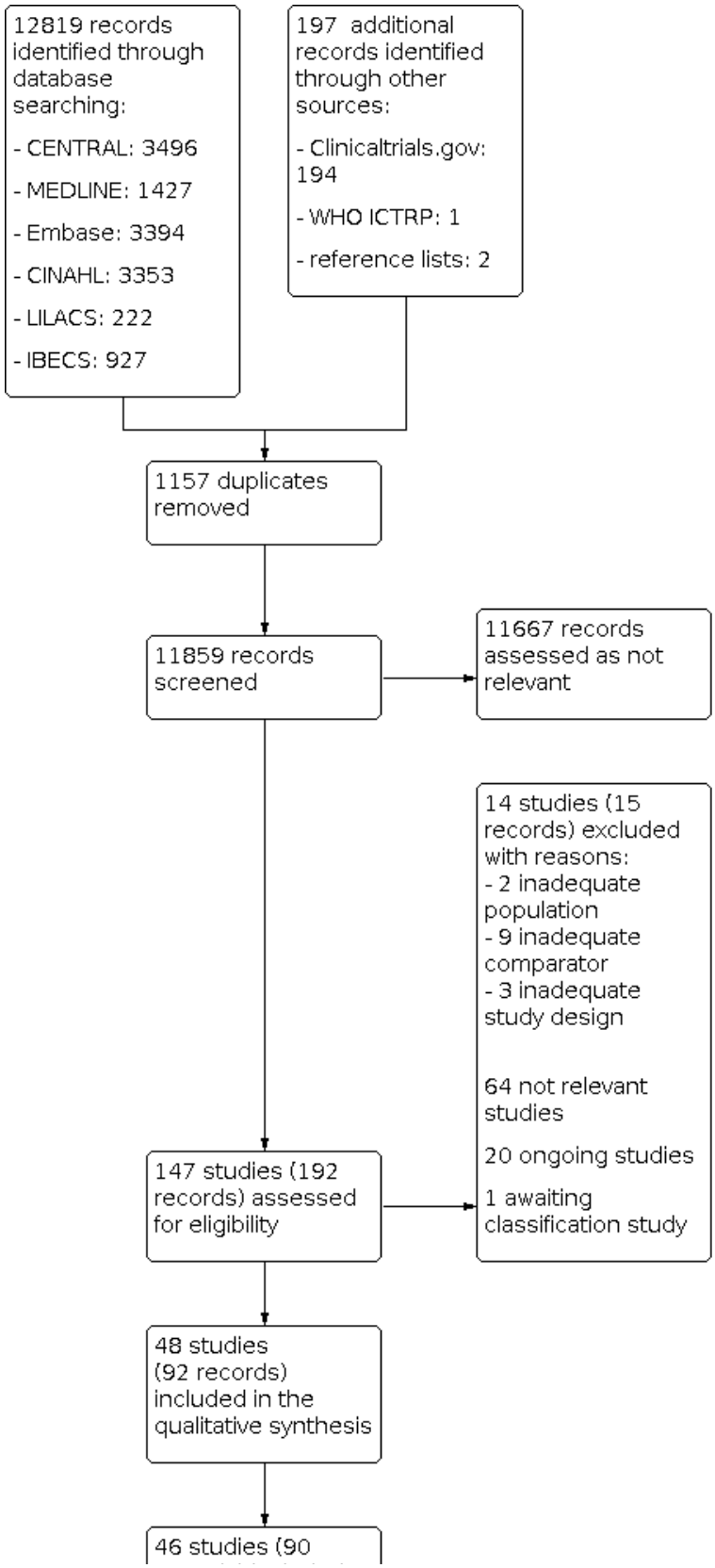
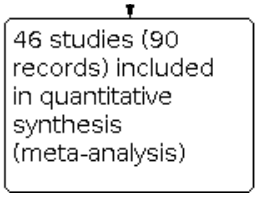


Figure 1. (Continued)



Included studies

The 48 studies (7997 participants) tested at least one of the following interventions: (1) palpation and landmarks; (2) Doppler auditory ultrasound assistance (DUA); or (3) direct ultrasound guidance (DUG) with B-mode or any other modified ultrasound technique for arterial (other than femoral) catheterisation in adults. These studies analysed ultrasound guidance in three different arteries (axillary, dorsalis pedis, and radial) and provided data for ten different comparisons.

Two trials did not report any data that we could use in our analysis (Edanaga 2012; Fujita 2012). Fujita 2012 is an abstract of events and provided no data for numerical analysis. Edanaga 2012 was evaluated in full text after translation from Japanese; investigators did not evaluate any outcomes of interest for our review.

For details of the included studies, see the Characteristics of included studies table.

Design

We classified all 48 included studies as randomised trials, but 21 of them did not provide details of the method used for randomisation (Abdalla 2017; Ammar 2017; Berk 2013; Burad 2017; Cao 2018; Edanaga 2012; Fujita 2012; Killu 2011; Laursen 2015; Nasreen 2016; NCT01663779; Nguyen 2019; Osuda 2020; Quan 2014; Rose 2018; Seyhan 2021; Seto 2015; Tada 2003; Yu 2019; Zaremski 2013; Zhefeng 2019).

Hansen 2014 and Gopalasingam 2014 are cross-over RCTs; all of the other 46 included studies are individual parallel RCTs. We did not identify any cluster-RCT.

No study was triple-blinded because the nature of the intervention did not allow blinding of personnel. Eight were single-blinded because the outcome assessment was blinded (Bai 2020; Cao 2020; Gibbons 2020; Kiberenge 2018; Kim 2021b; Nam 2020; Nguyen 2019; Ueda 2015), 17 studies were not blinded (Abdalla 2017; Anand 2019; Bobbia 2013; Burad 2017; Gopalasingam 2014; Grandpierre 2019; Khan 2018; Killu 2011; Li 2016; NCT01663779; Peters 2015; Quan 2014; Rajasekar 2021; Seto 2015; Seyhan 2021; Shiver 2006; Zhefeng 2019), and all of the other 25 studies were unclear about blinding.

Settings

Forty-seven included studies were conducted in 17 different countries: 10 in China (Bai 2020; Cao 2018; Cao 2020; Li 2016; Quan 2014; Wang 2017; Wang 2019; Yu 2019; Zeng 2020; Zhefeng 2019), 8 in the USA (Gibbons 2020; Kiberenge 2018; Killu 2011; NCT01663779; Seto 2015; Shiver 2006; Ueda 2015; Yeap 2019), 4 in Japan (Edanaga 2012; Fujita 2012; Osuda 2020; Tada 2003), 3 in Denmark (Gopalasingam 2014; Hansen 2014; Laursen 2015), 5 in India (Anand 2019; Goswami 2020; Khan 2018; Rajasekar 2021; Sethi 2017), 2 in Korea (Kim 2021a; Kim 2021b), 2 in France (Bobbia 2013; Grandpierre 2019), 2 in Pakistan (Ammar 2017; Nasreen 2016), 2 in Turkey (Berk 2013; Seyhan 2021), 2 in Oman (Arora 2021; Burad 2017), and 1 each in Australia (Nguyen 2019), Canada (Peters 2015), Egypt (Abdalla 2017), Israel (Levin 2003), Korea (Nam 2020), Thailand (Tangwiwat 2016), and Switzerland (Zaremski 2013). All these 47 included studies were conducted in hospital settings. Rose 2018 did not provide data on setting and country in which it was carried out.

Participants

The mean age of participants included in the 48 trials ranged from 41 to 73 years. Some trials did not report the age of participants. All included studies considered both men and women for enrolment.

Sample size

The number of participants included in each of the 48 studies ranged from 33 in Killu 2011 to 749 in Ueda 2015. However, most of the studies had small sample sizes.

Funding

Twenty-one trials did not report their funding sources (Ammar 2017; Arora 2021; Berk 2013; Bobbia 2013; Burad 2017; Edanaga 2012; Fujita 2012; Goswami 2020; Khan 2018; Killu 2011; Levin 2003; Nam 2020; Nasreen 2016; NCT01663779; Nguyen 2019; Osuda 2020; Rajasekar 2021; Rose 2018; Sethi 2017; Shiver 2006; Tada 2003). Twelve trials reported that they had no funding sources (Abdalla 2017; Anand 2019; Bai 2020; Cao 2020; Gibbons 2020; Kim 2021b; Quan 2014; Seto 2015; Seyhan 2021; Ueda 2015; Yeap 2019; Zeng 2020). The remaining fifteen trials were self-funded or were funded by government grants or host hospitals and universities.

Conflicts of interest

Most of the trials stated they had no conflicts of interest (Abdalla 2017; Anand 2019; Bai 2020; Berk 2013; Burad 2017; Cao 2020; Edanaga 2012; Gopalasingam 2014; Hansen 2014; Kiberenge 2018; Killu 2011; Kim 2021a; Kim 2021b; Li 2016; Nam 2020; Nguyen 2019; Osuda 2020; Peters 2015; Quan 2014; Rajasekar 2021; Seyhan 2021; Tangwiwat 2016; Ueda 2015; Wang 2017; Wang 2019; Yeap 2019; Zeng 2020; Zhefeng 2019); 3 studies declared a potential conflict of interest (Grandpierre 2019; Seto 2015; Zaremski 2013); and the remaining trials did not mention conflicts of interest (Ammar 2017; Arora 2021; Bobbia 2013; Cao 2018; Fujita 2012; Gibbons 2020; Goswami 2020; Khan 2018; Laursen 2015; Levin 2003; Nasreen 2016; NCT01663779; Rose 2018; Sethi 2017; Shiver 2006; Tada 2003; Yu 2019).

Interventions

Thirty-seven included studies tested two different types of ultrasound guidance for arterial (other than femoral) catheterisation: DUA, or DUG with B-mode or any other modified ultrasound technique.

DUA

Ueda 2015 randomised participants for one of these three interventions for radial artery catheterisation: DUA (n = 244), B-mode ultrasound guidance (n = 249), or palpation and landmarks (n = 256). Therefore, Ueda 2015 provided data for three different comparisons, and interventions were performed by inexperienced investigators for all methods. Tada 2003 compared DUA versus palpation in 166 participants. None of the other included studies provided data about DUA.

DUG

Forty-six included studies provided data comparing B-mode ultrasound guidance versus palpation and landmarks, DUA, modified B-mode ultrasound guidance, or near-infrared laser guidance for axillary, dorsalis pedis, or radial artery catheterisation.

Killu 2011 compared B-mode ultrasound versus palpation and landmarks for axillary artery catheterisation, and interventions were performed by inexperienced (medical residents) and experienced (fellow) personnel.

Anand 2019 compared B-mode ultrasound versus palpation and landmarks for dorsalis pedis artery catheterisation, and interventions were performed by a single experienced investigator.

Twenty-eight included studies compared B-mode ultrasound versus palpation and landmarks for radial artery catheterisation. Only experienced investigators performed the interventions in 18 studies (Ammar 2017; Burad 2017; Cao 2018; Grandpierre 2019; Hansen 2014; Khan 2018; Laursen 2015; Li 2016; Nasreen 2016; Nguyen 2019; Peters 2015; Rajasekar 2021; Seto 2015; Seyhan 2021; Wang 2017; Wang 2019; Yu 2019; Zaremski 2013), and inexperienced investigators performed the interventions in another 10 studies (Gibbons 2020; Gopalasingam 2014; Goswami 2020; Kim 2021b; Levin 2003; Rose 2018; Shiver 2006; Tangwiwat 2016; Ueda 2015; Yeap 2019). Kiberenge 2018 provided data about experienced and inexperienced operators.

Ueda 2015 also provided data about the comparisons 'B-mode ultrasound versus DUA' and 'DUA versus palpation and landmarks' for radial artery catheterisation, and interventions were performed by inexperienced investigators for all methods. Tada 2003 compared DUA versus palpation and landmarks for radial artery catheterisation, and interventions were performed by an inexperienced investigator for the DUA method.

Osuda 2020 compared B-mode ultrasound versus near-infrared laser guidance for radial artery catheterisation, and interventions were performed by inexperienced investigators for both methods.

Zhefeng 2019 compared B-mode ultrasound versus modified B-mode ultrasound (i.e. with addition of a developing line for radial artery catheterisation and interventions performed by inexperienced investigators for both methods). Kim 2021a compared B-mode ultrasound versus modified B-mode ultrasound (i.e. with addition of electromagnetic guidance for radial artery catheterisation and interventions performed solely by a unique experienced investigator).

Nine studies compared in-plane B-mode ultrasound versus out-of-plane B-mode ultrasound for radial artery catheterisation. Interventions were performed by experienced investigators for both methods in seven studies (Arora 2021; Berk 2013; Nam 2020; Quan 2014; Rajasekar 2021; Sethi 2017; Wang 2019), and by an inexperienced operator in Cao 2020. Abdalla 2017 did not provide details about the level of experience of operators.

All included studies assessed data from arterial catheterisation for diagnostic purposes mainly (pressure monitoring or completion of blood tests). Only three included studies included participants for therapeutic purposes in the radial artery catheterisation with different prevalences (Nguyen 2019 = 22.5% for PCI, Seto 2015 = 19.4% for PCI, Zaremski 2013 = PCI % not detailed).

Outcomes

In most of the studies included in this review, outcomes were similar, and study authors provided data for all relevant outcomes for this review. The main outcome measures were overall success rate, first-attempt success rate, and time needed for a successful procedure. These outcomes were assessed at different time periods, ranging from 5 minutes to 30 days after the start of the intervention, and major included studies evaluated data up to the end of the procedure. Therefore, all included studies reported data only for the early time point (at 30 days or less after intervention).

Primary outcomes

Forty studies reported our primary outcome 'first-attempt success rate' (Abdalla 2017; Ammar 2017; Anand 2019; Arora 2021; Bai 2020; Burad 2017; Cao 2018; Cao 2020; Gibbons 2020; Gopalasingam 2014; Grandpierre 2019; Hansen 2014; Khan 2018; Kiberenge 2018; Kim 2021a; Kim 2021b; Laursen 2015; Levin 2003; Li 2016; Nam 2020; Nasreen 2016; NCT01663779; Nguyen 2019; Osuda 2020; Peters 2015; Quan 2014; Rajasekar 2021; Sethi 2017; Seto 2015; Seyhan 2021; Shiver 2006; Tada 2003; Tangwiwat 2016; Ueda 2015; Wang 2017; Wang 2019; Yu 2019; Zaremski 2013; Zeng 2020; Zhefeng 2019).

Only Nguyen 2019 reported pseudoaneurysm.

Secondary outcomes

Forty-one studies reported overall success rate (Abdalla 2017; Ammar 2017; Anand 2019; Arora 2021; Bai 2020; Bobbia 2013; Burad 2017; Cao 2018; Cao 2020; Gibbons 2020; Gopalasingam 2014; Goswami 2020; Grandpierre 2019; Hansen 2014; Kiberenge 2018; Killu 2011; Kim 2021a; Kim 2021b; Levin 2003; Li 2016; Nam 2020; Nasreen 2016; Nguyen 2019; Osuda 2020; Peters 2015; Quan 2014; Rajasekar 2021; Rose 2018; Sethi 2017; Seto 2015; Seyhan 2021; Shiver 2006; Tada 2003; Tangwiwat 2016; Ueda 2015; Wang 2017; Wang 2019; Yeap 2019; Yu 2019; Zaremski 2013; Zhefeng 2019).

Forty studies reported time needed for a successful procedure (Abdalla 2017; Ammar 2017; Anand 2019; Arora 2021; Bai 2020; Berk 2013; Bobbia 2013; Burad 2017; Cao 2018; Cao 2020; Gibbons 2020; Gopalasingam 2014; Grandpierre 2019; Hansen 2014; Kiberenge 2018; Killu 2011; Kim 2021a; Kim 2021b; Laursen 2015; Levin 2003; Li 2016; Nam 2020; Nasreen 2016; Nguyen 2019; Osuda 2020; Peters 2015; Quan 2014; Rajasekar 2021; Sethi 2017; Seto 2015; Shiver 2006; Tangwiwat 2016; Ueda 2015; Wang 2017; Wang 2019; Yeap 2019; Yu 2019; Zaremski 2013; Zeng 2020; Zhefeng 2019).

Twenty-six studies reported major haematomas (Abdalla 2017; Arora 2021; Berk 2013; Cao 2018; Cao 2020; Gibbons 2020; Goswami 2020; Killu 2011; Kim 2021a; Kim 2021b; Li 2016; Nam 2020; Nasreen 2016; NCT01663779; Nguyen 2019; Peters 2015; Quan 2014;

Rajasekar 2021; Sethi 2017; Shiver 2006; Tangwiwat 2016; Wang 2017; Wang 2019; Yu 2019; Zaremski 2013; Zhefeng 2019).

Thirty studies reported adverse events (Abdalla 2017; Arora 2021; Bai 2020; Berk 2013; Bobbia 2013; Cao 2018; Cao 2020; Gibbons 2020; Goswami 2020; Grandpierre 2019; Hansen 2014; Khan 2018; Killu 2011; Kim 2021a; Kim 2021b; Li 2016; Nam 2020; NCT01663779; Nguyen 2019; Quan 2014; Rajasekar 2021; Sethi 2017; Seto 2015; Ueda 2015; Wang 2017; Wang 2019; Yu 2019; Zaremski 2013; Zeng 2020; Zhefeng 2019).

Only Bobbia 2013 reported quality of life (QoL) by a patient satisfaction scale.

Excluded studies

We excluded 14 studies for at least one reason (Characteristics of excluded studies). Two studies evaluated an inadequate population (i.e. paediatric participants) or femoral access (Anantasit 2017; NCT03537118). Nine studies used inadequate comparators (i.e. ultrasound guidance was used without differences for all participants, or differences between groups did not relate to ultrasound guidance) (Cronin 1986; CTRI/2018/11/016257; Dahl 1992; Elmahdy 2018; Kucuk 2014; Min 2016; NCT04001764; NCT04077762; Yao 2018). We excluded 3 other studies because they were not randomised (Mori 2020; Vaquerizo 2014; Wilson 2020). We considered Wilson 2020 a quasi-RCT because participants were randomised by the last digit of their medical record number. Although the Vaquerizo 2014 publication stated that it was an RCT, in personal communication, trial authors confirmed that it was not a truly an RCT because participants were enrolled according to availability of staff to carry out the intervention. Vaquerizo 2014 did not use any additional method for randomisation. Mori 2020 compared two interventions of interest but without randomisation. In addition, they performed the two interventions in different periods.

Awaiting studies

Flores-Arévalo 2016 compared B-mode ultrasound guidance versus palpation for arterial catheterisation in adults, but trial authors did not clarify the artery of interest; we, therefore, had to maintain the study in the 'awaiting classification' section. We did not use these data for any analysis.

Ongoing studies

We identified 20 ongoing studies evaluating at least one of the following interventions for arterial (other than femoral) catheterisation in adults.

- Palpation and landmarks (ChiCTR1800016772; ChiCTR-IOR-16009966; CTRI/2020/01/022989; CTRI/2020/06/025543; CTRI/2020/08/027199; CTRI/2020/12/029455; CTRI/2021/02/031051; NCT01189188; NCT01561196; NCT03144895; NCT03995264; NCT04318990; NCT04617106; NTR6107; TCTR20210202004).
- DUG with B-mode or any other modified ultrasound technique (ChiCTR1800016772; ChiCTR-IOR-16009966; CTRI/2020/01/022989; CTRI/2020/06/025543; CTRI/2020/08/027199; CTRI/2020/09/028136; CTRI/2020/12/029455; CTRI/2021/02/031051; KCT0004903; NCT01189188; NCT01561196; NCT02584673; NCT03144895; NCT03995264; NCT04318990; NCT04617106; NCT04806932; NTR6107; TCTR20210202004; UMIN000020698).

Eleven ongoing studies plan to report data on first-attempt success rate (ChiCTR-IOR-16009966; CTRI/2020/01/022989; CTRI/2020/06/025543; CTRI/2020/08/027199; CTRI/2020/12/029455; CTRI/2021/02/031051; KCT0004903; NCT01189188; NCT04617106; NCT04806932; TCTR20210202004). Twelve ongoing studies plan to report data on overall success rate (ChiCTR1800016772; CTRI/2020/06/025543; CTRI/2020/08/027199; CTRI/2020/09/028136; CTRI/2020/12/029455; KCT0004903; NCT03144895; NCT03995264; NCT04617106; NCT04806932; NTR6107; TCTR20210202004). Fifteen ongoing studies plan to report data on time needed for a successful procedure (ChiCTR-IOR-16009966; CTRI/2020/01/022989; CTRI/2020/06/025543; CTRI/2020/08/027199; CTRI/2020/09/028136; CTRI/2020/12/029455; CTRI/2021/02/031051; KCT0004903; NCT01561196; NCT02584673; NCT04617106; NCT04806932; NTR6107; TCTR20210202004; UMIN000020698). NCT01189188 and NCT04806932 plan to report major haematoma data. Fourteen studies plan to report data on adverse events (ChiCTR-IOR-16009966; CTRI/2020/01/022989; CTRI/2020/06/025543; CTRI/2020/08/027199; CTRI/2020/09/028136; CTRI/2020/12/029455; CTRI/2021/02/031051; KCT0004903; NCT01189188; NCT01561196; NCT04318990; NCT04617106; NCT04806932; TCTR20210202004). No ongoing studies plan to report data on pseudoaneurysm or QoL.

We tried to contact trial authors; we also searched by trial number of registration and by title of the study on all databases of interest for this review. However, we found no additional data for these ongoing studies.

Risk of bias in included studies

Risk of bias varied considerably across the included studies, and insufficient detail was provided to inform judgement in several cases. Figure 2 and Figure 3 summarise risk of bias in the included studies.

Figure 2. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

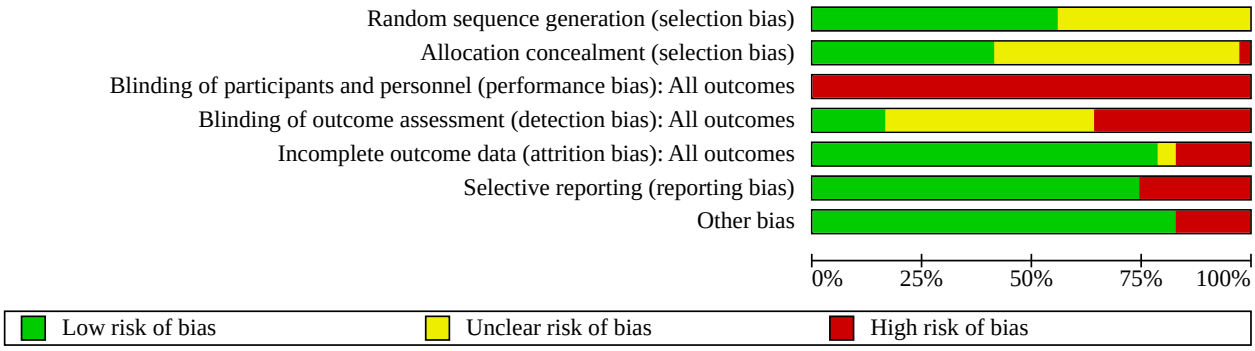


Figure 3. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.

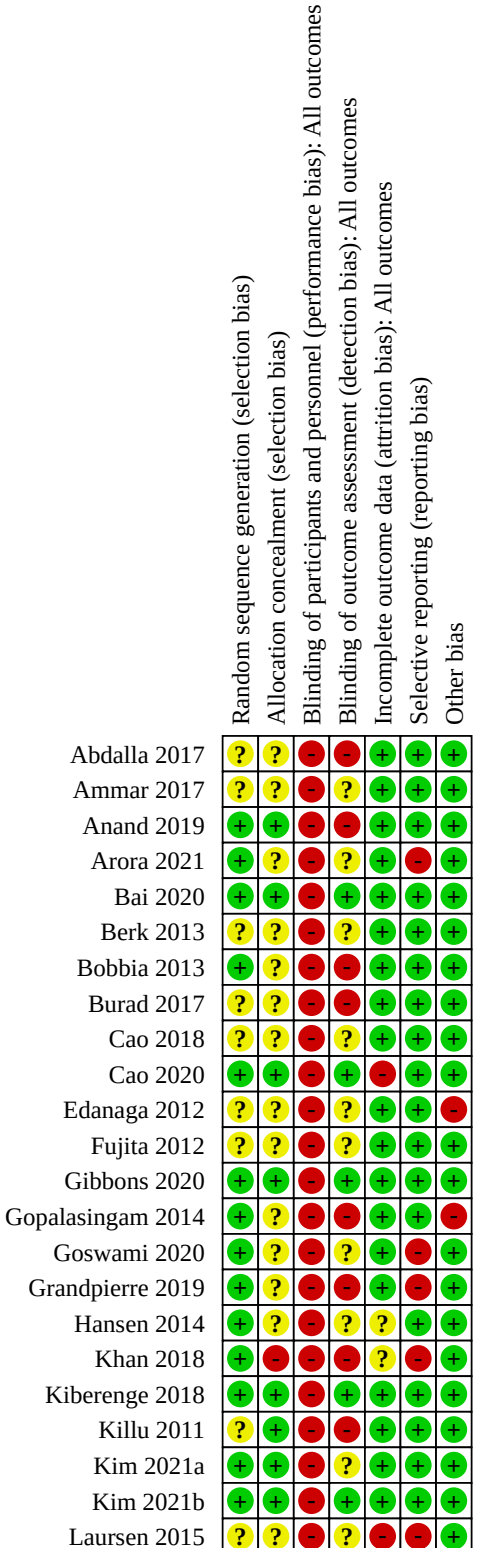
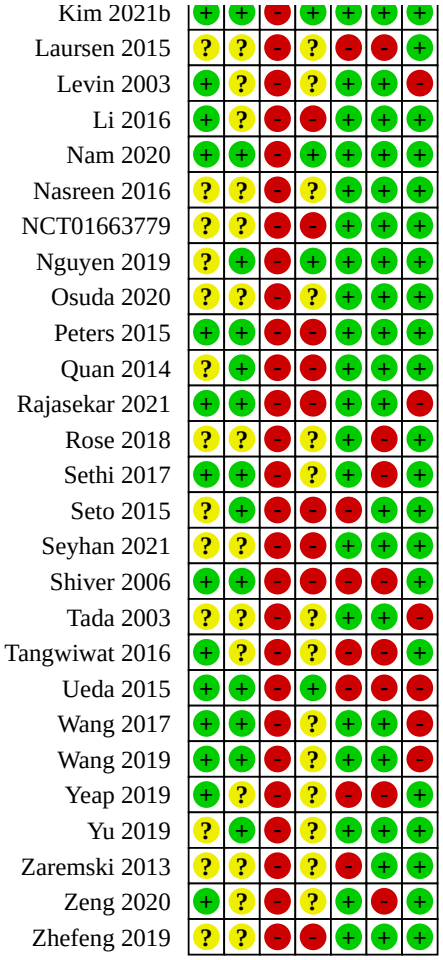


Figure 3. (Continued)



We judged the overall risk of bias in 15 included studies as high (Arora 2021; Cao 2020; Goswami 2020; Grandpierre 2019; Khan 2018; Laursen 2015; Rose 2018; Sethi 2017; Seto 2015; Shiver 2006; Tangwiwat 2016; Ueda 2015; Yeap 2019; Zaremski 2013; Zeng 2020). We judged all 33 other included studies as having low risk of bias.

Allocation

Twenty-seven of the 48 studies had low risk of bias for random sequence generation (Anand 2019; Arora 2021; Bai 2020; Bobbia 2013; Cao 2020; Gibbons 2020; Gopalasingam 2014; Goswami 2020; Grandpierre 2019; Hansen 2014; Khan 2018; Kiberenge 2018; Kim 2021a; Kim 2021b; Levin 2003; Li 2016; Nam 2020; Peters 2015; Rajasekar 2021; Sethi 2017; Shiver 2006; Tangwiwat 2016; Ueda 2015; Wang 2017; Wang 2019; Yeap 2019; Zeng 2020); all others had unclear risk of bias in this domain.

Twenty studies had low risk of bias for allocation concealment (Anand 2019; Bai 2020; Cao 2020; Gibbons 2020; Kiberenge 2018; Killu 2011; Kim 2021a; Kim 2021b; Nam 2020; Nguyen 2019; Peters 2015; Quan 2014; Rajasekar 2021; Sethi 2017; Seto 2015; Shiver 2006; Ueda 2015; Wang 2017; Wang 2019; Yu 2019); Khan 2018 was at high risk of bias for this domain. All others had unclear risk of bias in this domain.

Blinding

All included studies had high risk of bias for blinding of participants and personnel due to the nature of the interventions.

We assessed eight studies to be at low risk of bias for blinding of outcome assessment (Bai 2020; Cao 2020; Gibbons 2020; Kiberenge 2018; Kim 2021b; Nam 2020; Nguyen 2019; Ueda 2015), and 17 to be at high risk of bias for this domain (Abdalla 2017; Anand 2019; Bobbia 2013; Burad 2017; Gopalasingam 2014; Grandpierre 2019; Khan 2018; Killu 2011; Li 2016; NCT01663779; Peters 2015; Quan 2014; Rajasekar 2021; Seto 2015; Seyhan 2021; Shiver 2006; Zhefeng 2019). The other studies had unclear risk of bias in this domain.

Incomplete outcome data

Eight studies had high risk of bias for incomplete outcome reporting (Cao 2020; Laursen 2015; Seto 2015; Shiver 2006; Tangwiwat 2016; Ueda 2015; Yeap 2019; Zaremski 2013). Hansen 2014 and Khan 2018 had unclear risk of bias, and the other studies had low risk of bias for this domain.

Selective reporting

Eleven studies were at high risk of bias for selective reporting (Arora 2021; Goswami 2020; Grandpierre 2019; Khan 2018; Laursen 2015;

Rose 2018; Sethi 2017; Shiver 2006; Tangwiwat 2016; Ueda 2015; Yeap 2019; Zeng 2020); none was at unclear risk of bias for this domain. All other included studies (37/48) had low risk of bias for this domain.

Other potential sources of bias

We assessed 8 studies as having high risk for other potential sources of bias (Edanaga 2012; Gopalasingam 2014; Levin 2003; Rajasekar 2021; Tada 2003; Ueda 2015; Wang 2017; Wang 2019); all other studies were at low risk of bias for this domain.

Wang 2017 and Wang 2019 received the same trial registry number (ChiCTR-IOR-17011474) for their publications, but participants were enrolled in separate periods, without any overlap: 1 June 2017 to 27 October 2017 (Wang 2017), and 1 July 2018 to 24 November 2018 (Wang 2019). Characteristics of participants, interventions, and comparisons are different between studies. We therefore considered that no double-counting of the same participants occurred, and we analysed the data as from two different studies.

Effects of interventions

See: **Summary of findings 1** [Axillary] B-mode ultrasound guidance compared to palpation and landmarks for arterial (other than femoral) catheterisation in adults; **Summary of findings 2** [Dorsalis pedis] B-mode ultrasound guidance compared to palpation and landmarks for arterial (other than femoral) catheterisation in adults; **Summary of findings 3** [Radial] B-mode ultrasound guidance compared to palpation and landmarks for arterial (other than femoral) catheterisation in adults; **Summary of findings 4** [Radial] B-mode ultrasound compared to Doppler assistance for arterial (other than femoral) catheterisation in adults; **Summary of findings 5** [Radial] B-mode ultrasound compared to near-infrared laser guidance for arterial (other than femoral) catheterisation in adults; **Summary of findings 6** [Radial] B-mode ultrasound compared to modified B-mode ultrasound for arterial (other than femoral) catheterisation in adults; **Summary of findings 7** [Radial] In-plane B-mode ultrasound compared to out-of-plane B-mode ultrasound for arterial (other than femoral) catheterisation in adults; **Summary of findings 8** [Radial] Doppler assistance compared to palpation and landmarks for arterial (other than femoral) catheterisation in adults; **Summary of findings 9** [Radial] Dynamic out-of-plane B-mode ultrasound compared to static out-of-plane B-mode ultrasound for arterial (other than femoral) catheterisation in adults; **Summary of findings 10** [Radial] Oblique-axis in-plane B-mode ultrasound compared to long-axis in-plane B-mode ultrasound for arterial (other than femoral) catheterisation in adults

1. Axillary artery

1.1. B-mode ultrasound guidance versus palpation and landmarks

See Summary of findings 1. Killu 2011 compared real-time B-mode ultrasound guidance to palpation and landmarks for axillary artery catheterisation and reported all outcomes up to one hour after the intervention. We judged the overall risk of bias for Killu 2011 as low and did not perform any sensitivity analysis in this comparison.

Primary outcomes

First-attempt success rate

No data are available for this outcome.

Pseudoaneurysm

No data are available for this outcome.

Secondary outcomes

Overall success rate

We are uncertain about the effect of real-time B-mode ultrasound guidance on overall success rate when compared to palpation and landmarks up to one hour (risk ratio (RR) 1.35, 95% confidence interval (CI) 0.99 to 1.86; 33 participants, 1 study; very low-certainty evidence) (Analysis 1.1).

Time (minutes) needed for successful procedure

We are uncertain about the effect of real-time B-mode ultrasound guidance on time needed for a successful procedure when compared to palpation and landmarks up to one hour (mean difference (MD) -2.27 minutes, 95% CI -7.36 to 2.82; 33 participants, 1 study; very low-certainty evidence) (Analysis 1.2).

Major haematoma

We are uncertain about the effect of real-time B-mode ultrasound guidance on major haematomas when compared to palpation and landmarks up to one hour (RR 0.83, 95% CI 0.06 to 12.22; 33 participants, 1 study; very low-certainty evidence) (Analysis 1.3).

Adverse events (minor haematoma, pain, local infection, artery thrombosis, artery embolism, nerve injury, amputation, life-threatening events; fatal events)

We are uncertain about the effect of real-time B-mode ultrasound guidance on venous puncture when compared to palpation and landmarks up to one hour (RR 0.83, 95% CI 0.20 to 3.54; 33 participants, 1 study; very low-certainty evidence) (Analysis 1.4). We downgraded the certainty of evidence one level due to high risk of performance bias, and we downgraded two levels due to imprecision: few participants, few studies, and 95% CI consistent with possible benefit and possible harm. Killu 2011 also reported no events of nerve injury in both groups.

No data are available for pain or other adverse events.

Quality of life

No data are available for this outcome.

2. Dorsalis pedis artery

2.1. B-mode ultrasound guidance versus palpation and landmarks

See Summary of findings 2. Anand 2019 compared real-time B-mode ultrasound guidance to palpation and landmarks for dorsalis pedis artery catheterisation and reported all outcomes up to one hour after the intervention. We judged the overall risk of bias for Anand 2019 as low and did not perform any sensitivity analysis in this comparison.

Primary outcomes

First-attempt success rate

We are uncertain about the effect of real-time B-mode ultrasound guidance on first-attempt success rate when compared to palpation and landmarks up to one hour (RR 1.28, 95% CI 0.90 to 1.82; 60 participants, 1 study; very low-certainty evidence) (Analysis 2.1).

Pseudoaneurysm

No data are available for this outcome.

Secondary outcomes

Overall success rate

We are uncertain about the effect of real-time B-mode ultrasound guidance on overall success rate when compared to palpation and landmarks up to one hour (RR 1.00, 95% CI 0.91 to 1.10; 60 participants, 1 study; very low-certainty evidence) (Analysis 2.2).

Time (minutes) needed for successful procedure

We are uncertain about the effect of real-time B-mode ultrasound guidance on time needed for a successful procedure when compared to palpation and landmarks up to one hour (MD -0.04 minutes, 95% CI -0.16 to 0.08; 60 participants, 1 study; very low-certainty evidence) (Analysis 2.3).

Major haematoma

Anand 2019 reported that "complications were not noticed in any of the two groups", but they did not detail what complications were assessed.

Adverse events (minor haematoma, pain, local infection, artery thrombosis, artery embolism, nerve injury, amputation, life-threatening events; fatal events)

Anand 2019 reported that "complications were not noticed in any of the two groups", but they did not detail what complications were assessed.

Quality of life

No data are available for this outcome.

3. Radial artery

3.1. B-mode ultrasound guidance versus palpation and landmarks

See Summary of findings 3.

Two trials included in this comparison did not report any data that we could use in our analysis (Edanaga 2012; Fujita 2012). Fujita 2012 is an abstract of the event and provides no data for numerical analysis. Edanaga 2012 was evaluated in full text after translation from Japanese; investigators did not evaluate any outcomes of interest for our review.

Hansen 2014 and Gopalasingam 2014 are cross-over studies, and data from the first phase were shared by trial authors in personal communication.

We judged the overall risk of bias as high for 11 studies (Goswami 2020; Grandpierre 2019; Khan 2018; Laursen 2015; Rose 2018; Seto 2015; Shiver 2006; Tangwiwat 2016; Ueda 2015; Yeap 2019; Zaremski 2013), and as low for all other studies in this comparison. We performed a sensitivity analysis while excluding trials with high overall risk of bias and a cross-over design.

Primary outcomes

First-attempt success rate

Twenty-seven included studies evaluated the first-attempt success rate (Ammar 2017; Burad 2017; Cao 2018; Gibbons 2020; Gopalasingam 2014; Grandpierre 2019; Hansen 2014; Khan 2018; Kiberenge 2018; Kim 2021b; Laursen 2015; Levin 2003; Li 2016; Nasreen 2016; NCT01663779; Nguyen 2019; Peters 2015; Rajasekar 2021; Seto 2015; Seyhan 2021; Shiver 2006; Tangwiwat 2016; Ueda 2015; Wang 2017; Wang 2019; Yu 2019; Zaremski 2013; Zeng 2020). Kiberenge 2018 reported outcomes data separately by experienced and inexperienced operators; therefore, we included this study in both subgroups.

B-mode ultrasound guidance may improve the first-attempt success rate compared with palpation and landmarks up to one hour (RR 1.44, 95% CI 1.29 to 1.61; 4708 participants, 27 studies; I^2 = 85%; low-certainty evidence) (Analysis 3.1). The test for subgroup differences suggests that the experience of operators has not a modifying effect on the first-attempt success rate (Chi^2 = 0.98, df = 1 (P = 0.32), I^2 = 0%) (Analysis 3.1).

Sensitivity analyses including only trials at low risk of bias (RR 1.46, 95% CI 1.33 to 1.60) (Analysis 3.2) and including only individual parallel-design studies (RR 1.42, 95% CI 1.27 to 1.59) (Analysis 3.3) did not change the effect estimate substantially.

The related funnel plot was asymmetrical, and Egger's test was significant (t = 5.80, df = 26, P < 0.0001), suggesting that small studies in favour of palpation intervention may not have been published (Figure 4). When a trim-and-fill method was applied, the adjusted effect estimate changed substantially (RR 1.19, 95% CI 1.07 to 1.31) (Figure 5). The adjusted funnel plot is presented in Figure 6.

Figure 4. Funnel plot without adjustment of comparison: 3 [Radial] B-mode ultrasound guidance versus palpation and landmarks, outcome: 3.1 First-attempt success rate.

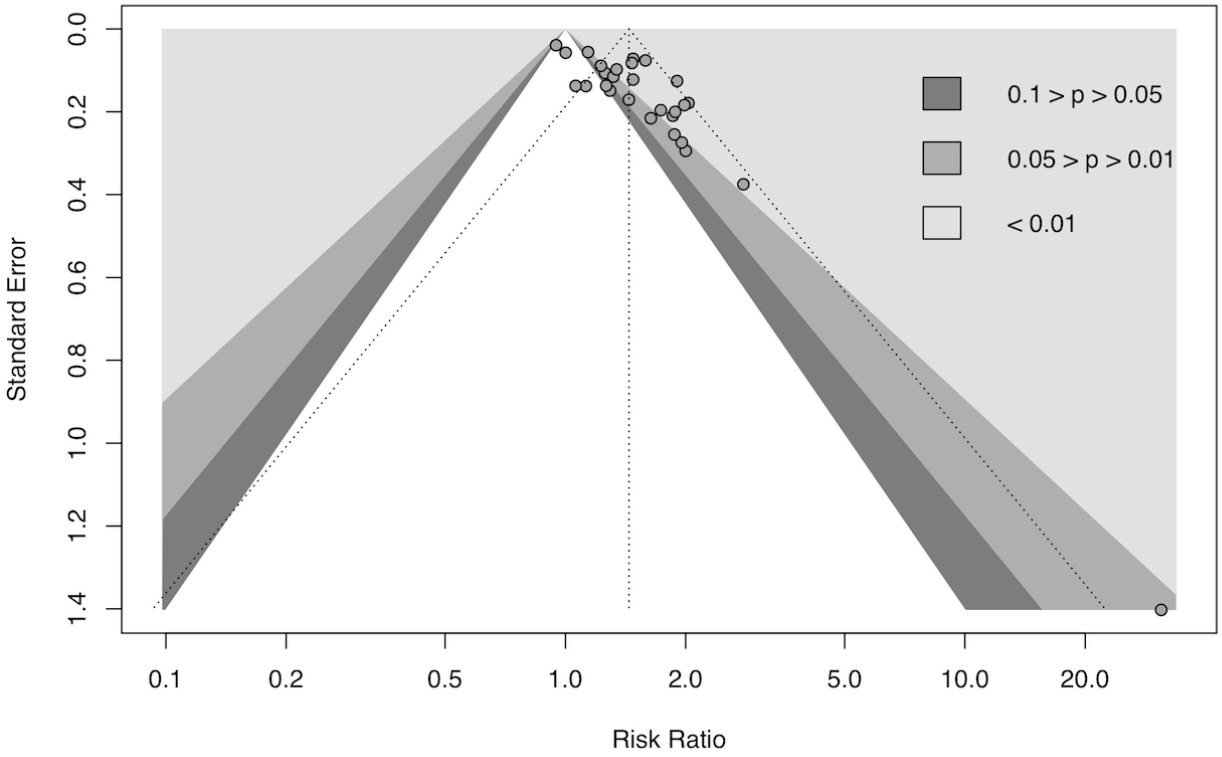


Figure 5. Forest plot with adjustment (trim and fill method) of comparison: 3 [Radial] B-mode ultrasound guidance versus palpation and landmarks, outcome: 3.1 First-attempt success rate. Filled studies: imputed studies

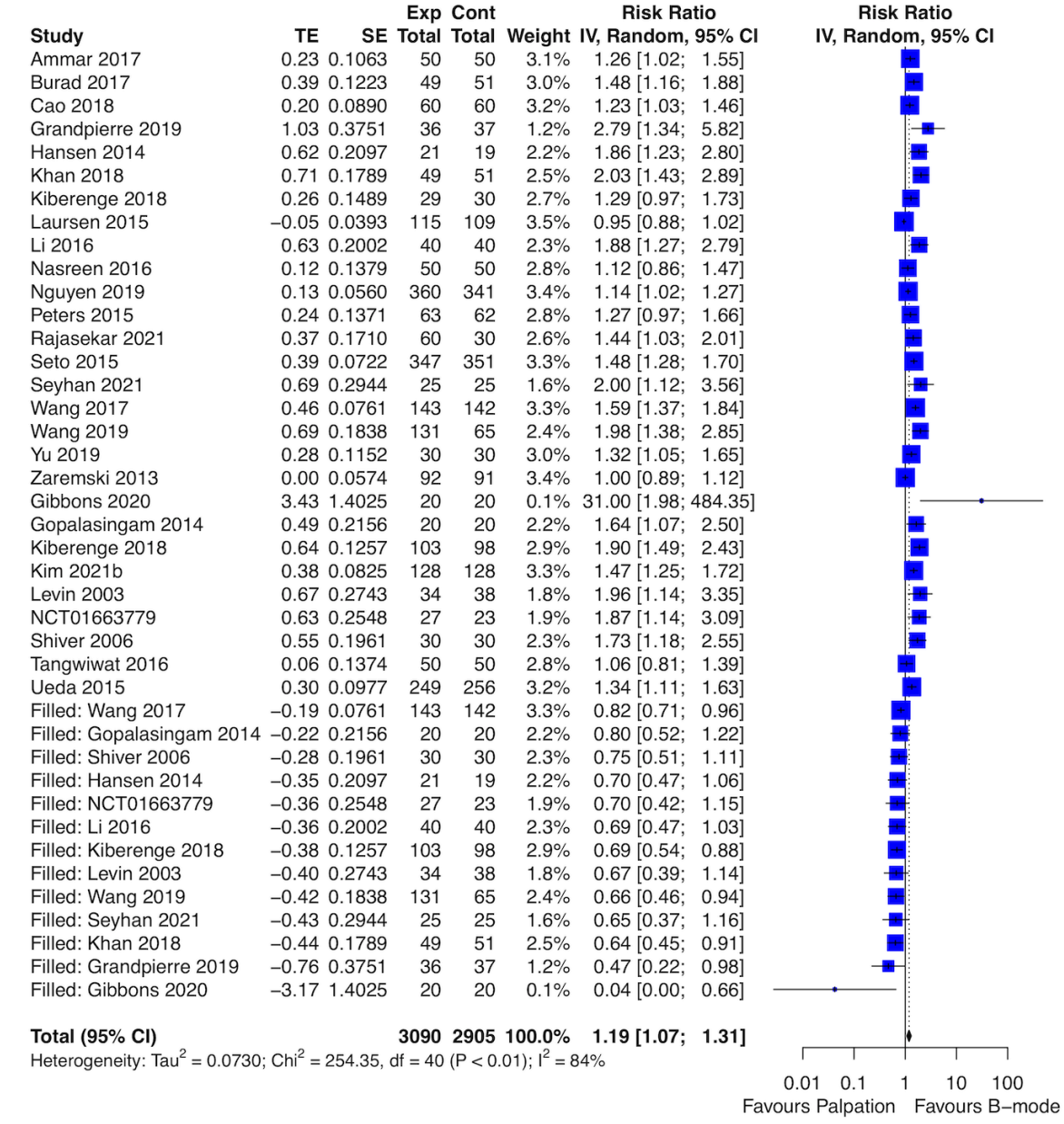
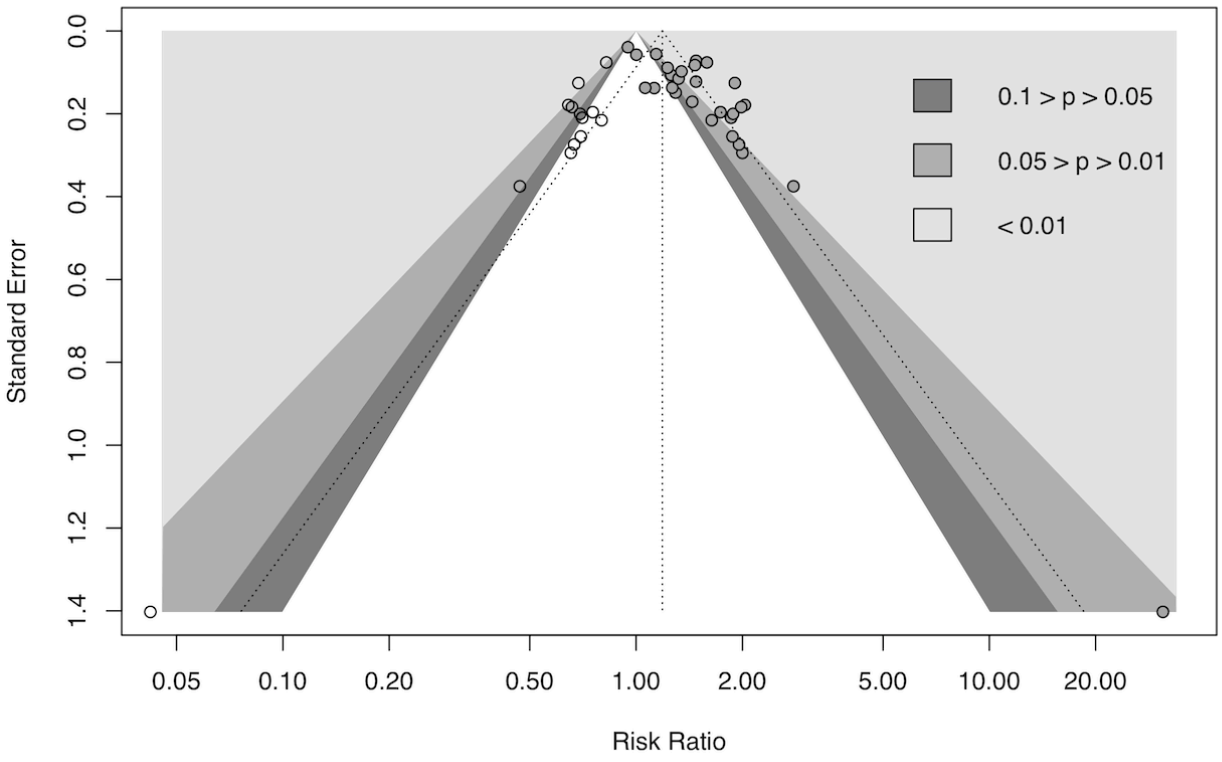


Figure 5. (Continued)

Figure 6. Funnel plot with adjustment (trim and fill method) of comparison: 3 [Radial] B-mode ultrasound guidance versus palpation and landmarks, outcome: 3.1 First-attempt success rate. Empty circles: imputed studies; Filled circles: original studies



Pseudoaneurysm

Nguyen 2019 showed uncertainty about the effects of real-time B-mode ultrasound guidance on pseudoaneurysm when compared to palpation and landmarks up to one month (RR 2.89, 95% CI 0.12 to 70.63; 679 participants, 1 study; very low-certainty evidence) (Analysis 3.4).

Secondary outcomes

Overall success rate

Twenty-eight included studies evaluated the overall success rate (Ammar 2017; Bobbia 2013; Burad 2017; Cao 2018; Gibbons 2020; Gopalasingam 2014; Goswami 2020; Grandpierre 2019; Hansen 2014; Khan 2018; Kiberenge 2018; Kim 2021b; Laursen 2015; Levin 2003; Li 2016; Nasreen 2016; NCT01663779; Nguyen 2019; Peters 2015; Rajasekar 2021; Seto 2015; Seyhan 2021; Shiver

2006; Tangwiwat 2016; Ueda 2015; Wang 2017; Wang 2019; Yu 2019; Zaremski 2013). Kiberenge 2018 reported outcomes data separately by experienced and inexperienced operators; therefore, we included this study in both subgroups.

B-mode ultrasound guidance may slightly improve the overall success rate compared with palpation and landmarks up to one hour (RR 1.11, 95% CI 1.06 to 1.16; 4955 participants, 28 studies; I^2 = 88%; low-certainty evidence) (Analysis 3.5). The test for subgroup differences suggests that the experience of operators does not have a modifying effect on overall success rate (Chi^2 = 1.54, df = 1 (P = 0.21), I^2 = 35.0%) (Analysis 3.5).

Sensitivity analyses including only trials at low risk of bias (RR 1.14, 95% CI 1.07 to 1.22) (Analysis 3.6) and including only individual parallel-design studies (RR 1.10, 95% CI 1.05 to 1.15) (Analysis 3.7) did not change the effect estimate substantially.

The related funnel plot was asymmetrical, and Egger's test was significant (t = 4.56, df = 27, P = 0.0001), suggesting that small studies in favour of palpation intervention may not have been published (Figure 7). When a trim-and-fill method was applied, the adjusted effect estimate changed substantially (RR 1.03, 95% CI 0.99 to 1.08) (Figure 8). The adjusted funnel plot is presented in Figure 9.

Figure 7. Funnel plot without adjustment of comparison: 3 [Radial] B-mode ultrasound guidance versus palpation and landmarks, outcome: 3.5 Overall success rate.

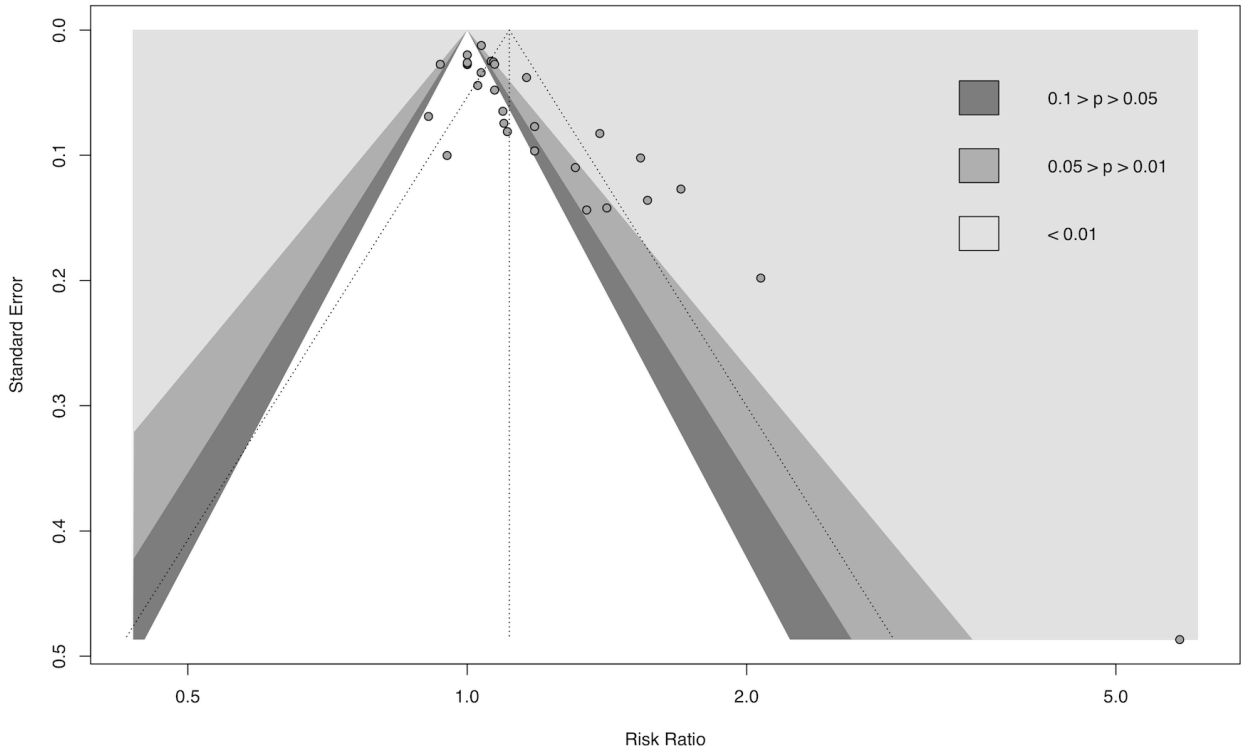


Figure 8. Funnel plot with adjustment (trim-and-fill method) of comparison: 3 [Radial] B-mode ultrasound guidance versus palpation and landmarks, outcome: 3.5 Overall success rate. Filled studies: imputed studies

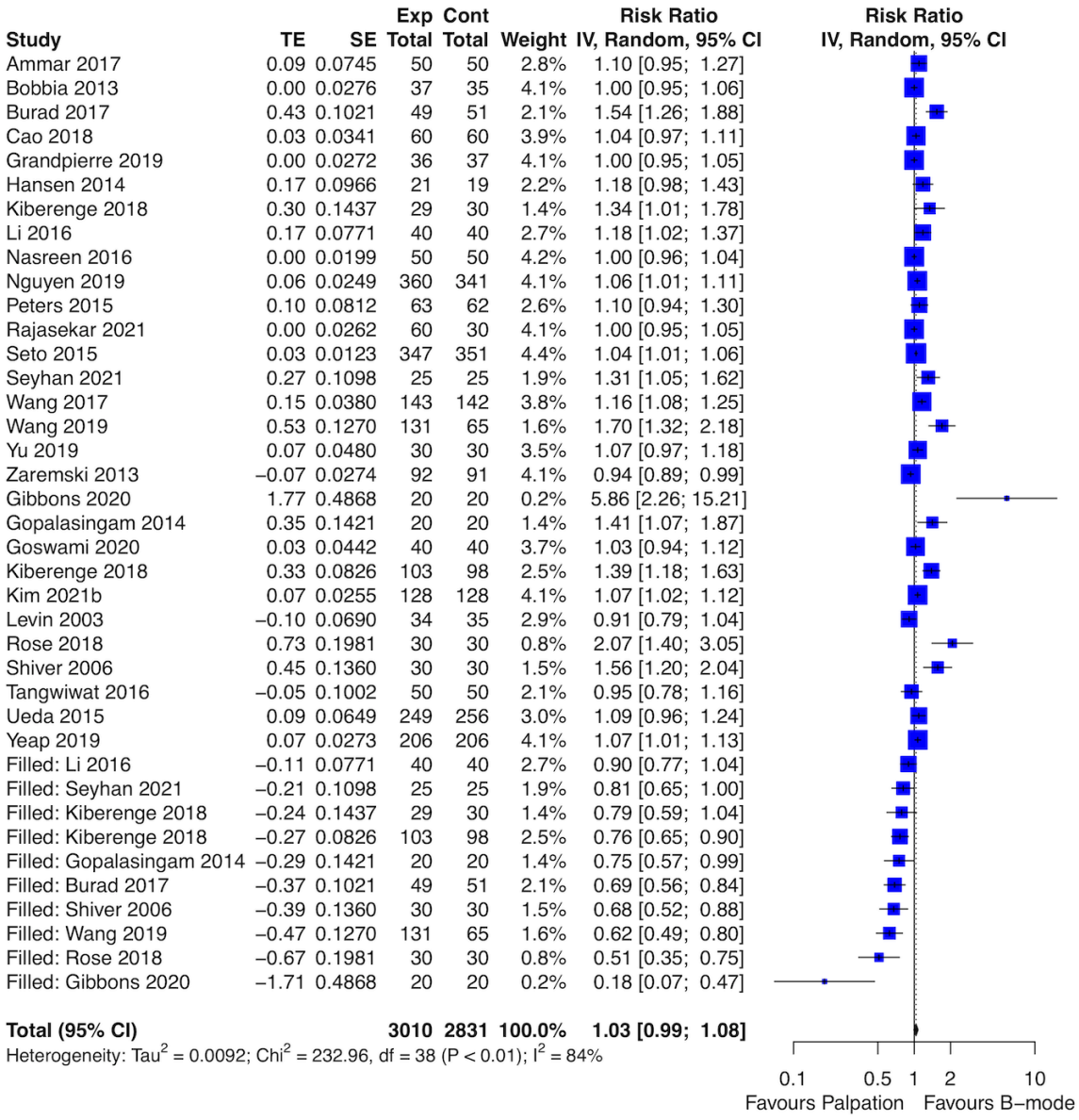
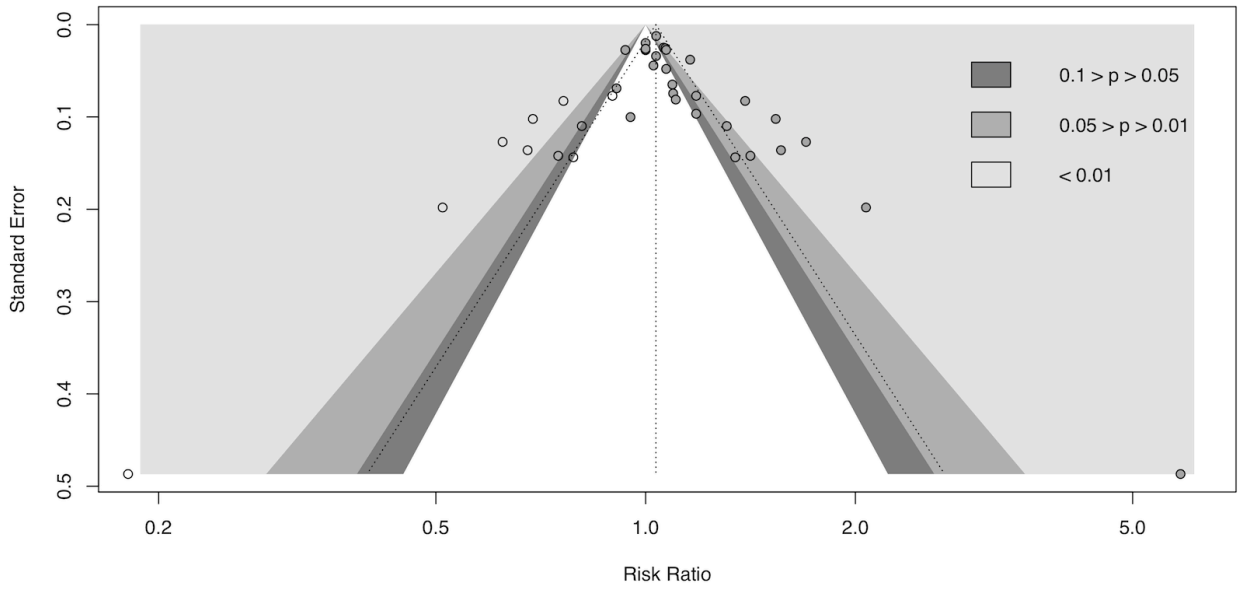


Figure 8. (Continued)

Figure 9. Funnel plot with adjustment (trim-and-fill method) of comparison: 3 [Radial] B-mode ultrasound guidance versus palpation and landmarks, outcome: 3.5 Overall success rate. Empty circles: imputed studies; Filled circles: original studies



Time (minutes) needed for a successful procedure

Twenty-six included studies evaluated the time needed for a successful procedure (Ammar 2017; Bobbia 2013; Burad 2017; Cao 2018; Gibbons 2020; Gopalasingam 2014; Grandpierre 2019; Hansen 2014; Kiberenge 2018; Kim 2021b; Laursen 2015; Levin 2003; Li 2016; Nasreen 2016; Nguyen 2019; Peters 2015; Rajasekar 2021; Seto 2015; Shiver 2006; Tangwiwat 2016; Ueda 2015; Wang 2017; Wang 2019; Yeap 2019; Yu 2019; Zaremski 2013).

B-mode ultrasound guidance may slightly decrease the time needed for a successful procedure compared with palpation and landmarks up to one hour (MD -0.33 minutes, 95% CI -0.54 to -0.13; 4902 participants, 26 studies; I^2 = 96%; low-certainty evidence) (Analysis 3.8). The test for subgroup differences suggests that the experience of operators may have a modifying effect on the time needed for a successful procedure (Chi^2 = 9.96, df = 1 (P = 0.002), I^2 = 90.0%) (Analysis 3.8).

Both sensitivity analyses including only trials at low risk of bias (MD -0.23 minutes, 95% CI -0.38 to -0.08) (Analysis 3.9) and including only individual parallel-design studies (MD -0.30 minutes, 95% CI -0.51 to -0.09) (Analysis 3.10) did not change the effect estimate substantially.

Although Egger's test was not significant (t = -0.67, df = 24, P = 0.5066), the related funnel plot was asymmetrical, suggesting that small studies in favour of palpation intervention may not have been published (Figure 10). When a trim-and-fill method was applied, the adjusted effect estimate changed substantially (MD -0.09, 95% CI -0.31 to 0.12) (Figure 11). The adjusted funnel plot is presented in Figure 12.

Figure 10. Funnel plot without adjustment of comparison: 3 [Radial] B-mode ultrasound guidance versus palpation and landmarks, outcome: 3.8 Time needed for a successful procedure [minutes].

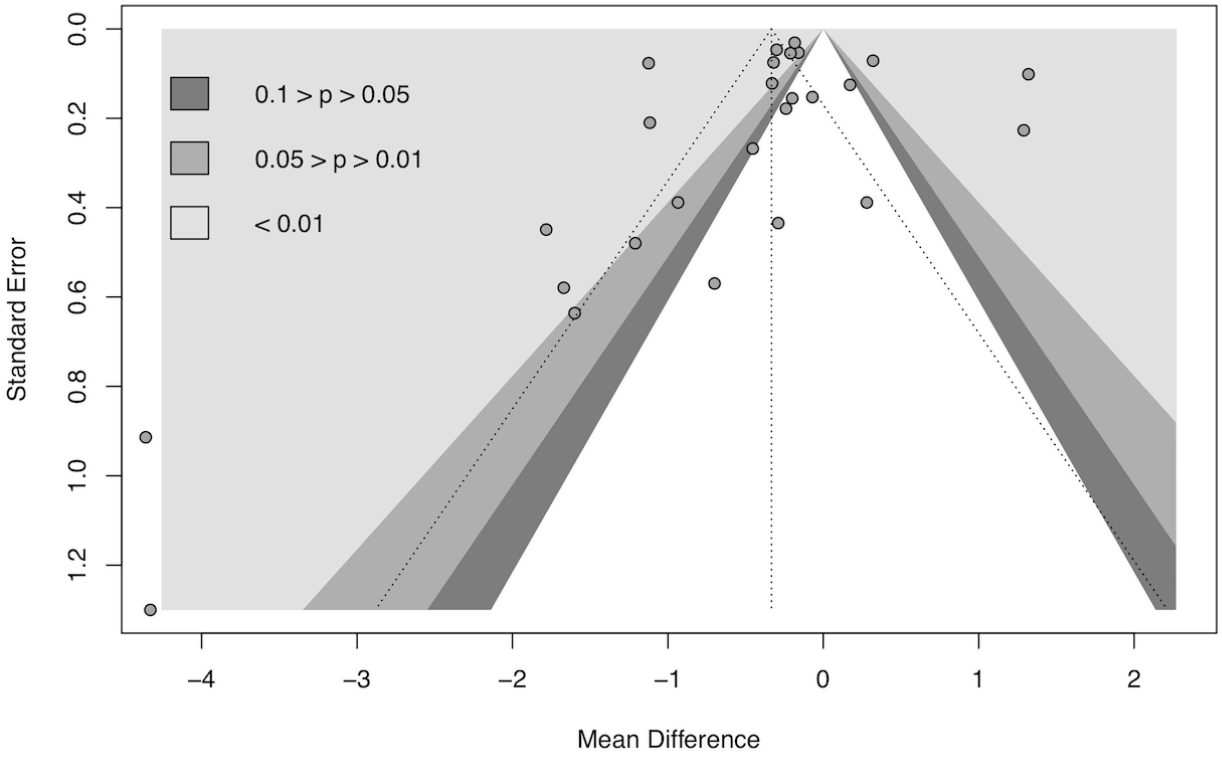


Figure 11. Funnel plot with adjustment (trim-and-fill method) of comparison: 3 [Radial] B-mode ultrasound guidance versus palpation and landmarks, outcome: 3.8 Time needed for a successful procedure [minutes]. Filled studies: imputed studies

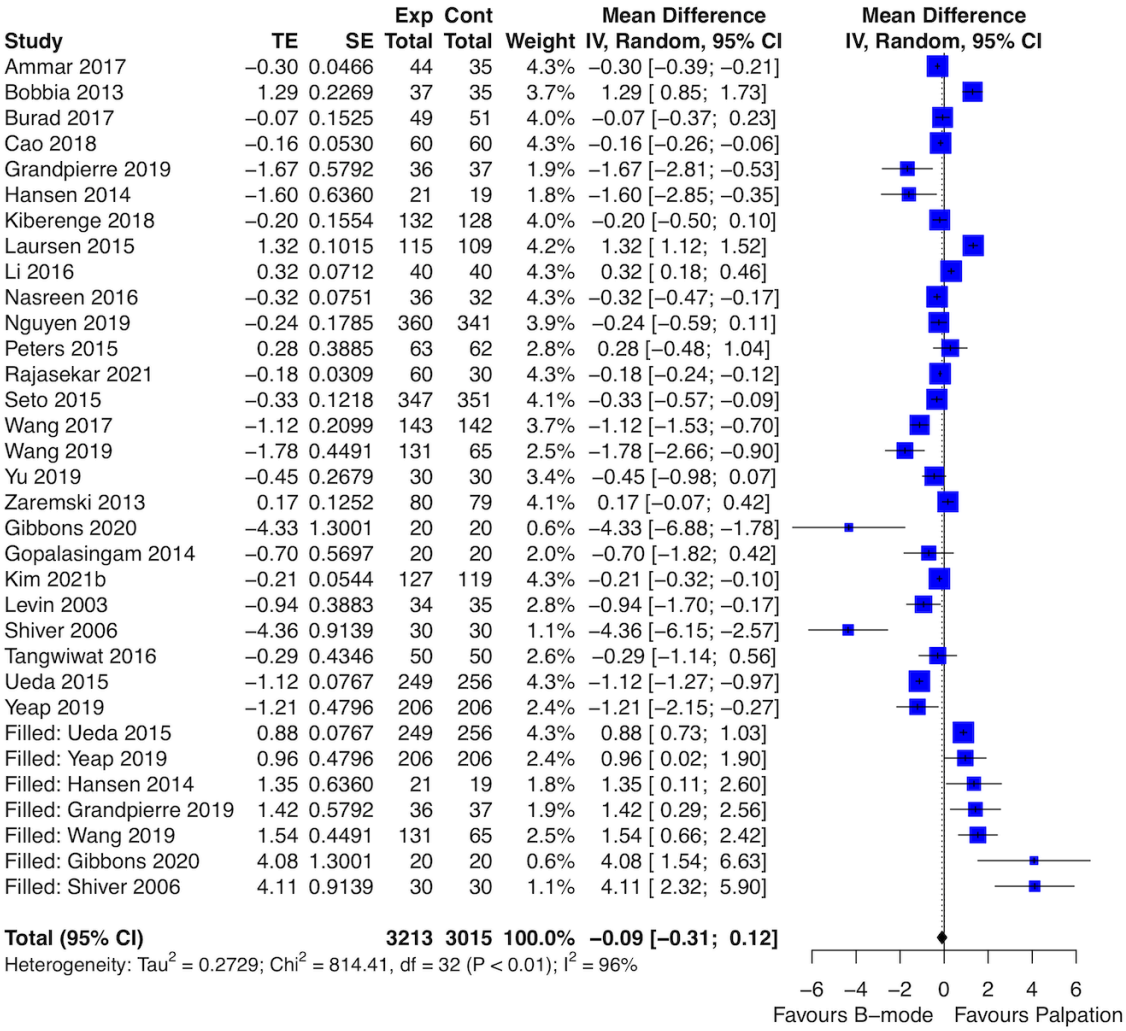
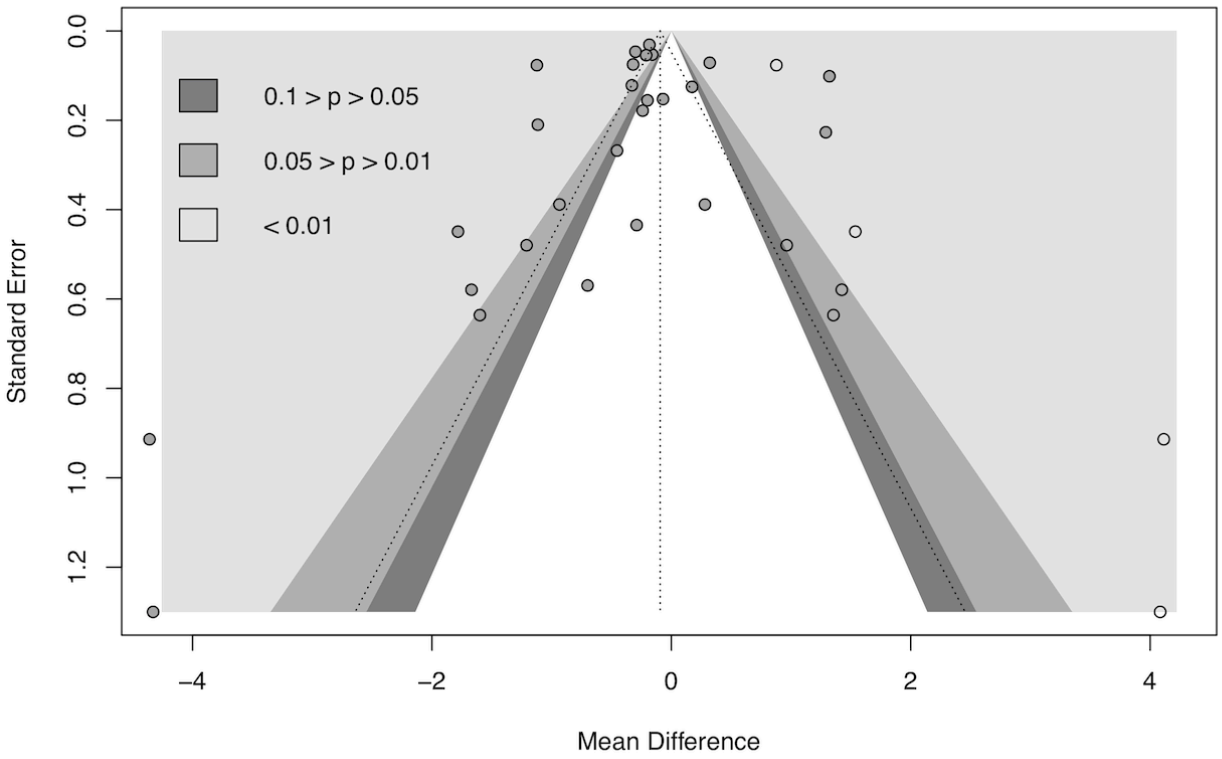


Figure 11. (Continued)

Figure 12. Funnel plot with adjustment (trim-and-fill method) of comparison: 3 [Radial] B-mode ultrasound guidance versus palpation and landmarks, outcome: 3.8 Time needed for a successful procedure [minutes]. Empty circles: imputed studies; Filled circles: original studies



We could not use Khan 2018 data on this outcome for meta-analysis because investigators reported these incompletely.

Major haematoma

Sixteen included studies evaluated major haematoma (Cao 2018; Gibbons 2020; Goswami 2020; Kim 2021b; Li 2016; Nasreen 2016; NCT01663779; Nguyen 2019; Peters 2015; Rajasekar 2021; Shiver 2006; Tangwiwat 2016; Wang 2017; Wang 2019; Yu 2019; Zaremski 2013). Cao 2018 did not differentiate haematomas in major and minor. Therefore, we dealt conservatively and considered all haematomas as major.

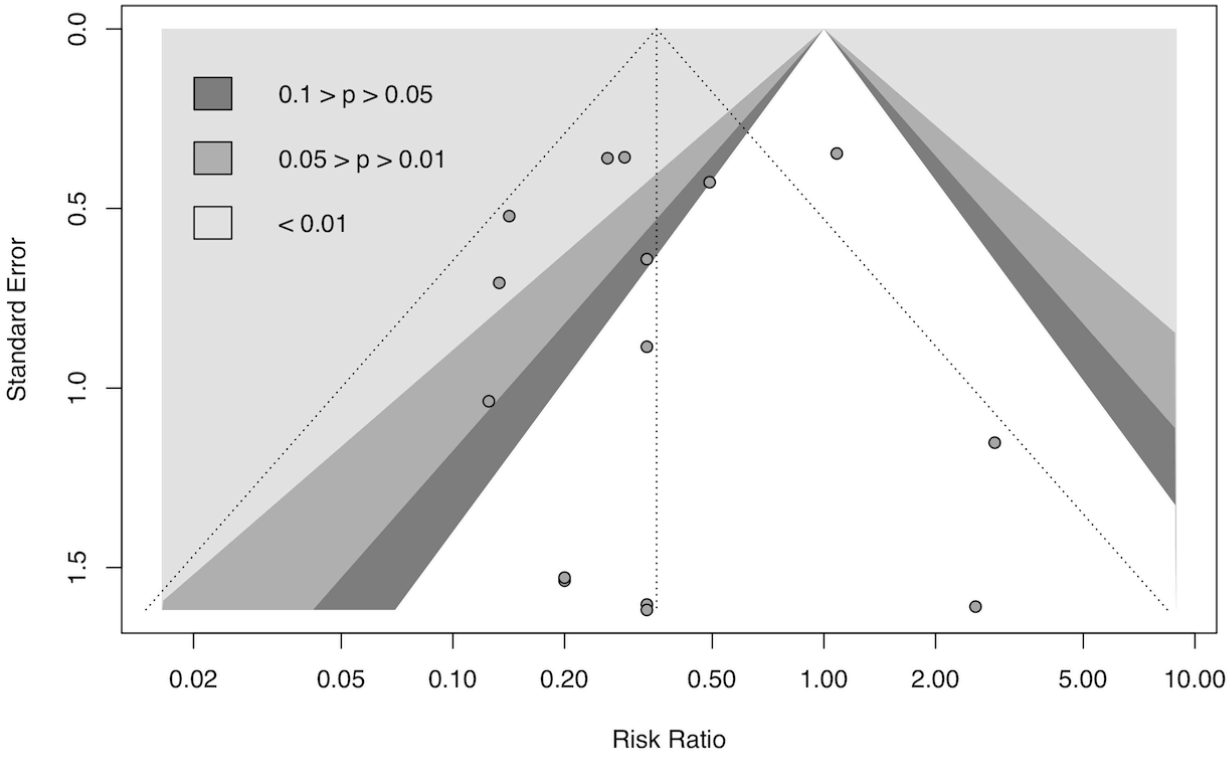
B-mode ultrasound guidance probably decreases major haematoma when compared to palpation and landmarks up to one month (RR 0.35, 95% CI 0.23 to 0.56; 2504 participants, 16 studies; I^2 = 40%; moderate-certainty evidence) (Analysis 3.11). The test

for subgroup differences suggests that the experience of operators does not have a modifying effect on time needed for a successful procedure (Chi^2 = 0.56, df = 1 (P = 0.45), I^2 = 0%) (Analysis 3.11).

Sensitivity analyses including only trials at low risk of bias (RR 0.30, 95% CI 0.21 to 0.43) (Analysis 3.12) did not change the effect estimate substantially. All trials that reported this outcome had individual parallel design; therefore, sensitivity analysis of trials with individual parallel design was not possible.

The related funnel plot was symmetrical and Egger's test was not significant (t = -0.30, df = 13, P = 0.7714), suggesting there is no suspicion that small studies in favour of palpation intervention may not have been published (Figure 13). Therefore, we did not perform a trim-and-fill method to adjust the effect estimate.

Figure 13. Funnel plot without adjustment of comparison: 3 [Radial] B-mode ultrasound guidance versus palpation and landmarks, outcome: 3.11 Major haematoma.



Adverse events (minor haematoma, pain, local infection, artery thrombosis, artery embolism, nerve injury, amputation, life-threatening events; fatal events)

Four studies provided data for pain (Bobbia 2013; Grandpierre 2019; Hansen 2014; Seto 2015). We are uncertain about the effect of B-mode ultrasound guidance on pain when compared to palpation and landmarks up to 24 hours (MD 0.81 visual analogue scale (VAS, 0 to 10), 95% CI -0.66 to 2.28; 883 participants, 4 studies; I^2 = 91%; very low-certainty evidence) (Analysis 3.13). Both sensitivity analyses including only trials at low risk of bias (MD -0.10, 95% CI -0.95 to 0.75) (Analysis 3.14) and including only individual parallel-design studies (MD 1.22, 95% CI -1.19 to 3.64) (Analysis 3.15) did not change the effect estimate substantially.

Khan 2018, Seto 2015, and Ueda 2015 reported bleeding, haematoma, ischaemia, or spasm as a combination of two or three outcomes. B-mode ultrasound guidance may lead to no difference in bleeding, haematoma, ischaemia, or spasm compared with palpation and landmarks up to three days (RR 0.86, 95% CI 0.49 to 1.52; 1303 participants, 3 studies; I^2 = 15%; low-certainty evidence) (Analysis 3.16). We downgraded the certainty of evidence one level due to high risk of selection, performance, detection, reporting, and other bias, and another level due to imprecision: 95% CI is consistent with possible benefit and possible harm. We did not perform any sensitivity analysis here because we judged Khan 2018, Seto 2015, and Ueda 2015 as having high overall risk of bias, and they had an individual parallel design.

We are uncertain about the effect of real-time B-mode ultrasound guidance on local infection when compared to palpation and landmarks up to two days (RR 0.33, 95% CI 0.04 to 3.15; 260 participants, 3 studies; I^2 = 0%; very low-certainty evidence) (Cao 2018; Goswami 2020; Yu 2019; Analysis 3.17). We downgraded the certainty of evidence one level due to high risk of performance bias, and two levels due to imprecision: wide 95% CI is consistent

with possible benefit and possible harm. The sensitivity analysis including only trials at low risk of bias (RR 0.33, 95% CI 0.01 to 8.02) (Analysis 3.18) did not change the effect estimate substantially. All trials that reported this outcome had an individual parallel design; therefore, the sensitivity analysis of trials with individual parallel design was not possible.

Li 2016 and Wang 2019 showed real-time B-mode ultrasound guidance may slightly decrease oedema when compared to palpation and landmarks up to three days (RR 0.15, 95% CI 0.04 to 0.64; 365 participants, 2 studies; I^2 = 0%; low-certainty evidence) (Analysis 3.19). We downgraded the certainty of evidence one level due to high risk of performance, detection, and other bias, and another level due to imprecision: 95% CI is consistent with possible benefit and possible harm. We did not perform any sensitivity analysis here because we judged Li 2016 and Wang 2019 as having low overall risk of bias, and they had an individual parallel design.

Goswami 2020, Kim 2021b, Nguyen 2019, Wang 2017, and Wang 2019 reported arterial thrombosis. We are uncertain about the effect of B-mode ultrasound guidance on arterial thrombosis compared with palpation and landmarks up to one month (RR 0.71, 95% CI 0.14 to 3.54; 1496 participants, 5 studies; I^2 = 0%; very low-certainty evidence) (Analysis 3.20). We downgraded the certainty of evidence one level due to high risk of performance and other bias, and two levels due to imprecision: wide 95% CI is consistent with possible benefit and possible harm. The sensitivity analysis including only trials at low risk of bias (RR 0.33, 95% CI 0.03 to 3.13) (Analysis 3.21) did not change the effect estimate substantially. All trials that reported this outcome had an individual parallel design; therefore, the sensitivity analysis of trials with an individual parallel design was not possible.

Nguyen 2019 reported death. We are uncertain about the effect of real-time B-mode ultrasound guidance on death when compared to palpation and landmarks up to one month (RR 0.32, 95% CI 0.01 to 7.85; 679 participants, 1 study; very low-certainty evidence) (Analysis 3.22). We downgraded the certainty of evidence one level due to high risk of performance bias, and two levels due to imprecision: 95% CI is wide.

Kim 2021b, Rajasekar 2021, Seto 2015, Wang 2017, and Wang 2019 reported spasm. B-mode ultrasound guidance may lead to no difference in spasm compared with palpation and landmarks up to three days (RR 1.11, 95% CI 0.62 to 1.97; 1525 participants, 5 studies; I^2 = 0%; low-certainty evidence) (Analysis 3.23). We downgraded the certainty of evidence one level due to high risk of performance, detection, attrition, and other bias, and another level due to imprecision: 95% CI is consistent with possible benefit and possible harm. The sensitivity analysis including only trials at low risk of bias (RR 0.90, 95% CI 0.30 to 2.64) (Analysis 3.24) did not change the effect estimate substantially. All trials that reported this outcome had an individual parallel design; therefore, the sensitivity analysis of trials with individual parallel design was not possible.

Wang 2019 showed real-time B-mode ultrasound guidance may slightly decrease posterior wall puncture when compared to palpation and landmarks up to three days (RR 0.41, 95% CI 0.28 to 0.61; 196 participants, 1 study; low-certainty evidence) (Analysis 3.25). We downgraded the certainty of evidence one level due to high risk of performance and other bias, and another level due to imprecision: 95% CI is consistent with possible benefit and possible harm.

Kim 2021b reported no events of ischaemia in both groups up to the end of the procedure (not detailed); therefore, we could not estimate the effects of interventions for this outcome.

Zaremski 2013 reported no arterial dissection in both groups for up to two days; therefore, we could not estimate the effects of interventions for this outcome.

Quality of life

We are uncertain about the effect of B-mode ultrasound guidance on QoL compared with palpation and landmarks up to the end of the procedure (MD 0.00, 95% CI -1.07 to 1.07; 72 participants, 1 study; very low-certainty evidence) (Analysis 3.26). Bobbia 2013 used a VAS to report patient satisfaction (0 to 10 scale); higher values mean better QoL, and a 30% change in the relative effect estimate means a minimally important effect.

3.2. B-mode ultrasound guidance versus Doppler auditory ultrasound assistance

See Summary of findings 4.

Primary outcomes

First-attempt success rate

Ueda 2015 showed real-time B-mode ultrasound guidance probably improves first-attempt success rate when compared to DUA up to 72 hours (RR 1.35, 95% CI 1.11 to 1.64; 493 participants, 1 study; moderate-certainty evidence) (Analysis 4.1).

Pseudoaneurysm

No data are available for this outcome.

Secondary outcomes

Overall success rate

Ueda 2015 showed real-time B-mode ultrasound guidance may increase overall success rate when compared to DUA up to 72 hours (RR 1.13, 95% CI 0.99 to 1.29; 493 participants, 1 study; low-certainty evidence) (Analysis 4.2).

Time (minutes) needed for a successful procedure

Ueda 2015 showed real-time B-mode ultrasound guidance probably improves time needed for a successful procedure when compared to DUA up to 72 hours (MD -1.57 minutes, 95% CI -1.78 to -1.36; 493 participants, 1 study; moderate-certainty evidence) (Analysis 4.3).

Major haematoma

No data are available for this outcome.

Adverse events (minor haematoma, pain, local infection, artery thrombosis, artery embolism, nerve injury, amputation, life-threatening events; fatal events)

Ueda 2015 showed real-time B-mode ultrasound guidance may lead to no difference in haematoma or ischaemia when compared to DUA up to 72 hours (RR 1.20, 95% CI 0.70 to 2.05; 493 participants, 1 study; low-certainty evidence) (Analysis 4.4). We downgraded the certainty of evidence one level due to high risk of performance, reporting, and other bias, and another level due to imprecision: 95% CI is consistent with possible benefit and possible harm.

No data are available for pain or other adverse events.

Quality of life

No data are available for this outcome.

3.3. B-mode ultrasound guidance versus near-infrared laser guidance

See Summary of findings 5.

Primary outcomes

First-attempt success rate

Osuda 2020 showed that the effect of real-time B-mode ultrasound guidance is uncertain for first-attempt success rate when compared to near-infrared laser guidance (ILG) up to the end of the procedure (less than one hour) (RR 0.76, 95% CI 0.48 to 1.20; 72 participants, 1 study; very low-certainty evidence) (Analysis 5.1).

Pseudoaneurysm

No data are available for this outcome.

Secondary outcomes

Overall success rate

Osuda 2020 showed that the effect of real-time B-mode ultrasound guidance on overall success rate is uncertain when compared to ILG up to the end of the procedure (less than one hour) (RR 0.97, 95% CI 0.86 to 1.10; 72 participants, 1 study; very low-certainty evidence) (Analysis 5.2).

Time (minutes) needed for a successful procedure

Osuda 2020 showed that the effect of real-time B-mode ultrasound guidance on time needed for a successful procedure is uncertain when compared to ILG up to the end of the procedure (less than one hour) (MD 0.20 minutes, 95% CI 0.09 to 0.31; 72 participants, 1 study; very low-certainty evidence) (Analysis 5.3).

Major haematoma

No data are available for this outcome.

Adverse events (minor haematoma, pain, local infection, artery thrombosis, artery embolism, nerve injury, amputation, life-threatening events; fatal events)

No data are available for this outcome.

Quality of life

No data are available for this outcome.

3.4. B-mode ultrasound guidance versus modified B-mode ultrasound guidance

See Summary of findings 6.

Zhefeng 2019 compared traditional real-time B-mode ultrasound guidance versus real-time B-mode ultrasound guidance with the addition of a developing line in the transducer. This line produced an acoustic shadow that could guide radial artery catheterisation. Kim 2021a compared traditional real-time B-mode ultrasound guidance versus real-time B-mode ultrasound guidance with the addition of electromagnetic guidance. We did not perform any sensitivity analysis here because we judged both studies as having low overall risk of bias, and they had an individual parallel design.

Primary outcomes

First-attempt success rate

Real-time B-mode ultrasound guidance may decrease first-attempt success rate when compared to modified B-mode ultrasound guidance up to one hour (RR 0.68, 95% CI 0.55 to 0.84; 153 participants, 2 studies; I^2 = 86%; low-certainty evidence) (Analysis 6.1).

Pseudoaneurysm

No data are available for this outcome.

Secondary outcomes

Overall success rate

Real-time B-mode ultrasound guidance may reduce overall success rate when compared to modified B-mode ultrasound guidance up to one hour (RR 0.93, 95% CI 0.86 to 1.01; 153 participants, 2 studies; I^2 = 88%; low-certainty evidence) (Analysis 6.2).

Time (minutes) needed for a successful procedure

Real-time B-mode ultrasound guidance may lead to no difference in time needed for a successful procedure when compared to modified B-mode ultrasound guidance up to one hour (MD 0.04 minutes, 95% CI -0.01 to 0.09; 153 participants, 2 studies; I^2 = 70%; low-certainty evidence) (Analysis 6.3).

Major haematoma

We are uncertain about the effects of real-time B-mode ultrasound guidance on major haematoma when compared to modified B-mode ultrasound guidance up to 48 hours (RR 3.23, 95% CI 1.37 to 7.60; 153 participants, 2 studies; I^2 = 23%; very low-certainty evidence) (Analysis 6.4).

Adverse events (minor haematoma, pain, local infection, artery thrombosis, artery embolism, nerve injury, amputation, life-threatening events; fatal events)

Zhefeng 2019 showed real-time B-mode ultrasound guidance may lead to no difference in spasm when compared to modified B-mode ultrasound guidance up to 48 hours (RR 1.39, 95% CI 0.89 to 2.16; 77 participants, 1 study; low-certainty evidence) (Analysis 6.5). We downgraded the certainty of evidence one level due to high risk of performance and detection bias, and another level due to imprecision: 95% CI is consistent with possible benefit and possible harm.

We could not estimate the effects of arterial thrombosis because Zhefeng 2019 and Kim 2021a reported no events in both groups.

It is uncertain whether real-time B-mode ultrasound guidance leads to no difference in posterior wall puncture when compared to modified B-mode ultrasound guidance up to 24 hours (RR 8.00, 95% CI 1.05 to 60.89; 76 participants, 1 study; low-certainty evidence) (Analysis 6.6; Kim 2021a). We downgraded the certainty of evidence one level due to high risk of performance and detection bias, and two levels due to imprecision: 95% CI is wide.

No data are available for pain or other adverse events.

Quality of life

No data are available for this outcome.

3.5. In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound

See Summary of findings 7. We judged the overall risk of bias as high for Arora 2021, Cao 2020, and Sethi 2017, and as low for all of the six other studies in this comparison. We performed sensitivity analyses while excluding the trial with high overall risk of bias and did not perform a sensitivity analysis for the study design because all studies had an individual parallel design.

Primary outcomes

First-attempt success rate

Eight included studies evaluated first-attempt success rate (Abdalla 2017; Arora 2021; Cao 2020; Nam 2020; Quan 2014; Rajasekar 2021; Sethi 2017; Wang 2019).

We are uncertain about the effect of in-plane B-mode ultrasound guidance on first-attempt success rate compared with out-of-plane B-mode ultrasound guidance up to one hour (RR 0.85, 95% CI 0.65 to 1.12; 1051 participants, 8 studies; I^2 = 91%; very low-certainty evidence) (Analysis 7.1). The sensitivity analysis including only trials at low risk of bias (RR 0.92, 95% CI 0.73 to 1.17) (Analysis 7.2) did not change the effect estimate substantially.

Pseudoaneurysm

No data are available for this outcome.

Secondary outcomes

Overall success rate

Eight included studies evaluated the overall success rate (Abdalla 2017; Arora 2021; Cao 2020; Nam 2020; Quan 2014; Rajasekar 2021; Sethi 2017; Wang 2019).

In-plane B-mode ultrasound guidance may lead to no difference in the overall success rate compared with out-of-plane B-mode ultrasound guidance up to one hour (RR 1.00, 95% CI 0.96 to 1.05; 1051 participants, 8 studies; I^2 = 64%; low-certainty evidence) (Analysis 7.3). The sensitivity analysis including only trials at low risk of bias (RR 1.05, 95% CI 0.95 to 1.16) (Analysis 7.4) did not change the effect estimate substantially.

Time (minutes) needed for a successful procedure

Nine included studies evaluated the overall success rate (Abdalla 2017; Arora 2021; Berk 2013; Cao 2020; Nam 2020; Quan 2014; Rajasekar 2021; Sethi 2017; Wang 2019).

In-plane B-mode ultrasound guidance may lead to no difference in time needed for a successful procedure compared with out-of-plane B-mode ultrasound guidance up to one hour (MD -0.06 minutes, 95% CI -0.16 to 0.05; 1134 participants, 9 studies; I^2 = 88%; low-certainty evidence) (Analysis 7.5). The sensitivity analysis including only trials at low risk of bias (MD -0.05 minutes, 95% CI -0.23 to 0.12) (Analysis 7.6) did not change the effect estimate substantially.

Major haematoma

Nine included studies evaluated major haematoma (Abdalla 2017; Arora 2021; Berk 2013; Cao 2020; Nam 2020; Quan 2014; Rajasekar 2021; Sethi 2017; Wang 2019).

We are uncertain about the effect of in-plane B-mode ultrasound guidance on major haematoma compared with out-of-plane B-mode ultrasound guidance up to 72 hours (RR 0.49, 95% CI 0.22 to 1.08; 1159 participants, 9 studies; I^2 = 67%; very low-certainty evidence) (Analysis 7.7). The sensitivity analysis including only trials at low risk of bias (RR 0.59, 95% CI 0.23 to 1.54) (Analysis 7.8) did not change the effect estimate substantially.

Adverse events (minor haematoma, pain, local infection, artery thrombosis, artery embolism, nerve injury, amputation, life-threatening events; fatal events)

Abdalla 2017 reported no local infection events in both groups; therefore we are unable to estimate related effects.

Berk 2013, Quan 2014, Sethi 2017, and Wang 2019 reported no thrombosis events in both groups. Nam 2020 reported one event of thrombosis; therefore, we are uncertain about the effects of in-plane B-mode ultrasound on thrombosis compared with out-of-plane B-mode ultrasound guidance up to 72 hours (RR 3.18, 95% CI 0.13 to 76.69; 136 participants, 1 study; very low-certainty evidence) (Analysis 7.9). We downgraded the certainty of evidence one level due to high risk of performance bias, and two levels due to imprecision: wide 95% CI is consistent with possible benefit and possible harm. The sensitivity analysis including only trials at low risk of bias (RR 3.18, 95% CI 0.13 to 76.69) (Analysis 7.10) did not change the effect estimate.

Quan 2014 and Sethi 2017 reported no oedema events in both groups. Berk 2013 reported one event of oedema. It is uncertain if in-plane B-mode ultrasound guidance leads to no difference in oedema compared with out-of-plane B-mode ultrasound guidance up to 72 hours (RR 0.07, 95% CI 0.00 to 1.14; 108 participants, 1 study; very low-certainty evidence) (Analysis 7.11). We downgraded the certainty of evidence one level due to high risk of performance bias, and two levels due to imprecision: wide 95% CI is consistent with possible benefit and possible harm. The sensitivity analysis including only trials at low risk of bias (RR 0.07, 95% CI 0.00 to 1.14) (Analysis 7.12) did not change the effect estimate.

Quan 2014 reported no vasospasm in both groups. Berk 2013, Nam 2020, Rajasekar 2021, Sethi 2017, and Wang 2019 reported vasospasm events, but we are uncertain about the effect of in-plane B-mode ultrasound guidance on vasospasm compared with out-of-plane B-mode ultrasound guidance up to 72 hours (RR 0.80, 95% CI 0.24 to 2.69; 748 participants, 6 studies; I^2 = 53%; very low-certainty evidence) (Analysis 7.13). We downgraded the certainty of evidence one level due to high risk of performance, reporting, and other bias, one level due to inconsistency (unexplained substantial heterogeneity), and two levels due to imprecision: wide 95% CI is consistent with possible benefit and possible harm. The sensitivity analysis including only trials at low risk of bias (RR 0.95, 95% CI 0.25 to 3.54) (Analysis 7.14) did not change the effect estimate.

Berk 2013, Nam 2020, and Wang 2019 evaluated posterior wall damage, but we are uncertain about the effect of in-plane B-mode ultrasound guidance on posterior wall damage compared with out-of-plane B-mode ultrasound guidance up to 72 hours (RR 0.45, 95% CI 0.10 to 1.97; 375 participants, 3 studies; I^2 = 86%; very low-certainty evidence) (Analysis 7.15). We downgraded the certainty of evidence one level due to high risk of performance and other bias, one level due to inconsistency (unexplained substantial heterogeneity), and one level due to imprecision: 95% CI is consistent with possible benefit and possible harm. We did not

perform any sensitivity analysis because we judged all three studies as having low risk of bias, and they had a parallel design.

No data are available for pain or other adverse events.

Quality of life

No data are available for this outcome.

3.6. Doppler auditory ultrasound assistance versus palpation and landmarks

See Summary of findings 8. We judged the overall risk of bias as high for Ueda 2015 and as low for Tada 2003. We performed sensitivity analyses while excluding the trial with high overall risk of bias and did not perform a sensitivity analysis for study design because studies had an individual parallel design.

Primary outcomes

First-attempt success rate

Ueda 2015 and Tada 2003 showed DUA may lead to no difference in first-attempt success rate compared to palpation and landmarks up to one hour (RR 1.01, 95% CI 0.90 to 1.14; 2 studies, 666 participants; low-certainty evidence) (Analysis 8.1). The sensitivity analysis including only trials at low risk of bias (RR 1.02, 95% CI 0.88 to 1.17) (Analysis 8.2) did not change the effect estimate.

Pseudoaneurysm

No data are available for this outcome.

Secondary outcomes

Overall success rate

Ueda 2015 and Tada 2003 showed DUA may lead to no difference in overall success rate when compared to palpation and landmarks up to one hour (RR 0.99, 95% CI 0.92 to 1.07; 666 participants, 2 studies; low-certainty evidence) (Analysis 8.3). The sensitivity analysis including only trials at low risk of bias (RR 1.00, 95% CI 0.96 to 1.03) (Analysis 8.4) did not change the effect estimate.

Time (minutes) needed for a successful procedure

Ueda 2015 showed DUA probably increases time needed for a successful procedure when compared to palpation and landmarks up to one hour (MD 0.45 minutes, 95% CI 0.20 to 0.70; 500 participants, 1 study; moderate-certainty evidence) (Analysis 8.5).

Major haematoma

No data are available for this outcome.

Adverse events (minor haematoma, pain, local infection, artery thrombosis, artery embolism, nerve injury, amputation, life-threatening events; fatal events)

Ueda 2015 showed DUA may lead to no difference in haematoma or ischaemia when compared to palpation and landmarks up to 72 hours (RR 0.80, 95% CI 0.47 to 1.35; 500 participants, 1 study; low-certainty evidence) (Analysis 8.6). We downgraded the certainty of evidence one level due to high risk of performance, reporting, and other bias, and one level due to imprecision: 95% CI is consistent with possible benefit and possible harm.

No data are available for pain or other adverse events.

Quality of life

No data are available for this outcome.

3.7. Dynamic out-of-plane B-mode ultrasound versus static out-of-plane B-mode ultrasound

See Summary of findings 9. Only Bai 2020 had data for this comparison and was judged as having low overall risk of bias.

Primary outcomes

First-attempt success rate

We are uncertain about the effect of dynamic out-of-plane B-mode ultrasound on first-attempt success rate compared to static out-of-plane B-mode ultrasound up to one hour (RR 0.91, 95% CI 0.67 to 1.23; 131 participants; 1 study; very low-certainty evidence) (Analysis 9.1).

Pseudoaneurysm

No data are available for this outcome.

Secondary outcomes

Overall success rate

We are uncertain about the effect of dynamic out-of-plane B-mode ultrasound on overall success rate compared to static out-of-plane B-mode ultrasound up to one hour (RR 1.07, 95% CI 0.92 to 1.25; 131 participants; 1 study; very low-certainty evidence) (Analysis 9.2).

Time (minutes) needed for a successful procedure

We are uncertain about the effect of dynamic out-of-plane B-mode ultrasound on time needed for a successful procedure compared to static out-of-plane B-mode ultrasound up to one hour (MD 0.37, 95% CI 0.07 to 0.66; 131 participants, 1 study; very low-certainty evidence) (Analysis 9.3).

Major haematoma

No data are available for this outcome.

Adverse events (minor haematoma, pain, local infection, artery thrombosis, artery embolism, nerve injury, amputation, life-threatening events; fatal events)

We are uncertain about the effect of dynamic out-of-plane B-mode ultrasound on posterior wall puncture compared to static out-of-plane B-mode ultrasound up to one hour (RR 0.52, 95% CI 0.34 to 0.81; 131 participants; 1 study; very low-certainty evidence) (Analysis 9.3). We downgraded one level due to high risk of performance bias, one level due to indirectness (few participants are not representative of the overall relevant population), and one level due to imprecision (few participants).

No data are available for pain or other adverse events.

Quality of life

No data are available for this outcome.

3.8. Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound

See Summary of findings 10. We judged overall risk of bias as high for Cao 2020 and Zeng 2020, and as low for Abdalla 2017. We performed sensitivity analyses while excluding trials with high

overall risk of bias and did not perform a sensitivity analysis for the study design because all studies had an individual parallel design.

Primary outcomes

First-attempt success rate

Abdalla 2017, Cao 2020, and Zeng 2020 showed that the effect of oblique-axis in-plane B-mode ultrasound on first-attempt success rate is uncertain when compared to long-axis in-plane B-mode ultrasound up to 72 hours (RR 1.11, 95% CI 0.44 to 2.79; 275 participants, 3 studies; I^2 = 87%; very low-certainty evidence) (Analysis 10.1). The sensitivity analysis including only trials at low risk of bias (RR 2.36, 95% CI 1.35 to 4.14) (Analysis 10.2) changed the effect estimate.

Pseudoaneurysm

No data are available for this outcome.

Secondary outcomes

Overall success rate

Abdalla 2017 and Cao 2020 showed oblique-axis in-plane B-mode ultrasound may slightly improve the overall success rate compared to long-axis in-plane B-mode ultrasound up to 72 hours (RR 1.27, 95% CI 1.05 to 1.53; 215 participants, 2 studies; I^2 = 0%; low-certainty evidence) (Analysis 10.3). The sensitivity analysis including only trials at low risk of bias (RR 1.28, 95% CI 1.01 to 1.61) (Analysis 10.4) did not change the effect estimate.

Time (minutes) needed for a successful procedure

Abdalla 2017, Cao 2020, and Zeng 2020 showed that the effect of oblique-axis in-plane B-mode ultrasound on time needed for a successful procedure is uncertain when compared to long-axis in-plane B-mode ultrasound up to 72 hours (MD -0.35 minutes, 95% CI -0.95 to 0.25; 275 participants; 3 studies; I^2 = 99%; very low-certainty evidence) (Analysis 10.5). The sensitivity analysis including only trials at low risk of bias (MD -0.83 minutes, 95% CI -0.88 to -0.79) (Analysis 10.6) changed the effect estimate.

Major haematoma

Abdalla 2017 and Cao 2020 showed that the effect of oblique-axis in-plane B-mode ultrasound on overall success rate is uncertain when compared to long-axis in-plane B-mode ultrasound up to 72 hours (RR 0.68, 95% CI 0.32 to 1.47; 215 participants, 2 studies; I^2 = 0%; very low-certainty evidence) (Analysis 10.7). The sensitivity analysis including only trials at low risk of bias (RR 0.55, 95% CI 0.22 to 1.34) (Analysis 10.8) did not change the effect estimate.

Adverse events (minor haematoma, pain, local infection, artery thrombosis, artery embolism, nerve injury, amputation, life-threatening events; fatal events)

Zeng 2020 showed that the effect of oblique-axis in-plane B-mode ultrasound on vasospasm or haematoma is uncertain when compared to long-axis in-plane B-mode ultrasound up to 72 hours (RR 0.09, 95% CI 0.01 to 1.57; 60 participants; 1 study; very low-certainty evidence) (Analysis 10.9).

Abdalla 2017 and Cao 2020 showed that the effect of oblique-axis in-plane B-mode ultrasound on time needed for a successful procedure is uncertain when compared to long-axis in-plane B-mode ultrasound up to 72 hours (RR 4.64, 95% CI 0.23 to 94.77; 215 participants, 2 studies; I^2 = 0%; very low-certainty evidence) (Analysis 10.10). We did not perform the sensitivity analysis including only trials at low risk of bias because Abdalla 2017 reported no events in both groups.

Abdalla 2017 also reported no events of local infection in both groups. Therefore, we could not estimate the effect of intervention on this outcome.

No data are available for pain or other adverse events.

Quality of life

No data are available for this outcome.

DISCUSSION

Summary of main results

This review assessed the effects of ultrasound guidance for arterial (other than femoral) catheterisation in adults. We included 48 randomised controlled trials (RCTs) that used Doppler auditory ultrasound assistance (DUA) or direct ultrasound guidance (DUG) with B-mode or any other modified ultrasound technique in 7997 participants. These studies compared ultrasound guidance with palpation and landmarks or with another ultrasound intervention for catheterisation in axillary, dorsalis pedis, or radial artery.

Two trials did not report any data that we could use in our analysis (Edanaga 2012; Fujita 2012). The other 46 included studies provided data for 10 different comparisons. We found few data related to pseudoaneurysm, adverse events, and quality of life (QoL), but all relevant outcomes had available data.

We found no data regarding indirect ultrasound guidance, nor data at more than 30 days after intervention.

Axillary artery

Real-time B-mode ultrasound versus palpation and landmarks

We are uncertain about the effect of real-time B-mode ultrasound guidance on overall success rate, time needed for a successful procedure, and major haematoma when compared to palpation and landmarks up to one hour (Summary of findings 1). First-attempt success rate, pseudoaneurysm, pain, and QoL were not reported.

Dorsalis pedis artery

Real-time B-mode ultrasound versus palpation and landmarks

We are uncertain about the effect of real-time B-mode ultrasound guidance on first-attempt success rate, overall success rate, and time needed for a successful procedure when compared to palpation and landmarks up to one hour (Summary of findings 2). Pseudoaneurysm, major haematoma, pain, and QoL were not reported.

Radial artery

Real-time B-mode ultrasound versus palpation and landmarks

Real-time B-mode ultrasound guidance may improve first-attempt success rate or overall success rate, or may decrease time needed for a successful procedure up to one hour compared to palpation and landmarks. B-mode ultrasound guidance probably decreases major haematoma up to one month compared to palpation and landmarks. We are uncertain about effects on

pseudoaneurysm, pain, and QoL because the certainty of evidence is very low (Summary of findings 3).

Real-time B-mode ultrasound versus DUA

Real-time B-mode ultrasound guidance probably improves first-attempt success rate and time needed for a successful procedure up to one hour compared to DUA. B-mode ultrasound guidance may increase overall success up to one hour and adverse events up to 72 hours compared to DUA (Summary of findings 4).

Real-time B-mode ultrasound versus near-infrared laser

We are uncertain about the effect of real-time B-mode ultrasound guidance on first-attempt success rate, overall success rate, and time needed for a successful procedure up to the end of the procedure (less than one hour) compared to near-infrared laser guidance (Summary of findings 5).

Real-time B-mode ultrasound versus modified real-time B-mode ultrasound

Real-time B-mode ultrasound guidance may decrease first-attempt success rate, may reduce overall success rate, and may lead to no difference in time needed for a successful procedure up to one hour compared to modified real-time B-mode ultrasound guidance. We are uncertain about effects on major haematoma because the certainty of evidence is very low (Summary of findings 6).

In-plane versus out-of-plane B-mode ultrasound

In-plane B-mode ultrasound guidance may lead to no difference in overall success rate and time needed for a successful procedure up to one hour. It is uncertain if in-plane B-mode ultrasound guidance leads to no difference in first-attempt success rate and haematoma up to one hour or leads to no difference in adverse events up to 72 hours compared to out-of-plane B-mode ultrasound guidance because the certainty of evidence is very low (Summary of findings 7).

DUA versus palpation and landmarks

DUA may lead to no difference in first-attempt success rate, overall success rate, or adverse events, and probably increases time needed for a successful procedure up to one hour compared to palpation and landmarks (Summary of findings 8).

Dynamic versus static out-of-plane B-mode ultrasound

We are uncertain about the effect of dynamic out-of-plane B-mode ultrasound guidance on first-attempt success rate, overall success rate, time needed for a successful procedure, or adverse events up to one hour compared to static out-of-plane B-mode ultrasound guidance (Summary of findings 9).

Oblique-axis versus long-axis in-plane B-mode ultrasound

Oblique-axis in-plane B-mode ultrasound guidance may slightly improve overall success rate up to 72 hours compared to long-axis in-plane B-mode ultrasound guidance. It is uncertain if oblique-axis in-plane B-mode ultrasound guidance leads to no difference in first-attempt success rate, time needed for a successful procedure, major haematoma, or adverse events up to 72 hours compared to long-axis in-plane B-mode ultrasound guidance (Summary of findings 10). We assessed differences between analyses with studies judged at high overall risk of bias and those judged at low overall risk of bias in sensitivity analyses. The direction and size of effects changed substantially in favour of oblique-axis intervention for first-attempt success rate and time needed for a successful procedure in the sensitivity analysis.

Overall completeness and applicability of evidence

Most evidence was obtained from people hospitalised with a severe disease that required arterial sample for blood test or pressure monitoring (diagnosis purposes), undergoing major surgery, or at high risk of cardiovascular events; therefore, evidence regarding ultrasound guidance for arterial (other than femoral) catheterisation in adults at lower risk and for therapeutic purposes remains uncertain. Second, information on clinical endpoints for all included studies was based on data until 30 days after the intervention only (i.e. no included studies evaluated long-term outcomes, mainly those as important as pseudoaneurysm, major haematoma, and other adverse events). Often follow-up for these trials was less than one hour, hence information on long-term efficacy and safety is absent. Cochrane Reviews focus on patient-relevant outcomes, and pseudoaneurysm is the most relevant adverse event in this setting. All other adverse events, regardless of their prevalence, are already addressed in our other outcomes (major haematoma and adverse events), but related available evidence is sparse.

Although most studies reported our primary outcome of first-attempt success rate, we identified very little evidence related to pseudoaneurysm and adverse events after arterial catheterisation. It is also noteworthy that no included studies clearly defined major haematoma, and only one study measured our secondary outcome quality of life.

We noted substantial heterogeneity in the methods of the included studies, some of which did not provide complete and clear information about their data. For instance, differentiation between ultrasound methods with or without needle tip control for a formal subgroup analysis is insufficient (fewer than 10 trials reported details). This is particularly relevant to allow the operator to sustain the target vessel and the needle, including the needle tip, under visual guidance during the entire dynamic procedure. This hindered quantitative analyses (e.g. increasing heterogeneity) and assessment of risk of bias in many studies.

The number of trials for nine of the ten possible comparisons was small, ranging from one to nine studies. Only one comparison involved 28 trials. Moreover, the included studies had small primary sample sizes (from 33 to 749 participants). Four studies randomised more than 400 participants, and all others analysed not more than 285 participants.

Another issue was the fact that we had two trials that fulfilled our selection criteria but could not be included in the analyses because their data were incompletely described, and we were unable to obtain full data, despite contacting the trialists.

Quality of the evidence

The certainty of evidence is very low to moderate. We downgraded the certainty of evidence due to risk of bias, particularly concerning lack of blinding of staff and participants, which could have an impact on the non-pharmacological intervention. We downgraded the certainty of evidence due to heterogeneity not explained among studies. We also downgraded the certainty of evidence due to imprecision resulting from small numbers of participants and wide

95% confidence intervals that are consistent with possible benefit and possible harm.

Reporting bias was addressed in funnel plots with the aid of additional statistical tests; this approach shows a degree of asymmetry involving small sample size studies, with an effect favouring palpation and landmarks absent for some primary and secondary outcomes. Currently available trials have been conducted primarily for scientific purposes without industry financial support; even so, it seems likely that any such studies, especially those with a negative effect of the new technology (ultrasound), remain unpublished. Besides, it is likely that this seeming asymmetry is a result of smaller studies selecting a different (possibly higher-risk) patient population to increase power.

Potential biases in the review process

We conducted a sensitive search of the literature, and we believe that we identified all relevant trials that met our inclusion criteria. However, we may have missed some trials, particularly in the grey literature.

We adhered to the inclusion and exclusion criteria prespecified in the protocol to limit subjectivity (Flumignan 2020). We made efforts to obtain additional relevant data from study authors but were unable to do so in some cases. If we can source supplementary data, we will consider them in future updates.

Selection, data extraction, and 'Risk of bias' assessment of included studies were performed in duplicate by two independent review authors to reduce potential bias in the review process. Additional analyses (subgroups and sensitivity analysis) were performed as planned in our protocol, but our conclusions were based on our primary analysis (Flumignan 2020).

Agreements and disagreements with other studies or reviews

A number of systematic reviews and meta-analyses have examined ultrasound guidance for arterial access, but most of them have evaluated mixed populations with paediatric and adult participants. Ultrasound guidance seems to have a role for arterial access in children and neonates, who have significantly smaller arterial diameters, higher heart rates, and vasoreactivity compared to adults (Aouad-Maroun 2016).

Shiloh 2011 searched randomised controlled trials (RCTs) in MEDLINE, Embase, Cochrane CENTRAL, and abstracts of societies of speciality without language or date limits. They searched only for RCTs comparing real-time ultrasound guidance versus palpation and landmarks for radial artery access. They used the obsolete Jadad criteria for risk of bias assessment. Although they considered adults and children, Shiloh 2011 included less than 10% of our number of participants for the same comparison, maybe because they used a limited and not sensible search strategy, and they ran it 10 years ago. Nevertheless, Shiloh 2011 included 311 participants and found that real-time B-mode ultrasound guidance increased first-attempt success rate in 71% compared to palpation. This group reported a reduction in haematoma from 50% in the palpation group to 7% in the ultrasound group in one of their included studies.

Gu 2014 used an even more limited search strategy in MEDLINE and Embase databases only. They included five trials with mixed adult and children populations - 129 adults from two trials included - that compared real-time B-mode ultrasound guidance versus palpation for radial artery catheterisation. They found 85% improvement in first-attempt success rate and reduction of 21% in mean time to success, favouring ultrasound.

Tang 2014 searched PubMed, Embase, and Cochrane CENTRAL for RCTs that compared real-time B-mode ultrasound guidance versus palpation for radial artery catheterisation. They analysed seven trials with mixed children and adult populations (241 adults from four trials). Tang 2014 found that ultrasound guidance increased first-attempt success rate in 51% and reduced haematoma rate in 83%.

Gao 2016 searched PubMed, Embase, and Cochrane CENTRAL for RCTs, published in English, that compared in-plane versus out-of-plane ultrasound guidance for vascular access. They included five trials that analysed vein and artery (271 participants from two trials) access in adult populations. Gao 2016 found no difference between in-plane and out-of-plane ultrasound guidance for first-attempt success rate, mean time for success, and haematoma.

Gu 2016 searched PubMed, Embase, and Cochrane CENTRAL, and ClinicalTrials.gov for RCTs that compared real-time B-mode ultrasound guidance or Doppler auditory ultrasound assistance (DUA) versus palpation for radial artery access. They included 13 RCTs, which analysed B-mode ultrasound guidance or DUA in paediatric or adult populations, used GRADE to assess the certainty of evidence, and used funnel plots to assess reporting bias. Gu 2016 analysed 2161 adults in 10 RCTs, which were also included in our review. They found that B-mode ultrasound guidance increased first-attempt success rate in 31% (moderate-certainty evidence), mean time to success in 43 seconds (very low-certainty evidence), and haematoma in 61% (low-certainty evidence). They also found no difference between DUA and palpation for first-attempt success rate (low-certainty evidence). Gu 2016 declared that their evidence of effect was sufficient and conclusive, and they were not suspicious of reporting bias based on funnel plots.

White 2016 searched CINAHL, SCOPUS, PubMed, MEDLINE, and Web of Science for RCTs that compared B-mode ultrasound guidance versus palpation for radial artery access in adult or paediatric populations. They included 11 trials, six of which analysed adult participants (n = 1080). They found that, compared with palpation, B-mode ultrasound guidance increased by 40% the first-attempt success rate, with no difference in haematoma.

Bhattacharjee 2018 searched PubMed and Cochrane CENTRAL for RCTs that compared B-mode ultrasound guidance versus palpation for radial artery access in adults. They included only published trials that reported first-attempt success rate or overall success rate, and they excluded trials that performed arterial puncture for blood sampling. They used a modified Cochrane tool for risk of bias (other bias was not assessed) and funnel plots for assessment of reporting bias. They found that, compared to palpation, B-mode ultrasound guidance increased first-attempt success rate (odds ratio (OR) 2.76, 95% confidence interval (CI) 1.86 to 4.1; n = 1835), led to no difference in overall success rate (OR 2.01, 95% CI 1.00 to 4.06; n = 1402), resulted in no difference in time for a successful procedure (standard mean difference (SMD) -0.31 minutes, 95% CI -0.65 to 0.04; n = 1855); and produced no difference in haematoma

(OR 0.53, 95% CI 0.21 to 1.29; n = 790). Bhattacharjee 2018 declared that visual inspection of funnel plots revealed no publication bias.

Pacha 2018 searched MEDLINE, Embase, and Cochrane CENTRAL for RCTs that compared B-mode ultrasound guidance versus palpation for radial artery access in adults. Although review authors applied no language restrictions, they included only published trials since 1996 to January 2018 - those reporting first-attempt success rate or overall success rate - and excluded trials that performed arterial puncture for blood sampling. They found that, compared to palpation, B-mode ultrasound guidance increased first-attempt success rate in 35% but led to no difference in mean time for a successful procedure nor in haematoma.

Zhao 2020 searched PubMed, Embase, and Cochrane CENTRAL for RCTs that compared ultrasound-guided versus palpation techniques for radial artery catheterisation in children and adults. They imposed no restrictions for publication status and language of trial reports, used a non-validated scale to judge the quality of trials, examined funnel plots and additional statistical tests to investigate reporting bias, and did not use the GRADE approach for certainty of evidence. They found that, compared to palpation, B-mode ultrasound guidance increased first-attempt success rate (risk ratio (RR) 1.39, 95% CI 1.21 to 1.59), decreased mean time to success (SMD -41.18 seconds, 95% CI -75.43 to -6.93), and decreased haematoma (RR 0.40, 95% CI 0.22 to 0.72).

Our review seems to be more comprehensive than these identified previous reviews, which used limited search strategies, imposed language or date limits, searched overlapping databases (e.g. SCOPUS, PubMed, MEDLINE, Web of Science in the same review), or searched a limited number of databases (e.g. PubMed, Cochrane CENTRAL only). Besides, these previous reviews analysed only one or two of all our possible comparisons of ultrasound guidance for arterial (other than femoral) access. Although Bhattacharjee 2018, Gu 2016, and Zhao 2020 used funnel plots, they did not identify the suspicion of reporting bias with impact on the estimation of effect identified in our review. Only Gu 2016 used the GRADE approach to assess the certainty of evidence. Similar to our review, these review authors found an increased first-attempt success rate in B-mode ultrasound guidance compared to palpation for radial artery catheterisation. However, their results for time needed for a successful procedure and for haematoma are conflicting. Moreover, our conclusions are more circumspect.

AUTHORS' CONCLUSIONS

Implications for practice

We are uncertain about effects for the following comparisons due to very low-certainty evidence and unreported outcomes: real-time B-mode ultrasound versus palpation and landmarks for axillary and dorsalis pedis arteries, real-time B-mode ultrasound versus near-infrared laser for radial artery, and dynamic versus static out-of-plane B-mode ultrasound for radial artery. Besides, all low- to moderate-certainty evidence is related to the radial artery.

Real-time B-mode ultrasound guidance probably has a relevant role for radial artery catheterisation guidance due to the body of evidence presented here. This systematic review and meta-analysis found that B-mode ultrasound guidance probably reduces major haematoma compared to palpation and probably improves first-attempt success rate and time needed for a successful procedure compared to Doppler assistance. We also found that Doppler assistance increases time needed for a successful procedure compared to palpation for a radial artery procedure. Still, we were underpowered to find other moderate- and high-certainty evidence for most other outcomes.

In addition, real-time B-mode ultrasound guidance may improve first-attempt success rate and overall success rate and may decrease time needed for a successful procedure up to one hour compared to palpation and landmarks. Furthermore, real-time B-mode ultrasound guidance may improve overall success rate up to 72 hours compared to DUA. Finally, real-time B-mode ultrasound guidance may decrease first-attempt success rate and overall success rate and may lead to no difference in time needed for a successful procedure up to one hour compared to modified real-time B-mode ultrasound guidance. However, data are lacking, or evidence is of very low certainty, for other relevant outcomes: it is uncertain whether real-time B-mode ultrasound guidance has any effect on pseudoaneurysm, pain, and quality of life (QoL) compared to palpation and landmarks; pseudoaneurysm, major haematoma, pain, and QoL were not reported for the comparison with DUA; and it is uncertain whether real-time B-mode ultrasound guidance has any effect on major haematoma compared to modified real-time B-mode ultrasound (pseudoaneurysm, pain, and QoL were not reported).

Evidence is lacking, is of very low certainty, or shows no significant differences related to all other relevant outcomes when in-plane versus out-of-plane real-time B-mode ultrasound guidance are compared up to one hour; DUA is compared with palpation and landmarks up to 72 hours; and oblique-axis is compared with long-axis in-plane B-mode ultrasound guidance up to 72 hours. Data for indirect ultrasound guidance and for effects 30 days after the intervention are lacking; therefore, no conclusions for a long-term time point can be drawn.

Implications for research

Given that first-attempt success rate and pseudoaneurysm are the most relevant outcomes for people who underwent arterial catheterisation and for their clinicians, it is important that future studies of ultrasound guidance for arterial catheterisation measure both as primary outcomes. Future trials need to be large enough to detect effects on clinical outcomes; they should not only include the main clinical outcomes (first-attempt success rate and pseudoaneurysm), but should also measure overall success rate, time needed for a successful procedure, major haematoma, adverse events, and QoL, and they should use validated scales. All foreseen outcomes must be reported at the end of the trial. Finally, studies must be of at least six months' duration of long-term effects of ultrasound guidance during the post-intervention period are to be assessed. Six months may be long enough to provide additional data on rare adverse events following arterial catheterisation and to assess its effects during the post-discharge period (e.g. pseudoaneurysm, thrombosis, major haematoma, nerve injury, amputation). Future trials should include participants with no or more previous arterial punctures, and should provide individual data by type of anaesthesia during the intervention. Continuous outcome data must be uniform, and similar scales should be used, especially for pain and for QoL.

Additional studies with the characteristics suggested above comparing ultrasound guidance with all other control interventions

are needed to evaluate ultrasound guidance for wider clinical use in people who have undergone arterial catheterisation. The 20 ongoing studies that we identified, which aimed to recruit over 2737 participants altogether, will add to the evidence presented here related to real-time B-mode ultrasound guidance and DUA.

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* Indicates the major publication for the study

CHARACTERISTICS OF STUDIES

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

Abdalla 2017

Study characteristics	
Methods	Single-centre prospective randomised controlled 3-arm parallel-assignment open-label study Egypt Duration: February 2015 to August 2015
Participants	• 126 participants randomised (experimental (oblique, in-plane) = 42, comparator (transverse, out-of-plane) = 42, comparator (longitudinal, in-plane) = 42) • 126 analysed • mean age (years) ± SD: 53 ± 16 (experimental), 55 ± 11 (comparator, transverse), 59 ± 9 (comparator, longitudinal) • gender (male/female): not reported • severity of condition: 80 operative participants, 46 ICU participants • comorbidities: not reported • body weight (kg): 82 ± 27 (experimental, oblique), 84 ± 31 (comparator, longitudinal), 84 ± 32 (comparator, transverse) • height (cm): 165 ± 7 (experimental, oblique), 167 ± 5 (comparative, longitudinal), 164 ± 8 (comparator, transverse) • artery of interest: radial • diameter (mm), mean ± SD: 1.6 ± 0.61 (experimental, oblique), 1.6 ± 0.31 (comparative, longitudinal), 1.8 ± 1.07 (comparator, transverse) • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or blood test, % not reported) Inclusion criteria • ASA I or II surgically listed or ICU-admitted patients indicated for radial artery catheterisation • both sexes • age from 20 to 50 years • BMI < 35 Exclusion criteria • positive Allen's test • coagulopathy (INR ≥ 1.5; platelet count ≤ 70 × 10^3/μL) • peripheral arterial disease • infection • burn at site of insertion
Interventions	Experimental: ultrasound-guided RA puncture (artery in oblique view, real-time, in-plane)

Abdalla 2017 *(Continued)*

	Comparator (longitudinal): ultrasound-guided RA puncture (artery in long axis, real-time, in-plane) Comparator (transverse): ultrasound-guided RA puncture (artery in short axis, real-time, out-of-plane) Level of experience of person carrying out the procedure: not reported Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • success rate of radial artery catheterisation up to 72 hours Primary (collected) • success rate • first-attempt success • time to cannulate • number of attempts • operator satisfaction • complications (haematoma, ischaemia, local infection) Secondary (specified) • not provided Secondary (collected) • no differentiation between primary and secondary outcomes Time points reported: until 72 hours after the procedure
Notes	Funding: study authors declared there was nil financial support and sponsorship Conflicts of interest: quote: "none" Protocol available (NCT02550223)

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Quote: "patients were randomly allocated into 3 equal groups using closed envelope technique in 7 blocks of 18 (6 patients for each group)"
Allocation concealment (selection bias)	Unclear risk	Quote: "patients were randomly allocated into 3 equal groups using closed envelope technique in 7 blocks of 18 (6 patients for each group)"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "a prospective randomized nonblinded study"
Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "a prospective randomized nonblinded study"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses

Abdalla 2017 *(Continued)*

Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Ammar 2017

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment open-label study Pakistan Duration: December 2015 to July 2016.
Participants	• 100 participants randomised (experimental = 50, comparator = 50) • 100 analysed • mean age (years) ± SD: 44.60 ± 7.54 (experimental), 45.54 ± 5.15 (comparator) • gender (male/female): 46/4 (experimental), 45/5 (comparator) • severity of condition: not reported • comorbidities: not reported • body weight (kg): not reported • height (cm): not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring and blood test, % not reported) Inclusion criteria • age > 20 years • any indication for arterial line catheterisation (continuous monitoring of arterial blood pressure and need for frequent arterial blood gas analysis) Exclusion criteria • haemodynamically unstable patients for whom arterial line was inserted before informed consent was received • previous attempts at radial line insertion
Interventions	Experimental: ultrasound-guided RA puncture (artery in short axis, real-time, out-of-plane) Comparator: percutaneously RA puncture by anatomical landmarks and palpation technique Level of experience of person carrying out the procedure: not reported Concomitant medications: local anaesthesia (details not provided) Excluded medications: not reported
Outcomes	Primary (specified) • time of insertion in first attempts • number of first successful attempts • maximum number of attempts used for insertion of arterial line Primary (collected)

Ammar 2017 *(Continued)*

- success rate (number of patients cannulated)
- first-attempt success
- number of attempts
- time to cannulate in first attempt

Secondary (specified)

- not provided

Secondary (collected)

- not provided

Time points reported: up to the end of the procedure (not specified)

Notes	Funding: not reported Conflicts of interest: not reported Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of interventions, we assumed that blinding of personnel is not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	Although there is no registered protocol, all prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Anand 2019

Study characteristics

Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment study (no mention of masking) India

Anand 2019 *(Continued)*

	Total duration and date of study not clear
Participants	• 60 participants randomised (experimental = 30, comparator = 30) • 60 analysed • mean age (years) ± SD: 41.4 ± 16.2 (experimental), 41.4 ± 19 (comparator) • gender (male/female): 16/14 (experimental), 18/12 (comparator) • severity of condition: participants undergoing ENT and maxillofacial surgery • comorbidities: not reported • body weight (kg): 55.2 ± 8.5 (experimental), 58.6 ± 9.8 (comparator) • height (cm): 164.7 ± 12.9 (experimental), 166.8 ± 13.5 9 (comparator) • artery of interest: dorsalis pedis artery • diameter: not reported • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring) Inclusion criteria • adult patients (between 18 and 65 years of age) • both sexes • undergoing any head–neck surgery or facio-maxillary surgery requiring arterial cannulation Exclusion criteria • Refusal to participate • Absence of an amplitude of DPA pulsation • Skin erosions near insertion site • Obesity defined by BMI > 30 kg/m^2
Interventions	Experimental: ultrasound-guided DPA puncture (artery in long axis, real-time, in-plane) Comparator: percutaneously punctured DPA by palpation technique Level of experience of person carrying out the procedure: quote: "all the cannulations were performed by a single investigator (Rahul Kumar Anand) who had experience of >50 DPA cannulations using each technique to minimise inter-individual variability in skills" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • first-attempt success to cannulate DPA • number of attempts to cannulate DPA. Time points reported: from skin puncture to artery cannulation Primary (collected) • First-attempt success to cannulate DPA Secondary (specified) • Time to success of DPA cannulation • Failure of DPA cannulation • Success rate of DPA cannulation • Number of patients in whom cross-over of DPA cannulation is done • Number of patients for whom procedure is abandoned • Incidence of complications of DPA cannulation. Time points reported: from skin puncture to artery cannulation Secondary (collected)

Anand 2019 *(Continued)*

	• number of attempts to cannulate • requirement of alternative techniques • screening time • cannulation time • total procedure time • cannulation failure • incidence of complications (digital ischaemia, haemorrhage, thrombosis, haematoma formation) Time points reported: until the end of the procedure (24 to 48 seconds)
Notes	Funding: study authors declared there was nil financial support and sponsorship Conflicts of interest: quote: "there are no conflicts of interest" Register number informed in the publication (CTRI/2018/04/019691) was not localised. We found another registration number (CTRI/2018/08/015525) related to this study

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "randomization sequence was generated by a web-based randomization program (www.randomizer.org)"
Allocation concealment (selection bias)	Low risk	Quote: "it was kept inside serially numbered opaque-sealed envelopes. Sealed envelopes were opened to reveal allocation just before the DPA cannulation"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Although the participant underwent the intervention after general anaesthesia, personnel for the intervention group were not blinded
Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "primary and secondary outcome data were collected by an unblinded anaesthesiologist who was not a part of this study"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses. Cross-over was done for 3 participants (1 participant in experimental group and 2 in comparator group), and successful cannulation was done in 1 patient of comparator group. The other 2 participant procedures were abandoned
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Arora 2021

Study characteristics

Methods	Single-centre prospective randomised study Oman Duration: not mentioned

Arora 2021 *(Continued)*

Participants	• 90 participants included; 84 completed the study with successful left radial artery cannulation. 6 were excluded due to surgical team decision • experimental group (out-of-plane) n = 42; control group (in-plane) n = 42 for left radial artery cannulation • mean age (years) SD: 54.10 53 ± 17.17(experimental), 56.69 ± 14.82(experimental) • gender (male/female): not reported • severity of condition: 84 operative participants (coronary bypass) • comorbidities: not reported • body mass index: 26.89 ± 4.22 (experimental, out-of-plane), 26.98 ± 4.17 (comparator, in-plane) • artery of interest: left radial • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring) Inclusion criteria • undergoing coronary bypass surgery • both sexes • positive modified Allen's test Exclusion criteria • negative Allen's test • ulnar artery occlusion • prevalent atherosclerosis • haemorrhagic shock • morbid obesity • Raynaud disease • peripheral vascular disease • myocardial infarction • unstable angina • cardiogenic shock • coagulation disorder • skin infection over insertion site • multiple previous radial artery interventional attempts
Interventions	Experimental (longitudinal): ultrasound-guided RA puncture (artery in long axis, real-time, in-plane) Comparator (transversal): ultrasound-guided RA puncture (artery in long axis, real-time, out-of-plane) Level of experience of person carrying out the procedure: quote: "the procedure in both groups was performed by the same experienced anesthesiologist, who had previously performed more than 50 radial artery cannulations in adult patients using either the in-plane or the out-of-plane ultrasound approach" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • number of first-pass successful attempts • number of times cannula was re-directed • number of skin punctures • haematoma • number of failed attempts Primary (collected)

Arora 2021 *(Continued)*

- number of first-pass successful attempts
- number of times cannula was re-directed
- number of skin punctures
- haematoma
- time to complete procedure

Secondary (specified)

- not provided

Secondary (collected)

- no differentiation between primary and secondary outcomes

Time points reported: during the surgery procedure

Notes	Funding: not reported Conflicts of interest: not reported Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "study participants were randomly assigned to the out-of-plane USG group (group I, n = 42) or the in-plane USG group (group II, n = 42) by a computerized random number generation chart (https://stattrek.com/statistics/random-number-generator.aspx)"
Allocation concealment (selection bias)	Unclear risk	Quote: "study participants were randomly assigned to the out-of-plane USG group (group I, n = 42) or the in-plane USG group (group II, n = 42) by a computerized random number generation chart (https://stattrek.com/statistics/random-number-generator.aspx)"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Although the participant underwent the intervention after general anaesthesia, personnel for the intervention group were not blinded
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	High risk	There is a difference between outcomes described in the methods and in the results. The outcome 'number of failed attempts in the 2 ultrasound imaging planes' was not reported in the results. The outcome 'time for completion of the procedure' was described only in the results - not in the methods
Other bias	Low risk	We do not suspect any other bias related to this study

Bai 2020

Study characteristics	
Methods	Single-centre prospective randomised intervention, parallel-assignment double-masked study China, Beijing Duration: September 2018 to February 2019
Participants	• 131 adult elective surgical patients • experimental group (ultrasound DNTP) n = 65; control group (ultrasound AP) n = 66 • mean age (years) 59 ± 14 (experimental), 58 ± 13 (control) • gender (male/female): 39/26 (experimental), 40/26 (control) • severity of condition: described as ASA level. ASA I and II 17, ASA III and IV 48 (experimental), ASA I and II 16, ASA III and IV 50 (control) • comorbidities: hypertension: 38 (59%) in experimental group, 33 (50%) in control group not reported; diabetes: 33 (51%) in experimental group, 31 (47%) in control group; coronary heart disease: 31 (48%) in experimental group, 35 (53%) in control group; smoking: 38 (59%) in experimental group, 39 (59%) in control group • type of surgery: experimental group - heart surgery 41 (63.1%); general surgery 8 (12.3%); orthopaedic surgery 2 (3.1%); urological surgery 8 (12.3%); vascular surgery 6 (9.2%); control group - heart surgery 46 (69.7%); general surgery 7 (10.6%); orthopaedic surgery 5 (7.6%); urological surgery 6 (9.1%); vascular surgery 2 (3.0%) • body mass index: 25 ± 3 (experimental), 25 ± 3 (control) • artery of interest: radial • diameter (mm), mean ± SD: 2.30 ± 0.50 (experimental, ultrasound DNTP), 2.38 ± 0.50 (comparative, ultrasound AP) • catheterisation purpose (experimental/control): all for diagnosis (pressure monitoring) Inclusion criteria • undergoing elective surgery and requiring arterial cannulation • older than 18 years • ASA level I to IV Exclusion criteria • contraindications for peripheral arterial puncture or catheterisation • blocked or embolised target vessel determined by ultrasound assessment • patient refusal
Interventions	Experimental (ultrasound DNTP): quote: "for the DNTP technique, the probe was placed to view the out-of-plane radial artery and moved to place the artery in the center of the ultrasound screen. Then, the needle was inserted at the point at which the middle mark of the probe contacted the skin and advanced through the skin at an angle of approximately 30 degrees until the tip was seen on the screen. The probe was moved along the long axis of the target artery away from the insertion point until the tip just disappeared from the screen. Then, we advanced the needle and catheter until the tip was just seen again. These steps were repeated until the tip was observed in the artery lumen" Control (ultrasound AD): quote: "the probe was placed to view the short-axis plane of the target artery and moved to place the artery in the center of the ultrasound screen. Then, the distance from the surface of the skin to the anterior wall of the artery was measured. The needle was inserted at the point at which the middle mark of the probe contacted the skin and advanced through the skin. Since an initial angle of 45 degrees between needle and skin was used for a puncture, the distance between point of insertion and central point of the probe was approximately equal to the distance from surface of the skin to anterior wall of the artery. Then, the needle was advanced until blood appeared in the hub. The needle angle was decreased slightly while the catheter was advanced slightly. The catheter was advanced into the target artery only if blood continued to flow into the hub"

Bai 2020 *(Continued)*

	Level of experience of person carrying out the procedure: quote: "the operator was an experienced senior anesthesiology resident in our department, who had already conducted the DNTP and AD techniques in over 100 patients each and was equally skilled in the 2 methods" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Outcomes Primary (specified) • successful rate without extravascular damage. Percentages of successful catheterisation without vascular damage of posterior wall Primary (collected) • first-pass success without posterior wall puncture Secondary (specified) • successful rate at first attempt • Time duration of catheterisation. From beginning of needle puncture to finish or failing of catheterisation • Relative factors of successful catheterisation without posterior wall damage. Relationship between independent variables (gender, age, BMI, BP, depth, etc.) and successful catheterisation without posterior wall damage • The effect of depth of the successful catheterisation without posterior wall puncture. Relationships between different depths of vascular anterior wall and successful catheterisation without posterior wall puncture Secondary (collected) • first-pass success rate • 10-minute overall success rate • cannulation time • posterior wall puncture • number of skin punctures Time points reported: during the surgery procedure
Notes	Funding: quote: "no funding was obtained for this study" Conflicts of interest: quote: "the authors declare that they have no competing interests" Protocol available (NCT03656978)

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "enrolled patients were randomized by computer generated numbers provided in sealed opaque envelopes to either the DNTP or AD group. The seal of the envelope was broken just before the cannulation procedure"
Allocation concealment (selection bias)	Low risk	Quote: "enrolled patients were randomized by computer generated numbers provided in sealed opaque envelopes to either the DNTP or AD group. The seal of the envelope was broken just before the cannulation procedure"

Bai 2020 *(Continued)*

		Quote: "the anesthesiologist who conducted the cannulation procedure knew the allocation of the patients. The patients were blinded to the allocation. The statistician did not know the allocation"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "the anesthesiologist who conducted the cannulation procedure knew the allocation of the patients"
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "the statistician did not know the allocation"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	Investigators collected 1 additional secondary outcome that was not planned in the protocol Quote: "the number of skin punctures"
Other bias	Low risk	We do not suspect any other bias related to this study

Berk 2013

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment open-label study Turkey Duration: June 2012 until August 2012.
Participants	• 108 participants randomised (experimental = 54, comparator = 54) • 108 analysed • mean age (years) ± SD: 56 ± 1 (experimental), 54 ± 2 (comparator) • gender (male/female): 23/31 (experimental), 30/24 (comparator) • severity of condition (experimental/comparator): all surgical participants (e.g. abdominal (19/20), head-neck (13/10)) • comorbidities (experimental/comparator): diabetes (13/18), hyperlipidaemia (2/1), hypertension (18/19) • body weight (kg): 78 ± 18 experimental, 76 ± 16 comparator • height (cm): not reported • artery of interest: radial • diameter (mm), mean ± SD: 4.2 ± 1.7 experimental, 4.5 ± 1.4 comparator • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or blood test, % not reported) Inclusion criteria • 18 to 70 years old • ASA I to III and deemed to require an arterial catheter for continuous blood pressure monitoring and/or frequent blood gas analysis Exclusion criteria

Berk 2013 *(Continued)*

- history of emergency surgery
- prevalent atherosclerosis
- haemorrhagic shock
- morbid obesity
- Raynaud disease
- peripheral vascular disease

Interventions	Experimental: ultrasound-guided RA puncture (artery in short axis, real-time, out-of-plane) Comparator: ultrasound-guided RA puncture (artery in long axis, real-time, in-plane) Level of experience of person carrying out the procedure: 2 researchers who had placed more than 50 arterial lines by using in-plane or out-of-plane approach Concomitant medications: GA using intravenous induction with thiopental 5 to 8 mg/kg, fentanyl 1 to 2 mcg/kg, and rocuronium 0.6 to 1 mg/kg. After endotracheal intubation, anaesthetic maintenance consisted of sevoflurane 2 and 50% oxygen in nitrous oxide Excluded medication: local anaesthetic was not used
Outcomes	Primary (specified) • cannulation time • number of attempts • number of cannula used • number of needle re-direction • number of posterior wall damage Primary (collected) • cannulation time • number of attempts • number of cannula used • number of needle re-direction • number of posterior wall damage • complications (thrombosis, haematoma, oedema, vasospasm) Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected) • no differentiation between primary and secondary outcomes Time points reported: up to the end of the procedure (not specified)
Notes	Funding: not reported Conflicts of interest: quote: "the authors declare that they have no conflict of interest" Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not sufficiently described. Quote: "patients were randomized by using sealed envelope method"

Berk 2013 *(Continued)*

Allocation concealment (selection bias)	Unclear risk	Not sufficiently described. Quote: "patients were randomized by using sealed envelope method"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Although the participant underwent the intervention after general anaesthesia, personnel for the intervention group were not blinded
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Bobbia 2013

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment open-label study France Duration: 15 August 2010 to 30 September 2010
Participants	• 72 participants randomised (experimental = 37, comparator = 35) • 72 analysed • mean age (years) ± SD: 69 ± 13 (experimental), 71 ± 10 (comparator) • gender (male/female): 12/25 (experimental), 17/18 (comparator) • severity of condition (experimental/comparator): all participants from emergency department • comorbidities (experimental/comparator): pulmonary embolism (31%), other pulmonary disease or dyspnoea (45%) • body weight (kg): 79 ± 12 experimental, 75 ± 15 comparator • height (cm): 167 ± 7 experimental, 163 ± 3 comparator • artery of interest: radial • diameter (mm), mean ± SD: not reported • catheterisation purpose (experimental/comparator): all for diagnosis (blood test) Inclusion criteria • ≥ 18 years old • requiring radial artery sample • free, informed, signed consent given and recorded Exclusion criteria • cardiac arrest • pregnant or lactating • refusing to give consent

Bobbia 2013 *(Continued)*

- participating in another study
- Allen's test positive
- local trauma of 2 wrists
- known severe local arteriopathy

Interventions	Experimental: ultrasound-guided RA puncture (real-time; artery axis and plane with needle were not reported) Comparator: RA puncture using palpation and landmarks Level of experience of person carrying out the procedure: 13 physicians were all graduates of accredited French Society of Emergency Medicine, in which theoretical and practical training of the gesture was taught. To avoid confusion, 3 hours of simulator training was given before the start of the study Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • number of attempts required for successful sample Primary (collected) • number of attempts required for successful sample Secondary (specified) • time to success • patient satisfaction (0 to 10 scale) • pain (0 to 10 scale) • physician satisfaction (0 to 10 scale) Secondary (collected) • time to success • patient satisfaction (0 to 10 scale) • pain (0 to 10 scale) • physician satisfaction (0 to 10 scale) • complications Time points reported: up to the end of the procedure (not specified)
Notes	Funding: not reported Conflicts of interest: not reported Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "the computer simultaneously created a time stamp in the research database, which represented the time of enrollment and designated the group in which the patient was (US-guided [group 1] or not [group 2])"
Allocation concealment (selection bias)	Unclear risk	Not described

Bobbia 2013 *(Continued)*

Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "this was a prospective, nonblinded, randomized trial"
Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "this was a prospective, nonblinded, randomized trial"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Burad 2017

Study characteristics	
Methods	Single-centre prospective randomised controlled 3-arm parallel-assignment open-label study Oman Duration: 15 August 2010 to 30 September 2010
Participants	• 100 participants randomised (experimental = 49, comparator = 51) • 100 analysed • mean age (years) ± SD: 46 ± 19.26 (experimental), 49.1 ± 19.09 (comparator) • gender (male/female): not reported • severity of condition (experimental/comparator): all participants from ICU and study authors mention the distribution of participants in haemodynamic subsets according to systolic blood pressure (< 80 mmHg, 81 to 100 mmHg, > 100 mmHg) • comorbidities (experimental/comparator): most participants had a respiratory disorder (3/5), trauma (10/8), surgery (11/12), and/or shock (17/20) as the primary clinical diagnosis • body weight (kg): not reported • height (cm): not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported • catheterisation purpose (experimental/comparator): not reported Inclusion criteria • 14 and 90 years of age • requiring arterial cannulation Exclusion criteria • not reported
Interventions	Experimental: ultrasound-guided RA puncture (real-time; artery axis and plane with needle not reported) Comparator: RA puncture using palpation and landmarks

Burad 2017 *(Continued)*

	Level of experience of person carrying out the procedure: quote: "all cannulations were performed by physicians well experienced with both techniques" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • first-pass success • final success rate Primary (collected) • first-pass success • final success rate Secondary (specified) • time taken • number of attempts evaluated Secondary (collected) • time taken • number of attempts evaluated Time points reported: up to the end of the procedure (not specified)
Notes	Funding: not reported Conflicts of interest: quote: "the authors declare that they have no conflicts of interest" Protocol (NCT02825615) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Quote: "we randomized 100 adult patients... to one of the techniques by blindly picking chits from unlabeled boxes" No clear description of whether randomisation allowed the same chance of allocation for both groups (experimental and comparator)
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "is a prospective, randomized, single-centre, non-blinded, intention-to-treat study"
Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "is a prospective, randomized, single-centre, non-blinded, intention-to-treat study"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses

Burad 2017 *(Continued)*

Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Cao 2018

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment single-blinded (outcomes assessor) study China Duration: December 2016 to May 2017.
Participants	• 120 participants randomised (experimental = 60, comparator = 60) • 120 participants analysed • mean age (years) ± SD: 51.9 ± 3.3 experimental, 52.3 ± 3.5 comparator • gender (male/female): 28/32 experimental, 31/29 comparator • severity of condition (experimental/comparator): all participants from the department of critical care medicine • comorbidities (experimental/comparator): peripheral vascular disease 26/15 • BMI (kg/m^2) ± SD: 30 ± 8 experimental, 31 ± 7 comparator • artery of interest: radial • diameter (mm), mean ± SD: 2.8 ± 0.7 experimental, 2.9 ± 0.7, comparator. Catheter diameter 22 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring) Inclusion criteria • needing radial arterial cannulation Exclusion criteria • peripheral vascular disease • positive for Allen's test • coagulopathy
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, needle out-of-plane) Comparator: RA puncture using palpation and landmarks Level of experience of person carrying out the procedure: quote: "nursing staff who have obtained the certificate of completion for critical care ultrasound" Concomitant medications: quote: "arterial cannulation was performed either before or after induction of general anesthesia based on the preference of the faculty anesthesiologist" Excluded medications: not reported
Outcomes	Primary (specified) • first-attempt success rate • total success rate • number of catheterisation attempts • rate of complications • time taken for entire procedure

Cao 2018 *(Continued)*

	Primary (collected) • first-attempt success rate • total success rate • number of catheterisation attempts • rate of complications • time taken for entire procedure Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected) • no differentiation between primary and secondary outcomes Time points reported: up to 5 minutes
Notes	Funding: quote: "this work was supported by the Research Fund of Health and Family Planning, Commission of Hunan Province, China (B2017012)" Conflicts of interest: not reported Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described.
Allocation concealment (selection bias)	Unclear risk	Not described.
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of interventions, we assumed that blinding of personnel is not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Cao 2020

Study characteristics

Cao 2020 *(Continued)*

Methods	[Preprint] Single-centre prospective randomised controlled 3-arm parallel-assignment open-label study China Duration: 1 April 2020 until 28 July 2020
Participants	• 216 participants randomised (number for each group not reported) • 201 analysed (experimental (LA/in-plane) = 63, comparator (SA/out-of-plane) = 70, comparator (OA/in-plane) = 68), losses not described • mean age (years) ± SD: 52 ± 10 (experimental), 50 ± 12 (comparator SA), 51 ± 13 (comparator OA) • gender (male/female): 34/29 (experimental), 32/38 (comparator SA), 33/35 (comparator OA) • severity of condition: patients who required continuous pressure monitoring during elective surgery • comorbidities: not mentioned • BMI (kg/m^2): 25 ± 4 (experimental LA), 25 ± 4 (comparator SA), 24 ± 3 (comparator OA) • artery of interest: radial • diameter (cm), mean ± SD: 22 ± 4 (experimental LA), 21 ± 4 (comparator SA), 20 ± 3 (comparator OA) • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring) Inclusion criteria • ASA status I to III who required continuous arterial pressure monitoring during scheduled surgery • both sexes • aged 40 to 65 years • BMI 20 to 35 kg/m^2 Exclusion criteria • inflamed skin near puncture site • skin colour not returning to normal within 10 seconds after Allen's test • abnormal coagulation function • peripheral arterial disease • recent arterial puncture < 1 month earlier • hypertension and diabetes • emergency surgery
Interventions	Experimental: LA, in-plane, B-mode, real-time; quote: "probe was placed parallel to the course of the artery, and the needle was directed parallel to the longitudinal axis of the probe" Comparator: SA, out-of-plane, B-mode, real-time; quote: "the probe was placed perpendicular to the course of the artery, and the needle was directed perpendicular to the longitudinal axis of the probe" Comparator: OA, in-plane, B-mode, real-time; quote: "the probe was positioned transversely perpendicular to the artery as in the SAX group and then rotated clockwise in situ by 60° according to maximum visualization" Level of experience of person carrying out the procedure: all participants were trained by a teacher who was familiar with the 3 approaches; they were "anaesthesia residents with no more than one year of experience in blind palpation for radial artery cannulation and who previously performed ultrasound-guided radial artery cannulation fewer than five times in patients" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • successful rate of catheterisation

Cao 2020 *(Continued)*

	Primary (collected) • successful arterial cannulation Secondary (specified) • puncture blood return time • catheterisation time • adverse reaction Secondary (collected) • first-attempt success • time needed for successful arterial cannulation • cannulation failure (longer than 5 minutes and presence of a non-arterial waveform) • incidence of adverse events - local haematoma and ischaemia Time points reported: not mentioned
Notes	Funding: quote: "none" Conflicts of interest: quote: "the authors declare that they have no competing interest" Protocol available (ChiCTR200030416)

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "the patients were assigned by a randomized block design to three groups. We allocated patients at a 1:1:1 ratio with a computer-generated list of random numbers in blocks of three, with the results accessible to only research nurses"
Allocation concealment (selection bias)	Low risk	Quote: "the sealed envelopes were opened immediately before the procedure"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "with the results accessible to only research nurses"
Incomplete outcome data (attrition bias) All outcomes	High risk	There are losses (15 participants; 6.9%) that were not described regarding motivation or proportion among groups
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Edanaga 2012

Study characteristics	
Methods	Single-centre prospective randomised controlled 3-arm parallel-assignment study; blinding not reported Japan Duration: not reported
Participants	• 36 participants randomised (experimental = 24 (short axis = 12, long axis = 12), comparator = 12) • 36 participants analysed • mean age (years) ± SD: 70.45 ± 9.8 experimental, 68.5± 7.2 comparator • gender (male/female): not reported • severity of condition (experimental/comparator): not reported • comorbidities (experimental/comparator): not reported • body weight (kg) ± SD: 61 ± 10.79 experimental, 62.8 ± 10.8 comparator • height (cm) ± SD: 161.1 ± 9.81 experimental, 164.5 ± 7.1 comparator • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter diameter 22 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring) Inclusion criteria • negative for Allen's test Exclusion criteria • not reported
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis (N = 12) and long axis (N = 12), needle plane not reported) Comparator: RA puncture via palpation and landmarks Level of experience of person carrying out the procedure: anaesthesiologist staff have performed all punctures Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • number of catheterisation attempts Primary (collected) • number of catheterisation attempts Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected) • no differentiation between primary and secondary outcomes Time points reported: up to the end of the procedure (not described)
Notes	Funding: not reported Conflicts of interest: study authors declared no conflicts of interest

Edanaga 2012 *(Continued)*

	Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	High risk	Study did not evaluate any safety outcome

Fujita 2012

Study characteristics

Methods	[Abstract of event] Single-centre prospective randomised controlled 2-arms parallel-assignment open-label study Japan Duration: not reported
Participants	• 38 participants randomised; number in each group and number analysed not described • mean age (years) ± SD: not reported • gender (male/female): not reported • severity of condition (experimental/comparator): all participants who underwent surgery • comorbidities (experimental/comparator): not reported • body weight (kg): not reported • height (cm): not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring) Inclusion criteria • underwent surgery • required arterial cannulation

Fujita 2012 *(Continued)*

	Exclusion criteria • not reported
Interventions	Experimental: ultrasound-guided RA puncture (real-time; artery axis and plane with needle not reported) Comparator: RA puncture via palpation and landmarks Level of experience of person carrying out the procedure: not reported Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • time from start of disinfection to catheterisation • number of punctures Primary (collected) • time from start of disinfection to catheterisation • number of punctures • initial success rate Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected) • no differentiation between primary and secondary outcomes Time points reported: up to the end of the procedure (not specified)
Notes	Funding: not reported Conflicts of interest: not reported Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described

Fujita 2012 *(Continued)*

Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Gibbons 2020

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arms parallel-assignment open-label study USA Duration: 1 Janurary 2018 to 31 December 2019
Participants	• 40 participants randomised • 40 analysed (experimental = 20, comparator = 20); trial authors declared no losses • mean age (years) ± SD: 59.25 ± 14.71 (experimental), 66.25 ± 13.64 (comparator) • gender (male/female): 13/7 (experimental), 11/9 (comparator) • severity of condition: required haemodynamic monitoring and cardiopulmonary resuscitation in an emergency department • comorbidities: not mentioned • BMI (kg/m^2): 29.95 ± 7.11 (experimental), 29.45 ± 6.10 (comparator) • artery of interest: radial • diameter (cm), mean ± SD: not reported • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring and frequent blood test) Inclusion criteria • both sexes • aged 18 years or older • indication for arterial line placement Exclusion criteria • Adult unable to consent • Member of vulnerable population
Interventions	Experimental: DNTP, out-of-plane, B-mode, real-time ultrasound-guided puncture (artery axis not described) Comparator: palpation-guided puncture Level of experience of person carrying out the procedure: all participants were trained by a teacher who was familiar with the approaches, but all were emergency interns Concomitant medications: 2 to 3 mL 1% lidocaine without epinephrine was used for patients who were conscious Excluded medications: not reported
Outcomes	Primary (specified)

Gibbons 2020 *(Continued)*

- number of attempts until successful cannulation

Primary (collected)

- number of attempts until successful cannulation

Secondary (specified)

- completion of arterial line placement after 3 attempts

Secondary (collected)

- first-attempt success
- time needed for successful arterial cannulation (limited to 15 minutes)
- cannulation failure (longer than 5 minutes and presence of a non-arterial waveform)
- complications
- need to cross over to alternative method

Time points reported: up to 1 day

Notes	Funding: quote: "no funding was provided for this study" Conflicts of interest: not reported Protocol available (NCT03326739)

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "blinded study investigators selected sealed envelopes containing study materials and prerandomized selection into USG vs. LMGP using Research Randomizer (v 4.0, available at http://www.randomizer.org/) (21)"
Allocation concealment (selection bias)	Low risk	Quote: "blinded study investigators selected sealed envelopes containing study materials and prerandomized selection into USG vs. LMGP using Research Randomizer (v 4.0, available at http://www.randomizer.org/) (21)"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "only novice emergency medicine interns, defined as interns with < 15 previous placements, who were not blinded, performed the cannulation"
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "an independent department research assistant who was blinded to the study's objectives assessed the operator with respect to first-pass success, number of attempts (limited to 3), time to completion using a stopwatch (limited to 15 min), complications, and need to crossover to the alternative method"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Gopalasingam 2014

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm cross-over participant-blinded study Denmark Duration: November 2012 to July 2013
Participants	• 40 participants randomised (experimental = 20, comparator = 20) • 40 participants and 80 arteries analysed • mean age (years, range): 71 (46 to 91) • gender (male/female): 28/12 • severity of condition (experimental/comparator): scheduled surgeries (coronary artery bypass graft = 25, mitral valve replacement = 1, aortic valve replacement = 11, combination procedures = 3) • comorbidities (experimental/comparator not reported): hypercholesterolaemia = 34, diabetes = 10, smoking = 16, hypertension = 34 • body weight (kg): 71 (46 to 91) • height (cm): 170 (157 to 190) • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter diameter 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or blood test, not detailed) Inclusion criteria • aged 20 to 90 years • undergoing elective cardiac surgery with routine preoperative catheterisation of the radial artery Exclusion criteria • lack of patient consent • ultrasound verification of arterial plaques • no-flow in either radial or ulnar artery or atrial fibrillation
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, and DNTP) as first intervention Comparator: RA puncture with palpation and landmarks as first intervention Level of experience of person carrying out the procedure: anaesthesiology residents (operators) had performed at least 20 of each procedure previous to this study Concomitant medications: after injection of 0.5 to 1.0 mL of lidocaine (10 mg/mL) Excluded medications: not reported
Outcomes	Primary (specified) • attempts [Time Frame: 1 hour]: number of attempts (skin punctures) per catheterisation • withdrawals [Time Frame: 1 hour]: number of withdrawals of the guide needle per catheterisation • time consume [Time Frame: minutes]: time spent on catheterisation procedure • catheters [Time Frame: 1 hour]: number of utilised catheters Primary (collected) • first-attempt success rate Secondary (specified)

Gopalasingam 2014 *(Continued)*

- pain [Time Frame: momentan]. Pain induced by the conventional method inclusive of preoperational lidocaine injection will be the same or more intense than using DNTT with local anesthesia measured on a VAS score
- ease of method for the operator [Time Frame: momentan]. Use of ultrasound will increase the operator's subjective feeling of having accomplished a successful procedure on a Likert scale

Secondary (collected)

- number of skin perforations
- number of attempts targeting the vessel (withdrawal of the guide cannula while the catheter remained inserted)
- needle manipulation time (beginning with catheter perforation of the skin)
- total time (group beginning when transducer was first placed on the patient's skin (DNTP group), and when the operator started to palpate the patient's skin (standard group))
- fraction of total time > 180 seconds defining unexpected difficult catheterisation
- number of catheters used
- frequency of aborted attempts or cross-overs (pooled)
- measurement of pain on a visual analogue scale (VAS)

Time points reported: up to the end of the procedure (not specified)

Notes	Funding: quote: "this work was funded by the Edgar Schnohr and wife Gilberte Schnohr's fund and Helga and Peter Korning's foundation" Conflicts of interest: quote: "none of the authors has financial interest related to this study to disclose" Protocol (NCT01690416) available Study authors provided data for the first phase, before the intervention cross-over

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "computer randomisation (www.randomization.com) was conducted"
Allocation concealment (selection bias)	Unclear risk	No details provided Quote: "the randomisation order was revealed to the observer just prior to catheterisation"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Participant blinded, but personnel not blinded Quote: "the study was randomised, controlled, patient-blinded"
Blinding of outcome assessment (detection bias) All outcomes	High risk	Blinding only for participants Quote: "the study was randomised, controlled, patient-blinded"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses. Besides the cross-over design, another cross-over (not planned) occurred in 4 participants in the comparator group (to ultrasound aid) and in none in the experimental group
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported

Gopalasingam 2014 *(Continued)*

Other bias	High risk	There is no plausible reason to change the outcome from primary on the protocol to secondary on the final report

Goswami 2020

Study characteristics	
Methods	[Abstract of event] Single-centre prospective randomised controlled 2-arm parallel-assignment open-label study India Duration: April to November 2019
Participants	• 80 participants randomised • 80 analysed (experimental = 40, comparator = 40), losses not described • mean age (years) ± SD: not reported • gender (male/female): not reported • severity of condition: not reported • comorbidities: not mentioned • BMI (kg/m^2): not reported • artery of interest: radial • diameter (cm), mean ± SD: not reported • catheterisation purpose (experimental/comparator): all for diagnosis (not detailed) Inclusion criteria • all adult critically ill patients (aged 18 to 60 years) admitted to ICU Exclusion criteria • Signs of skin infection/wound near puncture site • Recent arterial puncture < 1 month earlier • Peripheral artery disease • Requiring emergency surgery
Interventions	Experimental: ultrasound-guided puncture (not detailed) Comparator: palpation-guided puncture Level of experience of person carrying out the procedure: not reported Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • successful rate of catheterisation Primary (collected) • successful rate of catheterisation Secondary (specified) • first-attempt success in catheterisation • total number of attempts

Goswami 2020 *(Continued)*

	• time taken to cannulate • complications related to the procedure Secondary (collected) • total number of attempts • time taken to cannulate • complications related to the procedure Time points reported: not mentioned
Notes	Funding: not reported Conflicts of interest: not reported Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "recruitment and randomization was done using a computer-generated table"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	High risk	Two outcomes (first-attempt success in catheterisation and time taken to cannulate) of interest for this review were planned into trial methods but were not reported
Other bias	Low risk	We do not suspect any other bias related to this study

Grandpierre 2019

Study characteristics

Methods	Single-centre prospective randomised controlled 2-arms parallel-assignment open-label study France Duration: February 2014 to June 2016
Participants	• 73 participants randomised (experimental = 36, comparator = 37)

Grandpierre 2019 *(Continued)*

- 73 participants analysed
- mean age (years) ± SD: 73.3 ± 15 experimental, 73.3 ± 14.9 comparator
- gender (male/female): 13/23 experimental, 14/23 comparator
- severity of condition (experimental/comparator): all from emergency department (dyspnoea = 24/22, suspicion of acid–base balance disruption = 8/8, suspicion of pulmonary embolism = 5/5)
- comorbidities (experimental/comparator): not reported
- body weight (kg) ± SD: 77 ± 22 experimental, 73 ± 18 comparator
- height (cm) ± SD: 163 ± 11 experimental, 165 ± 6 comparator
- artery of interest: radial
- diameter (mm), mean ± SD: not reported.
- catheterisation purpose (experimental/comparator): all for diagnosis (blood test)

Inclusion criteria

- provided written informed consent
- affiliated with or beneficiary of a health insurance plan
- aged 18 years or older
- not previously included in this study
- presented with need for ABGA
- at least 1 of the 2 following features: (1) non-palpable radial arteries, or (2) 2 previous nurse puncture failures

Exclusion criteria

- participant chose not to continue to participate in the study

Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, needle out-of-plane) Comparator: RA puncture with palpation and landmarks Level of experience of person carrying out the procedure: quote: "all physicians had a university degree in point-of-care ultrasound and all had previously used ABGA ultrasound guidance in clinical practice" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • only 1 attempt at arterial puncture was necessary (yes/no) [Time Frame: Day 0 to end of procedure] Primary (collected) • number of successful punctures on first attempt Secondary (specified) • number of skin punctures [Time Frame: Day 0 to end of procedure] • length of time necessary for the procedure [Time Frame: Day 0 to end of procedure] • presence/absence of complications [Time Frame: Day 0 to end of procedure]. Presence/absence of complications including haematoma, nerve injury, vagal reaction, pseudoaneurysm • patient satisfaction [Time Frame: Day 0 to end of procedure]. Patient satisfaction evaluated on a visual analogue scale • operator satisfaction [Time Frame: Day 0 to end of procedure]. Operator satisfaction estimated on a visual analogue scale • patient pain evaluation [Time Frame: Day 0 to end of procedure]. Patients asked to evaluate experienced pain level on a visual analogue scale • number of catheters used [Time Frame: Day 0 to end of procedure] • was additional assistance necessary? yes/no [Time Frame: Day 0 to end of procedure]

Grandpierre 2019 *(Continued)*

	Secondary (collected) • number of attempts until successful puncture • elapsed time to successful puncture • patient pain during the procedure • physician satisfaction Time points reported: up to the end of the procedure (quote: "followed until the ABGA was obtained")
Notes	Funding: quote: "this work was supported by the University Hospital of Nimes. No author has received funding. The University Hospital of Nimes supported data collection, data management, and analysis" Conflicts of interest: quote: "XB declares a competing interest as an ultrasound teacher for GE (GE MEDICAL SYSTEMS ULTRASOUND) customers. This does not alter our adherence to PLOS ONE policies and sharing data and materials. The other authors state they have no competing interests" Protocol (NCT01789801) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "an SAS (Carry, NC, USA) program was used to create random block sizes of 4 or 6 and to stratify the reason for inclusion as non-palpable artery and two failures by the nurse, with a ratio of 1:1"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "the trial was conducted at a single center and was not blinded"
Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "the trial was conducted at a single center and was not blinded"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	High risk	Two of the outcomes (complications and participant satisfaction) of interest for this review were planned in the trial protocol but were not reported
Other bias	Low risk	We do not suspect any other bias related to this study

Hansen 2014

Study characteristics

Methods	Single-centre prospective randomised controlled 2-arm cross-over participant-blinded study Denmark Duration: 12 April 2012 to 3 October 2012

Hansen 2014 *(Continued)*

Participants	• 40 participants randomised (experimental = 22, comparator = 18) • 40 participants and 80 arteries analysed • mean age (years ± SD): 65.8 ± 16.1 • gender (male/female): 33/7 • severity of condition (experimental/comparator): scheduled surgeries (coronary artery bypass graft = 19, mitral valve replacement = 9, aortic valve replacement = 18, combination procedures = 4) • comorbidities (experimental/comparator not reported): hypercholesterolaemia = 31, diabetes = 10, smoking = 15, hypertension = 37 • body weight (kg) (mean ± SD): 84.4 ± 15.9 • height (cm) (mean ± SD): 174.4 ± 9.0 • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter diameter 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (not detailed) Inclusion criteria • aged ≥ 18 years • scheduled for elective cardiac surgery Exclusion criteria • lack of patient consent • positive modified Allen's test
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, DNTP) as first intervention Comparator: RA puncture with palpation and landmarks as first intervention Level of experience of person carrying out the procedure: quote: "the traditional palpation technique was performed by experienced specialists in anesthesiology" and "arterial catheterization with the ultrasonography dynamic needle tip positioning technique was performed by an experienced specialist in anesthesiology" Concomitant medications: quote: "no local anaesthesia was used for this procedure" Excluded medications: not reported
Outcomes	Primary (specified) • needle manipulation time Primary (collected) • needle manipulation time Secondary (specified) • number of skin perforations • number of attempts targeting the vessel • number of catheters placed in first attempt • number of catheters used Secondary (collected) • number of skin perforations • number of attempts targeting the vessel • number of catheters placed in first attempt • number of catheters used • overall success rate

Hansen 2014 *(Continued)*

	• pain Time points reported: up to the end of the procedure (not specified)
Notes	Funding: quote: "this work was funded by the Edgar Schnohr and wife Gilberte Schnohr's fund and Helga and Peter Korning's Foundation" Conflicts of interest: quote: "none of the authors has financial interest related to this study to disclose" Protocol not available Trial authors provided data for the first phase before intervention cross-over

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "patients were computer randomized"
Allocation concealment (selection bias)	Unclear risk	Not described.
Blinding of participants and personnel (performance bias) All outcomes	High risk	Participant blinded, but personnel not blinded Quote: "patients were blinded to randomization order and physically blinded to the individual technique used during the procedures"
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	There were no losses. Besides the cross-over design, another cross-over (not planned) occurred in 1 participant of the comparator group (to ultrasound aid) and in no participant of the experimental group
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Khan 2018

Study characteristics

Methods	[Abstract of event] Single-centre prospective randomised controlled 2-arm parallel-assignment open-label study India Duration: not reported
Participants	• 100 participants randomised, (experimental = 49, comparator = 51) • 100 participants analysed • mean age (years) ± SD: not reported • gender (male/female): not reported • severity of condition (experimental/comparator): critically ill participants

Khan 2018 *(Continued)*

- comorbidities (experimental/comparator): not reported
- body weight (kg): not reported
- height (cm): not reported
- artery of interest: radial
- diameter (mm), mean ± SD: not reported
- catheterisation purpose (experimental/comparator): all for diagnosis (not detailed)

Inclusion criteria

- aged > 18 years
- hypotension (or requiring vasopressor infusion)
- no previously cannulated radial artery

Exclusion criteria

- deformity or local trauma or local infection at arterial cannulation site
- severe coagulopathy (platelets < 30,000/mm^3 and/or INR > 2.0)
- non-palpable radial pulse
- radial artery already cannulated previously
- negative Barbeau test

Interventions	Experimental: ultrasound-guided RA puncture (real-time; artery short axis; needle in out-of-plane) Comparator: RA puncture via palpation and landmarks Level of experience of person carrying out the procedure: not reported Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • first-pass success rate Primary (collected) • first-pass success rate Secondary (specified) • final success rate • total number of attempts needed for catheterisation • time for successful catheterization (cannulation time) • total time taken in the procedure • failure rate • number of catheters used • posterior wall haemorrhage • haematoma • incidence of spasm and other complications • cross-over to either technique Secondary (collected) • cannulation time • rate of early complications Time points reported: up to the end of the procedure
Notes	Funding: not reported

Khan 2018 *(Continued)*

	Conflicts of interest: not reported Protocol (CTRI/2017/03/008020) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "computer generated randomization"
Allocation concealment (selection bias)	High risk	Quote: "an open list of random numbers"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Open-label study
Blinding of outcome assessment (detection bias) All outcomes	High risk	Open-label study
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	There were no losses. The account of cross-over to either intervention was planned but was not reported
Selective reporting (reporting bias)	High risk	Some data (final success rate, time for successful catheterisation (cannulation time), posterior wall haemorrhage, haematoma, incidence of spasm and other complications, cross-over to either technique) of interest for this review were planned in the trial protocol but were not reported or were reported incompletely (cannulation time)
Other bias	Low risk	We do not suspect any other bias related to this study

Kiberenge 2018

Study characteristics

Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment single-blinded (outcomes assessor) study USA Duration: May 2015 to December 2015
Participants	• 260 participants randomised (experimental = 132, comparator = 128) • 73 participants analysed • mean age (years) ± SD: 58 ± 15 experimental, 61 ± 16 comparator • gender (male/female): 74/58 experimental, 66/62 comparator • severity of condition (experimental/comparator): all participants undergoing non-emergent operation • comorbidities (experimental/comparator): peripheral vascular disease 26/15 • BMI (kg/m^2) ± SD: 30 ± 8 experimental, 31 ± 7 comparator • artery of interest: radial • diameter (mm), mean ± SD: 2.8 ± 0.7 experimental, 2.9 ± 0.7 comparator

Kiberenge 2018 *(Continued)*

- catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring)

Inclusion criteria

- needing radial arterial cannulation intraoperatively

Exclusion criteria

- refusal to consent
- minor
- incarcerated individual
- radial cannulation within past month
- negative modified Allen's test
- shock
- non-English-speaking
- pregnant
- requiring radial forearm flap harvest

Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, needle out-of-plane, DNTP) Comparator: RA puncture via palpation and landmarks Level of experience of person carrying out the procedure: quote: "arterial cannulation was performed by anaesthesia residents or faculty members" and "the operators (anesthesia residents, fellows, and faculty) placing the arterial catheters were required to have placed at least 10 radial arterial catheters using each technique prior to participation in the study" Outcome data were reported separately by experienced and inexperienced operators Concomitant medications: quote: "arterial cannulation was performed either before or after induction of general anesthesia based on the preference of the faculty anesthesiologist" Excluded medications: not reported
Outcomes	Primary (specified) • first-pass success [Time Frame: 5 minutes]. Placement of arterial cannula in 5 minutes after touching the wrist Primary (collected) • first-pass success of radial arterial line placement (yes/no) Secondary (specified) • overall success [Time Frame: 5 minutes]. Successful arterial cannulation after any number of passes as long as it is within 5 minutes Secondary (collected) • overall success rate • number of catheters used • number of skin perforations • time to achieve successful cannulation (seconds) • systolic blood pressure before and after radial artery puncture • diastolic blood pressure before and after radial artery puncture • heart rate before and after puncture Time points reported: up to 5 minutes
Notes	Funding: University of Iowa Hospitals and Clinics

Kiberenge 2018 *(Continued)*

	Conflicts of interest: quote: "the authors declare no conflicts of interest"
	Protocol (NCT02557828) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "the assignments were computer generated, with randomly selected block sizes using nQuery Advisor 7.0 (Statistical Solutions Ltd, Cork, Ireland) and then placed in sealed envelopes"
Allocation concealment (selection bias)	Low risk	Quote: "the technique to be used for cannulation was determined when the research team member opened an opaque randomization envelope containing a piece of paper with either ultrasound or palpation printed on it"
Blinding of participants and personnel (performance bias) All outcomes	High risk	No blinding for participants or personnel
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Protocol states that this was an 'outcomes assessor' blinding study
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported. Protocol violations were reported and were treated in an ITT analysis Quote: "there were 3 protocol violations: one was due to the use of a different catheter, one operator refused to use the palpation technique after randomization, and another used a wire to guide the catheter into the vessel lumen while using the dynamic needle tip positioning technique. These 3 patients were treated as failed attempts in the intention to treat analysis"
Other bias	Low risk	We do not suspect any other bias related to this study

Killu 2011

Study characteristics

Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment open-label study USA Duration: from 2005 to 2007
Participants	• 33 participants randomised (experimental = 18, comparator = 15) • 33 analysed • mean age (years) ± SD: 55.9 ± 18.5 • gender (male/female): 19/14 • severity of condition: critically ill participants from 2 ICUs; mean arterial pressure < 60 mmHg (experimental = 7, comparator = 2; P = 0.101) • comorbidities: not reported

Killu 2011 *(Continued)*

- BMI: not reported
- artery of interest: axillary
- diameter: not reported
- catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring)

Inclusion criteria

- about to undergo arterial line placement for haemodynamic monitoring or frequent arterial blood gas sampling

Exclusion criteria

- pregnant
- younger than 18 years
- no obtainable consent

Interventions	Experimental: ultrasound-guided AA puncture (real-time). Artery assessment axis and plane between needle and ultrasound not reported Comparator: percutaneously AA puncture by anatomical landmarks and palpation technique Level of experience of person carrying out the procedure: experimental (7 residents and 11 fellows), comparator (6 residents and 9 fellows) Concomitant medications: not reported Excluded medications: not reported Choice of right or left AA cannulation at the discretion of the operators. Right AA was cannulated in 63.6% (n = 21) of cases and left AA in 36.4% (n = 12). The AA catheter was inserted over a guide wire via the Seldinger technique
Outcomes	Primary (specified) • procedure duration (time) • number of skin punctures • needle re-positioning (partial needle withdrawal with needle tip remaining under the skin surface, followed by needle advancement) • complications (haematoma, venous cannulation, nerve injury) • aborted procedures (decision to abort the procedure was made by the operator and the supervising staff, when there was failure to cannulate using anatomical landmarks and palpation and a significant amount of time had passed) Primary (collected) • procedure duration (time) • number of skin punctures • needle re-positioning (partial needle withdrawal with needle tip remaining under the skin surface, followed by needle advancement) • complications (haematoma, venous puncture, nerve injury) • aborted procedure Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected) • no differentiation between primary and secondary outcomes

Killu 2011 *(Continued)*

	Time points reported: until the end of the procedure. The highest value was not reported, but the highest mean was 14.82 ± 12.14 minutes for residents in the comparator group
Notes	Funding: not reported Conflicts of interest: quote: "the authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article" We did not identify a register number for this study

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Low risk	Quote: "patients were randomized using concealed allocation into 2 groups"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "the study could not be blinded"
Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "the study could not be blinded"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	We did not identify an available protocol, but all prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Kim 2021a

Study characteristics

Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment open-label study Korea Duration: 3 March 2017 to 16 November 2017
Participants	• 76 participants randomised • 76 analysed (experimental = 38, comparator = 38), losses not described • mean age (years) ± SD: 52.5 ± 15.0 experimental, 50.6 ± 14.1 comparator • gender (male/female): 14/24 experimental, 21/17 comparator • severity of condition: requiring clinically indicated arterial cannulation, under general anaesthesia • comorbidities: not reported • BMI (kg/m^2): not reported • artery of interest: radial

Kim 2021a *(Continued)*

- diameter (cm), mean ± SD: 3.43 ± 1.23 experimental, 3.57 ± 1.07 comparator
- catheterisation purpose (experimental/comparator): all for diagnosis (not detailed)

Inclusion criteria

- adults over 19 years of age required to have an arterial line insertion

Exclusion criteria

- vascular malformation
- haemodynamically unstable
- blood coagulation disorder
- peripheral arterial occlusive disease
- reoperation
- emergency surgery

Interventions	Experimental: short-axis, out-of-plane, B-mode, real-time ultrasound-guided puncture Comparator: short-axis, out-of-plane, B-mode, real-time ultrasound-guided puncture plus electromagnetic guidance Level of experience of person carrying out the procedure: quote: "arterial cannulation was performed by a single anaesthesiologist who had successfully performed arterial cannulation under electromagnetic ultrasound guidance more than 50 times" Concomitant medications: all under general anaesthesia Excluded medications: not reported
Outcomes	Primary (specified) • percentage of success and vascular wall puncture Primary (collected) • percentage of success and vascular wall puncture Secondary (specified) • adverse events Secondary (collected) • first-attempt success rate • puncture site • cannulation time (seconds) • number of attempts • posterior wall puncture • haematoma • thrombosis Time points reported: up to 1 day
Notes	Funding: quote: "this study was carried out with our departmental funding source. There was no other source of funding except our departmental funding source" Conflicts of interest: quote: "the authors declare that they have no competing interests" Protocol available (KCT0002476)

Risk of bias

Kim 2021a *(Continued)*

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "the participants were randomly allocated into two groups using a computerized, randomized table"
Allocation concealment (selection bias)	Low risk	Quote: "the allocations were concealed in sequentially numbered, sealed, opaque envelopes"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "the provider could not be blinded because the activation of the electromagnetic guidance system was displayed on the screen"
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Kim 2021b

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment study, with participants and outcome assessor blinded Korea Duration: 6 March 2019 to 29 July 2019
Participants	• 256 participants randomised • 256 analysed (experimental = 128, comparator = 128), there were no losses • mean age (years) ± SD: 72.66 ± 7.49 experimental, 73.66 ± 6.74 comparator • gender (male/female): 43/85 experimental, 46/82 comparator • severity of condition: patients undergoing general anaesthesia for surgery that required arterial catheterisation; ASA (I/II/III) 8/89/31 experimental, 8/95/25 comparator • comorbidities: hypertension 86/92, diabetes 37/32, hypercholesterolaemia 35/37, peripheral vascular disease 28/18, history of smoking 13/8 • BMI (kg/m^2): 24.0 ± 4.0 experimental, 23.8 ± 3.5 comparator • artery of interest: radial • artery diameter (cm), mean ± SD: 2.3 ± 0.4 experimental, 2.3 ± 0.5 comparator. Catheter diameter 22 G • catheterisation purpose (experimental/comparator): all for diagnosis (not detailed) Inclusion criteria • 65 years of age or older • undergoing general anaesthesia for surgery requiring arterial catheterisation • ASA classification I, II, or III

Kim 2021b *(Continued)*

	Exclusion criteria • haemodynamically unstable (systolic blood pressure ≤ 60) • skin abnormality such as inflammation or haematoma at the cannulation site • abnormal results on modified Allen's test • history of hand or wrist surgery
Interventions	Experimental: short-axis, out-of-plane, B-mode, real-time ultrasound-guided puncture (DNTP) Comparator: short-axis, out-of-plane, B-mode, real-time ultrasound-guided puncture plus electromagnetic guidance Level of experience of person carrying out the procedure: quote: "residents in their second year of the four-year training were chosen as cannulation practitioners" Concomitant medications: all under general anaesthesia (1% lidocaine, propofol, and rocuronium) Excluded medications: not reported
Outcomes	Primary (specified) • success rate of first-time attempt Primary (collected) • success rate of first-time attempt Secondary (specified) • complications of the procedure • number of attempts • overall success rate of radial arterial cannulation • time consumption of radial arterial cannulation Secondary (collected) • complications of the procedure (haematoma, thrombosis, spasm, ischaemia) • number of attempts • overall success rate of radial arterial cannulation • time consumption of radial arterial cannulation Time points reported: up to the end of the procedure (not detailed)
Notes	Funding: quote: "the authors received no specific funding for this work" Conflicts of interest: quote: "interests: the authors have declared that no competing interests exist" Protocol available (KCT0003507)

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "randomization was performed by an independent person using a computer-generated random number list"
Allocation concealment (selection bias)	Low risk	Quote: "the allocation results were sealed in envelopes that were opened just before artery cannulation"

Kim 2021b *(Continued)*

Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "it was not possible to blind cannulation practitioners to method used. However, enrolled participants were blinded"
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "separate observer who was blinded to patient group measured the diameter and depth of the radial artery and recorded the outcomes. A barrier was placed between the practitioner and the outcome observer"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Laursen 2015

Study characteristics	
Methods	[Abstract of event] Single-centre prospective randomised controlled 2-arm study, with blinding not reported Denmark Duration: not reported
Participants	• 238 participants randomised (experimental = 115, comparator = 109) • 224 analysed • mean age (years, range): not reported • gender (male/female): not reported • severity of condition (experimental/comparator): not reported • comorbidities (experimental/comparator not reported): not reported • body weight (kg): not reported • height (cm): not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported • catheterisation purpose (experimental/comparator): all for diagnosis (blood test) Inclusion criteria • arterial puncture for blood gas analysis ordered by attending physician • participant admitted or treated in the acute emergency department Exclusion criteria • permanent mental disability • younger than 18 years • declining to participate • arterial puncture for blood gas analysis contraindicated
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, DNTP) Comparator: RA puncture via palpation and landmarks

Laursen 2015 *(Continued)*

	Level of experience of person carrying out the procedure: not reported Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • proportion of patients for whom arterial puncture for blood gas analysis was successful in the first attempt Primary (collected) • first-attempt success rate Secondary (specified) • median time used for the procedure • number of attempts to successful arterial puncture for blood gas analysis • patient cooperation. The degree of patient cooperation was assessed on a scale from 1 to 5, where 1 is very poor patient cooperation and 5 is perfect patient cooperation • patient pain (VAS) Secondary (collected) • median time used for the procedure • number of attempts to successful arterial puncture for blood gas analysis • patient cooperation. The degree of patient cooperation was assessed on a scale from 1 to 5, where 1 is very poor patient cooperation and 5 is perfect patient cooperation • patient pain (VAS) • adverse events Time points reported: up to 1 hour after puncture
Notes	Funding: quote: "the publication charges for this supplement were funded by TrygFonden" Conflicts of interest: not reported Protocol (NCT01660724) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias)	High risk	Trial authors reported data for 224 of 238 randomised participants. Trial authors did not report data for 14 of 238 (5.8%) participants

Laursen 2015 *(Continued)*
All outcomes

Selective reporting (reporting bias)	High risk	Trial authors apparently collected all planned outcomes but reported numerical data for only 2 of them, which showed a difference between intervention groups (first-attempt success rate and median time used for the procedure)
Other bias	Low risk	We do not suspect any other bias related to this study

Levin 2003

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm study, with blinding not reported Israel Duration: not reported
Participants	• 69 participants randomised (experimental = 34, comparator = 35) • 69 participants analysed • mean age (years) ± SD: 59.9 ± 14.8 experimental, 66.4 ± 14.3 comparator • gender (male/female): 24/10 experimental, 21/14 comparator • severity of condition (experimental/comparator): scheduled surgery (cardiothoracic = 16/17, abdominal surgery = 10/7, neurosurgery = 3/3, vascular surgery = 5/8) • comorbidities (experimental/comparator): ischaemic heart failure = 16/20, peripheral vascular disease = 6/9, smoking = 5/6, non-insulin-dependant diabetes mellitus = 7/8 • body weight (kg): 71.9 ± 12.6 experimental, 74.4 ± 13.4 comparator • height (cm): 169.9 ± 10.2 experimental, 168.8 ± 8.7 comparator • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter diameter 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (not detailed) Inclusion criteria • requiring radial artery catheterisation according to clinical indications in the operating room Exclusion criteria • not reported
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, out-of-plane) Comparator: RA puncture via palpation and landmarks Level of experience of person carrying out the procedure: quote: "both attendings and residents inserted arterial catheters during the course of the study." Attendings/residents: 7/55 attempts in experimental group, 14/100 attempts in comparator group Concomitant medications: quote: "for both techniques, local anesthetic (1% lignocaine) was infiltrated subcutaneously before commencing timing at the discretion of the anesthesiologist" Excluded medications: not reported
Outcomes	Primary (specified) • time required for insertion of radial artery catheter by the chosen technique (as detailed below) • number of attempts at arterial cannulation (each attempt defined as a new skin puncture) • number of cannulae used for successful catheter insertion

Levin 2003 *(Continued)*

	Primary (collected) • first-attempt success rate Secondary (specified) • cross-overs between techniques • need for assistance from a second anaesthetist • number of sites attempted Secondary (collected) • cross-overs between techniques • need for assistance from a second anaesthetist • number of sites attempted Time points reported: up to the end of the procedure (not specified)
Notes	Funding: not reported Conflicts of interest: not reported Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "before insertion of the radial artery catheter, the technique to be used was selected by random envelope"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	We did not identify an available protocol, but all prespecified outcomes were reported
Other bias	High risk	Trialists did not clearly describe or define the management of the outcome of number of attempts needed Quote: "failure of either technique was determined by the inserting physician subjectively when he or she felt uncomfortable proceeding with the current technique. In this event, data were recorded regarding subsequent attempts using the alternative technique but not included in the main analysis"

Li 2016

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm study, with blinding not reported China Duration: May 2014 to December 2014
Participants	• 88 participants randomised (experimental = 44, comparator = 44) • 80 (40/40) participants analysed • mean age (years) ± SD: 61.9 ± 14.24 experimental, 64.08 ± 12.43 comparator • gender (male/female): 27/13 experimental, 26/14 comparator • severity of condition (experimental/comparator): ICU shock patients • comorbidities (experimental/comparator): hypovolaemic shock = 7/6, septic shock = 29/30, cardiogenic shock = 4/4 • body weight (kg): not reported • height (cm): not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size not reported • catheterisation purpose (experimental/comparator): all for diagnosis (not detailed) Inclusion criteria • ICU shock; successively selected between May 2014 and December 2014 Exclusion criteria • history of forearm surgery • local infection • local artery embolism • abnormal results in a quantitative SaO_2 • Allen's trial (negative)
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery long axis, in-plane) Comparator: RA puncture via palpation and landmarks Level of experience of person carrying out the procedure: quote: "1 specialized nurse and 3 nurse-in-charge leaders with more than 10 years of experience in artery blind cannulation" Concomitant medications: quote: "continuous intravenous injection of butorphanol tartrate for analgesia and an intravenous injection of propofol for sedation" for all participants Excluded medications: not reported
Outcomes	Primary (specified) • rate of first puncture Primary (collected) • rate of first puncture Secondary (specified) • failure rate of puncture. Defined as 3 unsuccessful punctures at 1 site • puncture duration • haematoma • incidence of stasis

Li 2016 *(Continued)*

- time to achieve early goal-directed therapy
- overall duration

Secondary (collected)

- failure rate of puncture. Defined as 3 unsuccessful punctures at 1 site
- puncture duration
- haematoma
- incidence of stasis
- time to achieve early goal-directed therapy
- overall duration

Time points reported: up to 3 days after the puncture

Notes	Funding: quote: "Zhejiang Provincial Program for the Cultivation of High-level Innovative Health Talents (2014-108) and Zhejiang Provincial Medical and Health Science and Technology Plan (No. 2015111582)" Conflicts of interest: quote: "the authors declare that they have no actual or potential conflicts of interest" Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "a random number table developed by the clinical assessment center"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	High risk	Only 1 outcome (time to achieve early goal-directed therapy) was assessed by blinded staff
Incomplete outcome data (attrition bias) All outcomes	Low risk	All losses were reported; did not differ between groups Quote: "four withdrawal cases existed in the palpation group, of which 2 died within 3 days and 2 cases were discharged against medical advice within 3 days. One rejection case and 3 withdrawal cases existed in the ultrasound group, of which 1 case was excluded due to flexion and stenosis of bilateral radial arteries, 1 case died within 3 days, and 2 cases were discharged against medical advice"
Selective reporting (reporting bias)	Low risk	We did not identify an available protocol, but all prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Nam 2020

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm study, with blinding for participant and outcome assessment Korea Duration: January to June 2018
Participants	• 146 participants randomised (experimental = 70, comparator = 66) • 136 participants analysed • mean age (years) ± SD: 64.3 ± 13 experimental, 63.6 ± 13.3 comparator • gender (male/female): 43/27 experimental, 36/30 comparator • severity of condition (experimental/comparator): scheduled for elective cardiac surgery • comorbidities (experimental/comparator): hypertension = 29/22, diabetes = 22/14, chronic kidney disease = 8/5 • body weight (kg): 64.3 ± 14.9 experimental, 63.2 ± 12.2 comparator • height (cm): 162.4 ± 9.7 experimental, 160.8 ± 9.9 comparator • artery of interest: radial • diameter (mm), mean ± SD: 2.4 ± 0.6 experimental, 2.4 ± 0.6 comparator. Catheter size 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (not detailed) Inclusion criteria • over 18 years of age • scheduled for elective cardiac surgery Exclusion criteria • presence of an arteriovenous fistula for haemodialysis • history of Raynaud's syndrome • peripheral vascular disease • coagulopathy with significant bleeding tendency before surgery • morbid obesity (body mass index > 40 kg/m^2) • shock requiring vasopressor support • use of an extracorporeal membrane oxygenator or intra-aortic balloon pump • negative modified Allen's test
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, out-of-plane, DNTP) Comparator: ultrasound-guided RA puncture (real-time, artery long axis, in-plane) Level of experience of person carrying out the procedure: quote: "radial artery cannulations were performed prior to general anaesthesia induction by a single operator who performed more than 100 cases of radial artery cannulation per year" Concomitant medications: quote: "local anaesthesia using <1 mL of 2% lidocaine was then administered in both groups" Excluded medications: not reported
Outcomes	Primary (specified) • first-attempt success rate Primary (collected) • rate of first puncture

Nam 2020 *(Continued)*

	Secondary (specified) • time needed for cannulation Secondary (collected) • time needed for cannulation on first attempt • number of attempts • overall incidence of complications (posterior wall puncture, haematoma, thrombosis, vasospasm) Time points reported: up to 5 minutes, or until the end of the procedure
Notes	Funding: not reported Conflicts of interest: quote: "the authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript" Protocol (NCT03405623) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "patients were randomly allocated into the DNTP or LAX-IP group using a computer-generated random number table with a block size of two or four"
Allocation concealment (selection bias)	Low risk	Quote: "group assignments were sealed in opaque envelopes by a research assistant who was not involved in the study"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "the operator could not be blinded to the imaging methods"
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "we blinded the assessor of secondary endpoints"
Incomplete outcome data (attrition bias) All outcomes	Low risk	Exclusion after randomisation was described, was similar in both groups, and accounted for less than 10% of group amount. Experimental (3/70): due to surgery cancelled (1) and catheterised before surgery (2). Comparator (7/66): due to surgery cancelled (1), catheterised before surgery (5), and consent withdrawal (1)
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Nasreen 2016

Study characteristics

Methods	Single-centre prospective randomised controlled 2-arm study, with blinding not reported Pakistan

Nasreen 2016 *(Continued)*

	Duration: 1 January 2014 to 31 December 2014
Participants	• 100 participants randomised (experimental = 50, comparator = 50) • 100 participants analysed • mean age (years) ± SD: 43.0 ± 14.8 experimental, 41.0 ± 14.0 comparator • gender (male/female): 31/19 experimental, 29/21 comparator • severity of condition (experimental/comparator): scheduled for elective open cardiac surgery • comorbidities (experimental/comparator): not reported • body weight (kg): not reported • height (cm): not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (not detailed) Inclusion criteria • 18 to 70 years of age • both sexes • electively scheduled for open heart surgery Exclusion criteria • previous attempt at radial arterial cannulation during the same hospital visit • unstable condition such as emergency/urgent cardiac surgery • inadequate ulnar collateral flow
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, out-of-plane) Comparator: RA puncture via palpation and landmarks Level of experience of person carrying out the procedure: quote: "in both groups, radial artery cannulation was performed by a consultant anesthesiologist" Concomitant medications: quote: "lignocaine 1 ml was injected above the radial artery" Excluded medications: not reported
Outcomes	Primary (specified) • first-attempt success rate • average elapsed time • number of attempts • number of catheters used • complications noted with the related technique Primary (collected) • first-attempt success rate • average elapsed time • number of attempts • number of catheters used • complications noted with the related technique Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected)

Nasreen 2016 *(Continued)*

	• no differentiation between primary and secondary outcomes Time points reported: up to 5 minutes, or until the end of the procedure
Notes	Funding: not reported Conflicts of interest: not reported Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Quote: "the patients were randomly divided into two groups"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

NCT01663779

Study characteristics

Methods	Single-centre prospective randomised controlled 2-arm open-label parallel-assignment study USA Duration: August 2012 to 31 August 2015
Participants	• 50 participants randomised (experimental = 27, comparator = 23) • 50 participants analysed, there were no losses • mean age (years) ± SD: all 18 years or older (not detailed) • gender (male/female): not reported • severity of condition (experimental/comparator): participants hospitalised at surgical ICU • comorbidities (experimental/comparator): not reported • body weight (kg): not reported • height (cm): not reported

NCT01663779 *(Continued)*

- artery of interest: radial
- diameter (mm), mean ± SD: not reported. Catheter size not reported
- catheterisation purpose (experimental/comparator): all for diagnosis (not detailed)

Inclusion criteria

- 16 years of age and older
- both sexes

Exclusion criteria

- patient or his/her surrogate declining to participate or patient lacking a radial artery into which a catheter can be placed

Interventions	Experimental: real-time ultrasound-guided RA puncture (artery axis and needle/ultrasound plane not reported) Comparator: RA puncture using palpation and landmarks (artery axis not reported) Level of experience of person carrying out the procedure: quote: "arterial lines are placed by either postgraduate year 2 residents (surgery & anaesthesia) rotating through the ICU on a monthly basis, or by mid-level providers who are in the unit for indeterminate periods of time" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • first-attempt success rate Primary (collected) • first-attempt success rate Secondary (specified) • not described Secondary (collected) • haematoma Time points reported: up to the end of the procedure
Notes	Funding: not reported Conflicts of interest: not reported Protocol available (NCT01663779) | results described as raw data at ClinicalTrials.gov

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Unclear risk	Not described

NCT01663779 *(Continued)*

Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "masking: none (open-label)"
Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "masking: none (open-label)"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Nguyen 2019

Study characteristics	
Methods	Single-centre prospective randomised (radial vs femoral and standard vs ultrasound) 2 × 2 factorial single-blinded trial Australia Duration: November 2012 to November 2017
Participants	• 701 participants randomised (experimental = 360, comparator = 341) • 701 participants analysed • mean age (years) ± SD: 63.63 ± 11.1 • gender (male/female): 520/181 • severity of condition (experimental/comparator not reported): unstable angina 308 (44%), non-ST-segment elevation acute coronary syndrome 181 (25.9%), ST-segment elevation myocardial infarction 36 (5.1%) • comorbidities (experimental/comparator not reported): hypertension 450 (64.3%), diabetes mellitus 237 (33.8%), hypercholesterolaemia 420 (60.0%), peripheral vascular disease 10 (1.4%), smoking history 450 (64.3%) • BMI (kg/m^2): 29.84 ± 5.3 • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 5 Fr 33 (4.7%) or 6 Fr 667 (95.3%) • catheterisation purpose (experimental/comparator): for diagnosis (CA = 77.4%) or treatment (PCI = 22.5%) Inclusion criteria • 18 years of age or older referred for CA and PCI Exclusion criteria • cardiogenic shock • on dialysis • known severe peripheral vascular disease • previous failed access

Nguyen 2019 *(Continued)*

	• failed Allen's test
Interventions	Experimental: ultrasound-guided RA puncture (real-time; artery axis and needle plane not described) Comparator: RA puncture via palpation and landmarks Level of experience of person carrying out the procedure: quote: "all operators had performed at least 75 coronary interventions in the previous year, a minimum of 50 standard transradial access and transfemoral access, and 10 proctored ultrasound-guided access for both the radial and the femoral artery. All who satisfied the required training numbers were certified before taking part in the trial" Concomitant medications: quote: "lignocaine 1 ml was injected above the radial artery" Excluded medications: not reported
Outcomes	Primary (specified) • composite of ACUITY (Acute Catheterization and Urgent Intervention Triage strategY) major bleeding, major adverse cardiovascular events (MACE) comprising death, stroke, myocardial infarction, or urgent target lesion revascularisation, and vascular complications at 30 days Primary (collected) • composite of ACUITY (Acute Catheterization and Urgent Intervention Triage strategY) major bleeding, major adverse cardiovascular events (MACE) comprising death, stroke, myocardial infarction, or urgent target lesion revascularisation, and vascular complications at 30 days Secondary (specified) • access time • number of attempts • venipuncture • difficult access (requiring 5 or more attempts) • first-pass success Secondary (collected) • access time • number of attempts • venipuncture • difficult access (requiring 5 or more attempts) • first-pass success Time points reported: quote: "all patients were followed up at one week and one month"
Notes	Funding: not reported Conflicts of interest: quote: "the authors have no conflicts of interest to declare" Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Quote: "patients were randomised (1:1) to radial or femoral access, and (1:1) to either standard or ultrasound guidance"
Allocation concealment (selection bias)	Low risk	Quote: "sealed envelopes balanced in blocks of 50 were used for randomisation"

Nguyen 2019 *(Continued)*

Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "patients and investigators were not masked to access allocation"
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "randomised, single-blinded, 2x2 factorial trial"
Incomplete outcome data (attrition bias) All outcomes	Low risk	Loss to follow-up was similar between experimental and comparator groups (3% and 2.9%). Cross-over rates were similar between experimental and comparator groups (7.2% and 8.1%)
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Osuda 2020

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm study, with blinding not reported Japan Duration: 1 January 2014 to 31 December 2014
Participants	• 72 participants randomised (experimental = 36, comparator = 36) • 72 participants analysed • mean age (years) ± SD: 62.1 ± 13.4 experimental, 59.5 ± 15.0 comparator • gender (male/female): 12/24 experimental, 14/22 comparator • severity of condition (experimental/comparator): scheduled for elective cardiac surgery • comorbidities (experimental/comparator): hypertension 9/13, diabetes mellitus 2/2 • body weight (kg): 56.0 ± 9.9 experimental, 58.4 ± 10.2 comparator • height (cm): 157.2 ± 9.1 experimental, 159.0 ± 8.4 comparator • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 22 G • catheterisation purpose (experimental/comparator): all for diagnosis (not detailed) Inclusion criteria • aged 20 to 80 years • ASA I or II • undergoing scheduled operation Exclusion criteria • ulnar artery occlusion • BMI > 35 • scheduled for cardiovascular surgery • peripheral vascular disease • trauma around the radial artery • previous cannulation within 1 month

Osuda 2020 *(Continued)*

Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery long axis, in-plane) Comparator: RA puncture using near-infrared laser light Level of experience of person carrying out the procedure: quote: "our experience with the Mill Suss and LA-IP ultrasound-guided methods was very limited before this study" Concomitant medications: all participants under general anaesthesia; no details Excluded medications: not reported
Outcomes	Primary (specified) • number of times required for radial artery catheterisation • time required for catheterisation Primary (collected) • first-attempt success rate • average elapsed time • number of attempts • number of catheters used • complications noted with the related technique Secondary (specified) • not reported Secondary (collected) • success rate • first-attempt success rate • blood pressure at cannulation Time points reported: up to the end of the procedure (not specified)
Notes	Funding: not reported Conflicts of interest: quote: "the authors have no conflicts of interest associated with this study" Protocol (JPRN-UMIN000021546) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Quote: "using a block randomization method"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described

Osuda 2020 *(Continued)*

Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Peters 2015

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm single-blinded (outcome assessor) study Canada Duration: September 2013 to January 2014
Participants	• 125 participants randomised (experimental = 63, comparator = 62) • 125 participants analysed • mean age (years) ± SD: 67 ± 14 experimental, 67 ± 14 comparator • gender (male/female): 52/11 experimental, 46/16 comparator • severity of condition (experimental/comparator): scheduled for elective cardiac surgery • comorbidities (experimental/comparator): ASA physical status IV 36/59, peripheral vascular disease 3/3 • BMI (kg/m^2): 26 ± 4 experimental, 27 ± 5 comparator • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (not detailed) Inclusion criteria • aged 18 years or older • undergoing cardiac surgery • provided written informed consent Exclusion criteria • suspected inability to comply with study procedures (including language difficulties or medical history and/or concomitant disease) as judged by investigator • previous surgery at site of proposed radial artery catheterisation • any vascular condition that would preclude eligibility for radial artery line insertion as judged by investigator • ventricular assist device (no palpable arterial pulsatility)
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, out-of-plane) Comparator: RA puncture via palpation and landmarks Level of experience of person carrying out the procedure; quote: "all cardiac anaesthesiologists involved in the study had performed a minimum of 300 palpation-guided and 10 ultrasound-guided arterial catheter insertions prior to trial commencement"

Peters 2015 *(Continued)*

	Concomitant medications: all participants under general anaesthesia; quote: "local anaesthetic in the form of 1% lidocaine 0.2-1.0 mL was infiltrated superficially over the target structure at the discretion of the attending anaesthesiologist" Excluded medications: not reported
Outcomes	Primary (specified) • time to successful radial arterial catheterisation [Time Frame: up to 5 minutes] Primary (collected) • time to successful catheterisation Secondary (specified) • Number of attempts [Time Frame: up to 5 minutes] • Number of re-directions [Time Frame: up to 5 minutes] • Complication rate (haematoma) [Time Frame: up to 5 minutes] Secondary (collected) • number of attempts • number of re-directs • first-pass success rate • incidence of haematoma formation • overall failure rate Time points reported: up to 5 minutes
Notes	Funding: quote: "this study was funded by departmental sources (Department of Anesthesia, St. Paul's Hospital, Vancouver, BC). Dr. S. K. W. Schwarz holds the Dr. Jean Templeton Hugill Chair in Anesthesia, supported by the Dr. Jean Templeton Hugill Endowment for Anesthesia Memorial Fund" Conflicts of interest: quote: "none of the authors have any competing financial interests relating to patents and/or shareholdings in corporations involved in the development and/or marketing of any medication or medical device used in this study" Protocol (NCT02118441) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "we used consecutively numbered sealed opaque envelopes containing individual folded group assignment cards that were generated (C.P.) prior to commencement of enrolment via urn randomization in blocks of six to minimize selection bias and keep group sizes balanced"
Allocation concealment (selection bias)	Low risk	Quote: "after enrolment of an individual patient, one sealed envelope was drawn and opened by the patient's attending cardiac anesthesiologist who performed the allocated study intervention"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "it was not possible to blind data collectors to group allocation because data collection required direct observation of all insertions"
Blinding of outcome assessment (detection bias)	High risk	Quote: "it was not possible to blind data collectors to group allocation because data collection required direct observation of all insertions"

Peters 2015 *(Continued)*

All outcomes		
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Quan 2014

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm open-label study China Duration: September 2013 to January 2014
Participants	• 164 participants randomised (experimental = 83 (1 dropout), comparator = 81) • 163 participants analysed • mean age (years) ± SD: 46.1 ± 7.9 experimental, 49.2 ± 8.1 comparator • gender (male/female): 64/18 experimental, 59/22 comparator • severity of condition (experimental/comparator): resection of liver cancer 35/31, splenectomy 47/50 • comorbidities (experimental/comparator): diabetes mellitus 11/8, hyperlipidaemia 1/2, hypertension 2/6 • body weight (kg): 72.1 ± 10.5 experimental, 76.4 ± 12.2 comparator • artery of interest: radial • diameter (mm), mean ± SD: 2.4 ± 0.7 experimental, 2.3 ± 0.4 comparator. Catheter size 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring and blood sampling during surgery) Inclusion criteria • undergoing liver surgery or splenic resection under general anaesthesia • ASA I to III Exclusion criteria • negative Allen's test • ulnar artery occlusion • prevalent atherosclerosis • haemorrhagic shock • morbid obesity • Raynaud disease • peripheral vascular disease • myocardial infarction • unstable angina • cardiogenic shock • coagulation disorder • multiple previous radial artery interventional therapies
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery long axis, in-plane)

Quan 2014 *(Continued)*

	Comparator: ultrasound-guided RA puncture (real-time, short axis, out-of-plane) Level of experience of person carrying out the procedure: quote: "the procedure in both groups was performed by the same experienced anesthesiologist, who had previously cannulated 450 radial arteries and used the ultrasound-guided technique for approximately 200 procedures" Concomitant medications: all participants under general anaesthesia; quote: "local anaesthesia (0.2 mL, 2% lidocaine)" Excluded medications: not reported
Outcomes	Primary (specified) • rate of cannula insertion success on first attempt Primary (collected) • rate of cannula insertion success on first attempt Secondary (specified) • insertion failure rate • inner diameter of radial artery • depth of artery from the skin • ultrasonic location time • cannulation time • vascular complications (thrombosis, haematoma, oedema, vasospasm) Secondary (collected) • insertion failure rate • inner diameter of radial artery • depth of artery from the skin • ultrasonic location time • cannulation time • vascular complications (thrombosis, haematoma, oedema, vasospasm) Time points reported: up to 5 minutes
Notes	Funding: quote: "none" Conflicts of interest: quote: "the authors declare no conflicts of interest" Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not sufficiently described Quote: "using a sealed envelope method, patients were randomly assigned (allocation ratio 1:1) into 2 groups"
Allocation concealment (selection bias)	Low risk	Quote: "using a sealed envelope method, patients were randomly assigned (allocation ratio 1:1) into 2 groups"
Blinding of participants and personnel (performance bias)	High risk	Open-label trial

Quan 2014 *(Continued)*

All outcomes		
Blinding of outcome assessment (detection bias) All outcomes	High risk	Open-label trial
Incomplete outcome data (attrition bias) All outcomes	Low risk	One dropout after randomisation (1/83, experimental group) due to participant consent withdrawn
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Rajasekar 2021

Study characteristics	
Methods	Single-centre prospective randomised controlled 3-arm open-label parallel-assignment trial India Duration: not reported
Participants	• 90 participants randomised (experimental (in-plane) = 30, experimental (out-of-plane) = 30, comparator (palpation) = 30) • 90 participants analysed, there were no losses • mean age (years) ± SD: age 41 to 50 years = 15 (in-plane), 19 (out-of-plane), 16 (palpation) • gender (male/female): 20/10 in-plane, 20/10 (out-of-plane), 21/9 palpation • severity of condition (experimental/comparator): scheduled for elective surgery • comorbidities (experimental/comparator): not reported • BMI (kg/m^2), mean: 26.97 in-plane, 26.70 out-of-plane, 26.70 palpation, SD not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or blood test) Inclusion criteria • 18 to 50 years of age • both sexes • coming for various surgeries requiring radial artery cannulation for invasive blood pressure monitoring or frequent arterial blood gas analysis in the course of preoperative management Exclusion criteria • any sign of infection near the puncture site • recent arterial cannulation at the same site during this hospital admission • haemodynamically unstable • history or evidence of peripheral vascular disease and coagulopathy • refusal after recruiting • negative modified Allen's test
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery long axis, in-plane)

Rajasekar 2021 *(Continued)*

	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, out-of-plane) Comparator: RA puncture via palpation and landmarks Level of experience of person carrying out the procedure: quote: "all the data were collected by the same anesthesiologist in all the patients" Concomitant medications: quote: "skin was infiltrated with 1 ml of 2% lignocaine" Excluded medications: not reported
Outcomes	Primary (specified) • time of insertion of cannula Primary (collected) • first-attempt success rate Secondary (specified) • number of attempts for successful cannulation • need for cross-over between techniques • complications Secondary (collected) • number of attempts for successful cannulation • time taken for cannulation • need for cross-over between techniques • complications • total success rate Time points reported: up to the end of the procedure
Notes	Funding: not reported. Conflicts of interest: quote: "nil" Protocol available (CTRI/2019/02/017749)

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "the enrolled 90 patients were blocked randomized into one of the three groups (30 in each group) using computer-generated randomization numbers and concealed by sealed enveloped technique"
Allocation concealment (selection bias)	Low risk	Quote: "the enrolled 90 patients were blocked randomized into one of the three groups (30 in each group) using computer-generated randomization numbers and concealed by sealed enveloped technique"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "blinding was not possible in our study"
Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "blinding was not possible in our study"

Rajasekar 2021 *(Continued)*

Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses and the need for cross-over among groups was balanced (5 (16.7%) palpation, 1 (3.3%) in-plane, 2 (8.9%) out-of-plane)
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	High risk	Trial authors changed the primary outcome of interest from 'Time of insertion of cannula' (protocol) to 'First-attempt success rate' (article) without a reasonable motivation

Rose 2018

Study characteristics	
Methods	[Abstract of event] Single-centre prospective randomised controlled 2-arm open-label study Site and duration not reported
Participants	• 60 participants randomised (experimental = 30, comparator = 30) • 60 participants analysed • mean age (years) ± SD: not reported • gender (male/female): not reported • severity of condition (experimental/comparator): not reported • comorbidities (experimental/comparator): not reported • body weight (kg): not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size not reported • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or frequent blood test) Inclusion criteria • 18 years of age or older at a tertiary care urban academic emergency department • requiring radial catheter placement for continuous blood pressure monitoring or frequent blood draws Exclusion criteria • contraindications to radial arterial access • pre-existing arterial catheter at alternative site
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery axis and needle plane not described) Comparator: RA puncture by palpation and landmarks Level of experience of person carrying out the procedure: quote: "performed by emergency medicine residents with standard ultrasound training" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • number of attempts • duration of procedure

Rose 2018 *(Continued)*

- resident experience
- complication rate

Primary (collected)

- number of attempts
- duration of procedure
- resident experience
- complication rate
- successful radial arterial line rate

Secondary (specified)

- no differentiation between primary and secondary outcomes

Secondary (collected)

- no differentiation between primary and secondary outcomes

Time points reported: up to the end of the procedure (not described)

Notes	Funding: not described Conflicts of interest: not described Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described Quote: "patients were randomized"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	High risk	Baseline characteristics between groups and safety outcomes were planned but were reported only by descriptions (i.e. without numerical values) for each group
Other bias	Low risk	We do not suspect any other bias related to this study

Sethi 2017

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm open-label study India Duration: not reported
Participants	• 150 participants randomised (experimental = 75, comparator = 75) • 150 participants analysed • mean age (years) ± SD: 57.7 ± 7.6 experimental, 59.5 ± 8.2 comparator • gender (male/female): 41/34 experimental, 46/29 comparator • severity of condition (experimental/comparator): not reported • comorbidities (experimental/comparator): not reported • body weight (kg): 64.6 ± 12.2 experimental, 62.8 ± 11.6 comparator • artery of interest: radial • diameter (mm), mean ± SD: 2.24 ± 0.43 experimental, 2.25 ± 0.42 comparator. Catheter size 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or frequent blood test) Inclusion criteria • ASA I to III Exclusion criteria • negative Allen's test • ulnar artery occlusion • atherosclerotic vascular disease • haemorrhagic shock • morbid obesity • Raynaud's disease • peripheral vascular disease • coagulation disorder
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery long axis, in-plane) Comparator: ultrasound-guided RA puncture (real-time, short axis, out-of-plane) Level of experience of person carrying out the procedure: quote: "each of the two anaesthetists had placed more than 100 arterial lines by using either in-plane or out-of-plane approaches before commencing this study" Concomitant medications: all participants under general anaesthesia Excluded medications: not reported
Outcomes	Primary (specified) • successful cannulation in first attempt Primary (collected) • successful cannulation in first attempt Secondary (specified) • anteroposterior arterial diameter • skin-to-artery distance

Sethi 2017 *(Continued)*

- ultrasonic localisation time
- cannulation time
- number of attempts to cannulate artery
- cannula insertion failure
- vascular complications (haematoma formation, posterior arterial wall puncture, thrombosis)

Secondary (collected)

- anteroposterior arterial diameter
- skin-to-artery distance
- ultrasonic localisation time
- cannulation time
- number of attempts to cannulate artery
- cannula insertion failure
- vascular complications (haematoma formation, posterior arterial wall puncture, thrombosis)

Time points reported: up to the end of the procedure (not described)

Notes	Funding: not reported Conflicts of interest: not reported Protocol (CTRI/2015/02/005552) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "patients were randomized into two groups according to a computer-generated random number table"
Allocation concealment (selection bias)	Low risk	Quote: "randomization sequences were kept on an opaque sealed envelope to maintain confidentiality and were handed over to the operator just before arterial by an anesthesiologist who was not a part of the study"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	High risk	One of the planned safety outcomes (posterior arterial wall puncture) was not reported
Other bias	Low risk	We do not suspect any other bias related to this study

Seto 2015

Study characteristics

Seto 2015 *(Continued)*

Methods	Multi-centre (6 hospitals) prospective randomised controlled 2-arm open-label study USA Duration: 1 December 2011 to 29 March 2013
Participants	• 698 participants randomised (experimental = 347, comparator = 351) • 698 participants analysed • mean age (years) ± SD: 61.5 ± 11.5 experimental, 62.3 ± 10.6 comparator • gender (male/female): 254/93 experimental, 262/89 comparator • severity of condition (experimental/comparator): not reported • comorbidities (experimental/comparator): obesity (BMI > 30) 149/153, hypertension 292/305, hypercholesterolaemia 254/265, diabetes mellitus 149/151, tobacco 128/107, PVD 14/16 • BMI (kg/m^2): 30.4 6.9 experimental, 30.2 7.2 comparator • artery of interest: radial • diameter (mm), mean ± SD: 2.24 ± 0.43 experimental, 2.25 ± 0.42 comparator. Catheter size 5-F or 6-F sheath • catheterisation purpose (experimental/comparator): for CA (274/288) or PCI (73/63) Inclusion criteria • adult patients presenting for cardiac or peripheral catheterisation with planned radial approach • Barbeau's or Allen's test indicating at least some degree of collateral circulation in palmar vessels • functional ultrasound equipment with ultrasound-trained attending operator Exclusion criteria • non-palpable radial pulse • abnormal hand collateral circulation (abnormal Allen's test or Barbeau class D) • inability to provide informed consent • femoral access • emergency procedure (shock, STEMI) • end-stage renal disease on haemodialysis • previous ipsilateral puncture within 1 week
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, out-of-plane); quote: "single- or double-wall technique was used per operator preference" Comparator: RA puncture by palpation and landmarks; quote: "single- or double-wall technique was used per operator preference" and "palpation-guided procedures were allowed to cross over to rescue US guidance after 5 min of attempts" Level of experience of person carrying out the procedure; quote: "this study included operators experienced in transradial catheterization to minimize potential confounders" Concomitant medications: conscious sedation, intra-arterial and/or subcutaneous lidocaine as per local practice, minimum of 2000 IU of intravenous unfractionated heparin or bivalirudin for anticoagulation, and minimum of 2.5 mg of intra-arterial verapamil or 100 mg nitroglycerin for spasm prophylaxis Excluded medications: not reported
Outcomes	Primary (specified) • number of forward attempts required for access (up to 30 minutes) Primary (collected) • number of forward attempts required for access • first-pass success rate

Seto 2015 *(Continued)*

- time to sheath insertion

Secondary (specified)

- time to sheath Insertion (seconds) [Time Frame: Immediately during procedure (within 30 minutes)]. Time from initiation of vascular access attempts to successful aspiration or flushing of the sheath. Time for lidocaine administration, palpation of pulse, or imaging is excluded
- first-pass success rate [Time Frame: Immediate]. Proportion of procedures achieving access on first attempt
- radial artery spasm [Time Frame: Immediately during procedure (within 30 minutes)]. Spasm defined and identified by operator as any significant resistance or patient pain with catheter manipulation
- difficult access procedures ± 5 attempts [Time Frame: Immediately during procedure (within 30 minutes)]. Difficult procedures were defined as requiring ± 5 attempts
- difficult access ± 5 minutes [Time Frame: Immediate (within 30 minutes)]. Access requires ± 5 minutes from first attempt to sheath insertion
- bleeding complication [Time Frame: After procedure (within 24 hours)]. Any haematoma > 2 cm or bleeding requiring intervention
- pain score [Time Frame: 2 to 8 hours after procedure]. Patient-reported wrist pain on a visual analogue scale (0 to 10) 2 to 8 hours after the procedure, where 0 is no pain and 10 is severe pain

Secondary (collected)

- pain (0 to 10 VAS)
- incidence of spasm
- difficult procedure
- bleeding complication
- access site cross-over
- failure of sheath insertion with original technique

Time points reported: range 30 minutes to 24 hours (bleeding)

Notes	Funding: quote: "the study was investigator initiated and unsponsored" Conflicts of interest: quote: "Dr. Abu-Fadel serves on the Speakers Bureau of Abbott Vascular. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose" Protocol (NCT01605292) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Low risk	Quote: "patients were randomized in a 1:1 fashion to either palpation or US guidance using sealed envelopes balanced in blocks of 50 to 80 generated at each center"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Open-label study
Blinding of outcome assessment (detection bias) All outcomes	High risk	Open-label study

Seto 2015 *(Continued)*

Incomplete outcome data (attrition bias) All outcomes	High risk	There was imbalance in cross-over interventions between experimental (0/347) and comparator (10/351) groups Quote: "ten patients in the control group required crossover to US guidance after 5 min of failed palpation attempts with 8 of 10 (80%) having successful sheath insertion with US"
Selective reporting (reporting bias)	Low risk	All prespecified outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Seyhan 2021

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm open-label parallel-assignment study Turkey Duration: 1 January 2020 to 1 April 2020
Participants	• 59 participants assessed for eligibility, with 9 excluded (not meeting inclusion criteria = 7, declined to participate = 2), 50 randomised • 50 analysed: experimental = 25, palpation = 25; there were no losses after randomisation • mean age (years): 78% = 66 years or older (not detailed) • gender (male/female): 21/29 (not detailed) • severity of condition: all participants had septic shock at an emergency department • comorbidities: not reported • BMI (kg/m^2): not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 23 G • catheterisation purpose (experimental/comparator): all for diagnosis (blood test) Inclusion criteria • septic shock in emergency department • 18 years of age or older • both sexes • undergoing radial artery puncture for blood gas analysis Exclusion criteria • positive Allen's test • local infection at puncture site • trauma at puncture site • arteriovenous fistula • vascular graft • coagulopathy disorder • refusal to participate
Interventions	Experimental: ultrasound-guided RA puncture (real-time, short-axis approach, out-of-plane) Comparator: palpation-guided RA puncture

Seyhan 2021 *(Continued)*

	Level of experience of person carrying out the procedure; quote: "clinicians who have point-of-care US certificate perform this procedure" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • number of successful first entry Primary (collected) • number of successful first entry Secondary (specified) • number of attempts before a successful puncture • time until a successful puncture Secondary (collected) • number of attempts before a successful puncture • time until a successful puncture (reported by category) • total successful catheterisation rate (success up to 3 attempts) Time point reported: up to the end of the procedure
Notes	Funding: quote: "the author(s) received no financial support for the research, authorship, and/or publication of this article" Conflicts of interest: quote: "the author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article" Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Quote: "once enrolment was complete, the patients were then randomized". It was not clear how randomisation was done
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "this prospective-pilot study was nonblinded"
Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "this prospective-pilot study was nonblinded"
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All planned outcomes were reported

Seyhan 2021 *(Continued)*

Other bias	Low risk	We do not suspect any other bias related to this study

Shiver 2006

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm open-label study USA Duration: 6 months (not specified).
Participants	• 60 participants randomised (experimental = 30, comparator = 30) • 60 participants analysed • mean age (years) ± SD: not reported • gender (male/female): not reported • severity of condition (experimental/comparator): not reported • comorbidities (experimental/comparator): number of patients intubated 22/23 • weight (kg): not reported • height (cm): not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or blood test, in critically ill patients) Inclusion criteria • 18 years of age or older • deemed to require an arterial line by the treating attending emergency physician Exclusion criteria • previous attempts at an arterial line during the visit • unstable patient in whom an arterial line had to be placed before study randomisation
Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery long axis, in-plane) Comparator: RA puncture by palpation and landmarks Level of experience of person carrying out the procedure: quote: "none of the four had previously placed US-guided arterial catheters, but all had experience placing US-guided peripheral and central venous lines" Concomitant medications: all participants under general anaesthesia Excluded medications: not reported
Outcomes	Primary (specified) • time to placement • number of attempts • sites used • complications (arterial laceration, thrombosis, haematoma) Primary (collected) • first-attempt success rate

Shiver 2006 *(Continued)*

	• time to placement • number of attempts • sites used • complications (arterial laceration, thrombosis, haematoma) Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected) • no differentiation between primary and secondary outcomes Time points reported: up to the end of the procedure (not described)
Notes	Funding: not reported Conflicts of interest: not reported Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "each patient included in the study was randomly assigned to either the US-guided or palpation-technique group by using a random-number generator"
Allocation concealment (selection bias)	Low risk	Quote: "randomization results with a data sheet were kept in a sealed envelope in a locked and secured area"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "because this study could not be effectively blinded"
Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "because this study could not be effectively blinded"
Incomplete outcome data (attrition bias) All outcomes	High risk	There was an imbalance in cross-over interventions between experimental (0/30) and comparator (11/30) groups Quote: "eleven (37%) patients in the palpation group required rescue with US guidance. None of the patients in the US-guided group required more than two attempts, and none were switched to the palpation technique for rescue"
Selective reporting (reporting bias)	High risk	Two of the planned safety outcomes were not reported (arterial laceration and thrombosis)
Other bias	Low risk	We do not suspect any other bias related to this study

Tada 2003

Study characteristics

Methods	Single-centre prospective randomised controlled 2-arm study, with blinding not described

Tada 2003 *(Continued)*

	Japan Duration: April 1999 to March 2002
Participants	• 166 participants randomised (experimental = 72, comparator = 94) • 166 participants analysed • mean age (years) ± SD: 62.2 ± 11.8 experimental, 64.1 ± 11.9 comparator • gender (male/female): 43/29 experimental, 59/35 comparator • severity of condition (experimental/comparator): not reported • comorbidities (experimental/comparator): number of patients intubated 22/23 • mean BMI (kg/m^2) ± SD: 22.7 ± 3.6 experimental, 23.0 ± 3.6 comparator • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size not reported • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or blood test, % not reported, during surgery) Inclusion criteria • hospitalised patient who underwent general anaesthesia and required arterial cannulation Exclusion criteria • not reported
Interventions	Experimental: Doppler assistance-guided RA puncture (real-time, artery axis not applicable) Comparator: RA puncture by palpation and landmarks Level of experience of person carrying out the procedure: quote: "board-certified anaesthesiologist who had been trained in the ultrasound technique in 20 patients prior to the current study" Concomitant medications: all participants under general anaesthesia Excluded medications: not reported
Outcomes	Primary (specified) • first-attempt success rate • overall success rate Primary (collected) • first-attempt success rate • overall success rate Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected) • no differentiation between primary and secondary outcomes Time points reported: up to the end of the procedure (not described)
Notes	Funding: not reported Conflicts of interest: not reported Protocol not available

Tada 2003 *(Continued)*

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Quote: "166 patients were randomly assigned to two study groups"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	Low risk	All planned outcomes were reported
Other bias	High risk	There were imbalances between experimental and comparator groups: participant number (72/94), male participants (43/59), and female participants (29/35). This imbalance is considered not to be possible by chance

Tangwiwat 2016

Study characteristics

Methods	Single-centre prospective randomised controlled 2-arm study, with blinding not described Thailand Duration: November 2009 to October 2010
Participants	• 100 participants randomised (experimental = 30, comparator = 30) • 100 participants analysed • mean age (years) ± SD: 51.0 ± 15.3 experimental, 50.4 ± 15.1 comparator • gender (male/female): 20/30 experimental, 19/31 comparator • severity of condition (experimental/comparator): all participants undergoing neurosurgery, ASA 1 (4/3), ASA 2 (36/41), ASA 3 (10/6) • comorbidities (experimental/comparator): number of patients intubated 22/23 • body weight (kg): not reported • height (cm): not reported • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or blood test, % not reported, during neurosurgery) Inclusion criteria

Tangwiwat 2016 *(Continued)*

- undergoing neurosurgery
- >18 years old
- indication for radial artery cannulation

Exclusion criteria

- pregnant women
- negative modified Allen's test
- severe vascular morbidity such as limb ischaemia from multiple insertion attempts and air emboli

Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery short axis, out-of-plane) Comparator: RA puncture by palpation and landmarks Level of experience of person carrying out the procedure: quote: "ten third-year residents, having performed USG vascular catheterization as yet less than 3 times" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • time to placement • number of attempts • sites used • success rate • complications (haematoma, infection, retained catheter, radial nerve damage, arterial thrombosis/ischaemia, carpal tunnel syndrome) Primary (collected) • success rate in first attempt • time to placement • number of attempts • sites used • success rate • complications (haematoma) Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected) • no differentiation between primary and secondary outcomes Time points reported: up to 24 hours
Notes	Funding: quote: "this work was supported by Siriraj Research Development Fund, Faculty of Medicine Siriraj Hospital, Mahidol University" Conflicts of interest: quote: "none" Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement

Tangwiwat 2016 *(Continued)*

Random sequence generation (selection bias)	Low risk	Quote: "using computer generated block randomization (mixed block size)"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	High risk	There was an imbalance in cross-over interventions between experimental (6/50) and comparator (1/50) groups
Selective reporting (reporting bias)	High risk	Some of the planned safety outcomes were not reported (infection, retained catheter, radial nerve damage, arterial thrombosis/ischaemia, carpal tunnel syndrome)
Other bias	Low risk	We do not suspect any other bias related to this study

Ueda 2015

Study characteristics	
Methods	Single-centre prospective randomised controlled 3-arm parallel-assignment study, with outcomes assessment blinded USA Duration: February 2010 to December 2011
Participants	• 749 participants randomised (experimental (Doppler) = 244, experimental (B-mode) = 249, comparator = 256) • 749 participants analysed • mean age (years) ± SD: 59.66 ± 17.15 B-mode, 61.33 ± 15.66 Doppler, 59.66 ± 14.91 palpation (register site) • gender (male/female): 143/106 B-mode, 137/107 Doppler, 150/106 palpation (register site) • severity of condition (experimental/comparator): not available • comorbidities (experimental/comparator): not available • body weight (kg): not available • height (cm): not available • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring during scheduled surgery) Inclusion criteria • 18 to 99 years of age • requiring continuous arterial pressure monitoring during scheduled surgery

Ueda 2015 *(Continued)*

	Exclusion criteria • inflamed skin near puncture site • cool, mottled skin with poor capillary refill • radial artery punctured within previous 30 days • arteriovenous shunt in upper extremity (register site)
Interventions	Experimental (Doppler): ultrasound-assisted RA puncture (real-time, artery axis not relevant, needle plane not relevant) Experimental (B-mode): ultrasound-guided RA puncture (real-time, artery short axis, out-of-plane) Comparator: RA puncture by palpation and landmarks Level of experience of person carrying out the procedure: quote: "we used a simulated artery to teach anaesthetists how to use Doppler and ultrasound probes, which they had used less than five times before the study" (article). Quote: "performed by anaesthesia residents" (register site) Concomitant medications: quote: "less than 1 ml lidocaine 2% was injected subcutaneously over the radial artery" Excluded medications: not reported
Outcomes	Primary (specified) • success rate in first attempt • number of attempts • complications (thrombosis, haematoma, infection, ischaemia) Primary (collected) • success rate in first attempt • time to placement • number of attempts • total success rate • complications (haematoma, ischaemia) Secondary (specified) • Time to successful cannulation • Total success rate Secondary (collected) • no differentiation between primary or secondary outcomes Time points reported: up to 3 days (article) and up to 5 minutes (register site)
Notes	Funding: quote: "no external funding and no competing interests declared" Conflicts of interest: quote: "no external funding and no competing interests declared" Protocol available, but not linked in the article (NCT01276171)

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "we allocated participants in a 1:1:1 ratio with a computer-generated list of pseudo-random numbers in blocks of six, accessible only to research nurses"

Ueda 2015 *(Continued)*

Allocation concealment (selection bias)	Low risk	Quote: "the total allocation sequence was prepared by research nurses before the first participant was recruited, using sealed envelopes" and "the sealed envelopes were opened immediately before arterial cannulation"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "masking: single (outcomes assessor)" (register site)
Incomplete outcome data (attrition bias) All outcomes	High risk	There were no losses, but we found inconsistencies related to time points (up to 3 days in the article vs up to 5 minutes in the protocol) and to number of events (Doppler group had 96 first attempt success events at article vs 101 events at protocol)
Selective reporting (reporting bias)	High risk	Two planned safety outcomes were not reported (thrombosis and infection)
Other bias	High risk	Trial authors stated that "all subsequent procedures were performed in a sterile fashion", but figure 1 shows an example of Doppler-assisted radial artery cannulation without any sterile cover. Infection was one of the planned safety outcomes

Wang 2017

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm study, with blinding not described China Duration: 1 June 2017 to 27 October 2017
Participants	• 288 participants randomised (experimental = 144 (1 excluded), comparator = 144 (2 excluded)) • 285 participants analysed • mean age (years) ± SD: 62.62 ± 11.99 experimental, 61.1 ± 12.3 comparator • gender (male/female): 59/84 experimental, 60/82 comparator • severity of condition (experimental/comparator): resection of lung tumour 103/102, urinary surgery 20/22, others 20/18 • comorbidities (experimental/comparator): hypertension 22/17, coronary disease 4/4, diabetes mellitus 9/9, peripheral vascular disease 6/5 • BMI (kg/m^2): 22.99 ± 3.28 experimental, 22.99 ± 3.33 comparator • artery of interest: radial • diameter (mm), mean ± SD, left artery: 2.34 ± 0.13 experimental, 2.34 ± 0.14 comparator, diameter (mm), mean ± SD, right artery: 2.36 ± 0.13 experimental, 2.37 ± 0.14 comparator. Catheter size 20 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or blood test during surgery) Inclusion criteria • adult patients with diameter of the radial artery not less than 2.2 mm scheduled for elective surgery Exclusion criteria

Wang 2017 *(Continued)*

- ulnar artery occlusion
- history of forearm surgery
- skin infection at puncture site
- abnormal modified Allen's test
- coagulation dysfunction

Interventions	Experimental: ultrasound-guided RA puncture (real-time, artery long axis, in-plane) Comparator: RA puncture by palpation and landmarks Level of experience of person carrying out the procedure: quote: "three anaesthesiologists who performed radial artery cannulation were divided into 3 categories according to the years of clinical training in anaesthesia after graduation from medical college: 1 year (CA1), 3 years (CA3), and 5 years (CA5). At least 15 cases of radial artery catheterization guided by the M-LAINUT were performed for each operator before starting the study" Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • success rate of puncture • puncture-related complications Primary (collected) • first radial artery cannulation success rate • total radial artery cannulation success rate Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected) • number of attempts • cannulation time • incidence of complications (haematoma) Time points reported: up to 1 day and up to 3 days after the procedure
Notes	Funding: quote: "this work was supported in part by the Fujian Province Science and Technology Innovation Joint Fund Project of China (2017Y9008) and the National Natural Science Foundation of China (Grant number: 81641038). They were not involved in research design, collection, data analysis, or approved to submit articles for publication" Conflicts of interest: quote: "the authors have no conflicts of interest to disclose" Protocol (ChiCTR-IOR-17011474) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "all the random numbers were generated by a computer and placed in sealed envelopes"
Allocation concealment (selection bias)	Low risk	Quote: "study assignment was concealed until after the decision had been made to radial artery cannulation and the patient was enrolled in the trial"

Wang 2017 *(Continued)*

Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There was balanced dropout among groups: experimental 1/144 (1 reluctance to randomise), comparator 2/144 (1, the attending anaesthesiologist, decided not to insert the cannula into the radial artery, 1 loss of medical records)
Selective reporting (reporting bias)	Low risk	All planned outcomes were reported
Other bias	High risk	There are 2 preprints and 1 published article with the same registration number (ChiCTR-IOR-17011474) but with differences in study design and period of carry-out. Wang 2020 reported randomisation in 2 different groups (1:1) and period of carry-out between 1 June 2017 and 27 October 2017. Wang 2019 reported randomisation in 3 different groups (1:1:1) and period of carry-out between 1 July 2018 and 24 November 2018. We considered these data as 2 different studies due to method characteristics, distinct participants, and period of carry-out

Wang 2019

Study characteristics	
Methods	[Preprint] Single-centre prospective randomised controlled 3-arm study, with blinding not described China Duration: 1 July 2018 to 24 November 2018
Participants	• 201 participants randomised (experimental (in-plane) = 67 (1 excluded), experimental (out-of-plane) = 67 (2 excluded), comparator = 67 (2 excluded)) • 196 participants analysed • mean age (years) ± SD: 67.5 ± 13.8 experimental (in-plane), 67.5 ± 17.8 experimental (out-of-plane), 68 ± 8.5 comparator • gender (male/female): 15/51 experimental (in-plane), 16/49 experimental (out-of-plane), 13/52 comparator • severity of condition (in-plane/out-of-plane/comparator): ASA 1 (7/8/7), ASA 2 (51/52/52), ASA 3 (8/5/6) • comorbidities (in-plane/out-of-plane/comparator): hypertension (21/25/24), diabetes mellitus (9/9/11), coronary disease (2/5/6) • BMI (kg/m^2): 22.2 ± 3.5 in-plane, 21.9 ± 3.5 out-of-plane, 23.0 ± 4.0 comparator • artery of interest: radial • diameter (mm), mean ± SD, left artery: 1.82 ± 0.21 in-plane, 1.83 ± 0.16 out-of-plane, 1.85 ± 0.16 comparator, diameter (mm), mean ± SD, right artery: 1.86 ± 0.20 in-plane, 1.85 ± 0.17 out-of-plane, 1.86 ± 0.16 comparator. Catheter size 22 G • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or blood test during surgery, % not reported) Inclusion criteria • adult patients

Wang 2019 *(Continued)*

	• radial artery diameter < 2.2 mm Exclusion criteria • forearm surgery • ulnar artery occlusion • ipsilateral radial cannulation within a week before the procedure • coagulation dysfunction • abnormal Allen's test • skin infection at puncture site
Interventions	Experimental (in-plane): ultrasound-guided RA puncture (real-time, artery long axis, in-plane) Experimental (out-of-plane): ultrasound-guided RA puncture (real-time, artery short axis, out-of-plane) Comparator: RA puncture by palpation and landmarks Level of experience of person carrying out the procedure: punctures were performed "by two anaesthesiologists who had previously performed more than 160 arterial cannulations each year (including 30 in-plane, 30 out-of-plane, and 100 palpation)" Concomitant medications: quote: "2% lidocaine could be used for local anaesthesia in the puncture site" Excluded medications: not reported
Outcomes	Primary (specified) • success rate of puncture Primary (collected) • success rate in first attempt • success of total cannulation Secondary (specified) • first location time • cannulation time • number of attempts Secondary (collected) • cannula insertion failure • number of attempts • cannulation time • first location time • complications (haematoma, thrombosis, oedema, infection, vasospasm, posterior wall puncture) Time points reported: up to 1 day and up to 3 days after the procedure
Notes	Funding: quote: "this work was supported in part by Fujian Province Science and Technology Innovation Joint Fund Project of China(2017Y9008) and the National Natural Science Foundation of China (Grant number: 81641038)" Conflicts of interest: quote: "the authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article" Protocol (ChiCTR-IOR-17011474) available
Risk of bias	

Wang 2019 *(Continued)*

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Computer generated
Allocation concealment (selection bias)	Low risk	Sealed opaque envelopes used to ensure allocation concealment
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There was balanced dropout among groups: in-plane 1/67 (1 cancelled procedure), out-of-plane 2/67 (1 loss of medical data set and 1 transducer faulty for invasive blood pressure), palpation 2/67 (1 cancelled procedure and 1 loss of medical data set)
Selective reporting (reporting bias)	Low risk	All planned outcomes were reported
Other bias	High risk	There are 2 preprints and 1 published article with the same registration number (ChiCTR-IOR-17011474) but with differences in study design and period of carry-out. Wang 2017 reported randomisation in 2 different groups (1:1) and period of carry-out between 1 June 2017 and 27 October 2017. Wang 2019 reported randomisation in 3 different groups (1:1:1) and period of carry-out between 1 July 2018 and 24 November 2018. We considered these data as 2 different studies due to method characteristics, distinct participants, and period of carry-out

Yeap 2019

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm study, with blinding not described USA Duration: 2014 to 2016
Participants	• 421 participants randomised (experimental = 206, comparator = 215 (9 excluded)) • 412 participants analysed, 1 exclusion is not clear • mean age (years) ± SD: not reported • gender (male/female): 101/105 experimental, 107/99 comparator • severity of condition (experimental/comparator): ASA 1 (1/0), ASA 2 (11/8), ASA 3 (191/196), ASA 4 (3/2), ASA 5 (0/0) • comorbidities (experimental/comparator): not reported • body weight (kg): 87.9 ± 2.0 experimental, 88.0 ± 2.0 comparator • artery of interest: radial • diameter (mm), mean ± SD, left artery: 1.82 ± 0.21 in-plane, 1.83 ± 0.16 out-of-plane, 1.85 ± 0.16 comparator, diameter (mm), mean ± SD, right artery: not reported. Catheter size 20 G

Yeap 2019 *(Continued)*

- catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring)

Inclusion criteria

- undergoing surgery
- ASA 1 to 4

Exclusion criteria

- arterial catheterisation in an awake patient
- preexisting arterial catheterisation during the same visit within 7 days
- emergency surgery

Interventions	Experimental: ultrasound-guided RA puncture (real-time; artery axis and needle plane not described) Comparator: RA puncture by palpation and landmarks Level of experience of person carrying out the procedure: quote: "all residents had done at least 5 TBP and 5 USG radial arterial catheterizations prior to the study" Concomitant medications: all participants were under "general anaesthesia and endotracheal intubation". Details are not provided Excluded medications: not reported
Outcomes	Primary (specified) • time required for placement of arterial line • number of sites • number of catheters used • number of operators required to insert arterial line • first-time success rate Primary (collected) • time required for placement of arterial line • number of sites • number of catheters used • number of operators required to insert arterial line Secondary (specified) • no differentiation between primary and secondary outcomes Secondary (collected) • no differentiation between primary and secondary outcomes Time points reported: up to 1 day and up to 3 days after the procedure
Notes	Funding: quote: "the authors report no external funding source for this study" Conflicts of interest: quote: "the authors declare they have no competing interests" Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement

Yeap 2019 *(Continued)*

Random sequence generation (selection bias)	Low risk	Quote: "the participants were randomised by a computer program (Research Randomizer, www.randomizer.org)"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	High risk	There was imbalance between experimental and comparator cross-over interventions Quote: "ultrasound rescue was required in 12 out of 151 patients in the blind palpation group. In contrast, only 1 out of 147 patient cross over to the palpation technique in ultrasound technique group"
Selective reporting (reporting bias)	High risk	There was an imbalance between experimental (0/206) and comparator (9/215) exclusions. The reason for 1 of the exclusions was not described. No safety outcomes were planned or reported. One of the planned outcomes (first-time success rate) was not reported
Other bias	Low risk	We do not suspect any other bias related to this study

Yu 2019

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm study, with blinding not described China Duration: October 2018 to December 2018
Participants	• 62 participants randomised (experimental = 31, comparator = 31) • 60 participants analysed, 2 were excluded because catheter retention time was > 6 hours) • mean age (years) ± SD: 58.83 ± 14.65 experimental, 54.57 ± 13.44 comparator • gender (male/female): 17/13 experimental, 16/14 comparator • severity of condition (experimental/comparator): not reported • comorbidities (experimental/comparator): not reported • body weight (kg): 75.60 ± 32.82 experimental, 63.90 ± 9.2 comparator • height (cm) 154.07 ± 31.10 experimental, 165.43 ± 5.04 comparator • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 20 • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring) Inclusion criteria • adult patients (18 to 90 years of age) undergoing an elective surgical procedure • requiring continuous invasive arterial blood pressure monitoring as determined by the attending anaesthesiologist

Yu 2019 *(Continued)*

	Exclusion criteria • patient in shock • positive Allen's test result • unconscious • ASA classification ≥ 4 • had received radial artery cannulation within previous 30 days • catheter retention time > 6 hours
Interventions	Experimental: ultrasound-guided RA puncture (real-time; artery short axis, out-of-plane) Comparator: RA puncture by palpation and landmarks Level of experience of person carrying out the procedure: quote: "the 2 operators were resident anaesthesiologists (had finished 3 years of Chinese standard training for residents) who were trained in arterial cannulation using ultrasonography or palpation and had performed the procedure at least 30 or 200 times, respectively" Concomitant medications: quote: "local anesthesia was administered with lidocaine 2% (Zhaohui Company, Shanghai, China) at the puncture site" Excluded medications: not reported
Outcomes	Primary (specified) • first-attempt success rate • total success rate • cannulation duration • total procedure duration Primary (collected) • first-attempt success rate • total success rate • cannulation duration • total procedure duration Secondary (specified) • rate of complications attributable to cannulation (haematoma, infection) Secondary (collected) • rate of complications attributable to cannulation (haematoma, infection) Time points reported: up to 1 day and up to 2 days after the procedure
Notes	Funding: quote: "this work is partially supported by National Natural Science Foundation of China (No.81770295) and Key Project of Excellent Youth in Higher Education Institution of Anhui Province (gxyqZD2018028)" Conflicts of interest: not reported Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement

Yu 2019 *(Continued)*

Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Low risk	Quote: "the technique used in certain patients was chosen via a sealed envelope"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	There was balanced exclusion in both groups. Two participants were excluded because their catheter retention time was > 6 hours (1 experimental and 1 comparator)
Selective reporting (reporting bias)	Low risk	All planned outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Zaremski 2013

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment study, with blinding not described Switzerland Duration: not described
Participants	• 202 participants randomised (experimental = 92, comparator = 91) • 183 participants analysed, 19 excluded due to protocol violation • mean age (years) ± SD: 69.33 ± 11.29 experimental, 66.66 ± 5.27 comparator • gender (male/female): 55/37 experimental, 64/27 comparator • severity of condition (experimental/comparator): elective procedure 63/61, emergency/urgent procedure 29/30 • comorbidities (experimental/comparator): smoker 14/19, hypertension 72/69, dyslipidaemia 67/65, history of cardiovascular disease 54/53, chronic lung disease 15/8 • BMI (kg/m^2): 29.36 ± 5.79 experimental, 28.66 ± 4.89 comparator • artery of interest: radial • diameter (mm), mean ± SD: not reported. Catheter size 20 G • catheterisation purpose (experimental/comparator): emergency or elective CA or PCI (not detailed) Inclusion criteria • scheduled for emergency or elective cardiac catheterisation • percutaneous coronary intervention via transradial access Exclusion criteria • history of unsuccessful transradial access

Zaremski 2013 *(Continued)*

- pathologic Allen's test
- cognitive impairment
- younger than 18 years of age

Interventions	Experimental: ultrasound-guided RA puncture (real-time; artery short axis, out-of-plane) Comparator: RA puncture by palpation and landmarks Level of experience of person carrying out the procedure: quote: "operator performing >200 transradial procedures per year" Concomitant medications: quote: "local anesthesia was administered with lidocaine 2% (Zhaohui Company, Shanghai, China) at the puncture site" Excluded medications: not reported
Outcomes	Primary (specified) • total success rate • cannulation duration Primary (collected) • total success rate • cannulation duration • first-attempt success rate Secondary (specified) • rate of complications attributable to cannulation (vessel dissection and access-site haematoma requiring medical attention) Secondary (collected) • rate of complications attributable to cannulation (vessel dissection and access-site haematoma requiring medical attention) Time points reported: up to 1 day and up to 2 days after the procedure
Notes	Funding: quote: "HU was supported by an unrestricted research grant by the University of Basel, Switzerland" Conflicts of interest: quote: "Dr. Quesada is a member of the Abbott Advisory Board; a consultant for the Medicines Company; and a consultant/speaker's bureau member for Abbott, Boston Scientific, Cordis Corporation, St Jude Medical, WL Gore, NMT Medical, and Terumo; he also reports travel expenses from the above companies" Protocol not available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias)	High risk	Not described, but due to the nature of the interventions, we assumed that blinding of personnel was not possible

Zaremski 2013 *(Continued)*

All outcomes		
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not described
Incomplete outcome data (attrition bias) All outcomes	High risk	There was a balanced but large amount of cross-over interventions in both groups (12/92 experimental (6 switch to palpation and 6 switch to femoral) and 12/91 comparator (all switch to ultrasound)). Ten participants in experimental group and 9 in comparator group were switched to femoral access
Selective reporting (reporting bias)	Low risk	All planned outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

Zeng 2020

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment study, with blinding not described China Duration: not described
Participants	• 60 participants included • experimental group (OA-IP - oblique axis/in-plane) n = 30; control group (LA-IP long-axis/in-plane) n = 30 for radial artery cannulation • mean age (years) not mentioned. Described as "18 to 70 years" • gender (male/female): not reported • severity of the condition: ASA I to III • comorbidities: not reported • BMI (kg/m^2): not reported • artery of interest: radial • diameter (mm), mean ± SD: 2.2 ± 0.4 (OA-IP - oblique axis/in-plane), 2.3 ± 0.3 (LA-IP long axis/in-plane). Catheter size 20 G standard arterial cannula • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring during surgery) Inclusion criteria • surgical patients who required invasive arterial access Exclusion criteria • positive Allen's test • BMI > 40 kg/m^2 • emergency surgery • hand/wrist operation • haemorrhagic shock • infection at puncture site
Interventions	Experimental (OA-IP - oblique axis/in-plane): real-time, B-mode ultrasound-guided RA puncture (quote: "after a longitudinal axis view of the radial artery was obtained, the probe was rotated 10 to 15 degrees

Zeng 2020 *(Continued)*

	(clockwise on the right hand, or counter-clockwise on the left hand) to orient the longitudinal axis of the probe obliquely to the artery") Comparator (LA-IP long axis/in-plane): real-time, B-mode ultrasound-guided RA puncture (artery in long axis, real-time, needle in-plane) Level of experience of person carrying out the procedure: quote: "radial artery cannulation was performed by one of two experienced anaesthesiologists: both had placed more than 50 radial arterial lines with in-plane approaches before commencing this study" Concomitant medications: quote: "we induced anaesthesia with sufentanil, propofol and cisatracurium. After tracheal intubation, a radial arterial catheter was inserted" Excluded medications: not reported
Outcomes	Primary (specified) • success rate at first attempt • cannulation time Primary (collected) • first-attempt success rate Secondary (specified) • number of attempts • total success rate Secondary (collected) • cannulation time • total procedure time • number of attempts • number of punctures • vasospasm or haematoma Time point reported: during the surgery procedure
Notes	Funding: quote: "none" Conflicts of interest: quote: "none" Protocol available (ChiCTR-IOR-16007748)

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "patients were assigned to either of the OA-IP or LA-IP groups, according to a computer-generated randomization"
Allocation concealment (selection bias)	Unclear risk	Quote: "patients were assigned to either of the OA-IP or LA-IP groups, according to a computer-generated randomisation"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Although the participant underwent the intervention after general anaesthesia, personnel for the intervention group were not blinded
Blinding of outcome assessment (detection bias)	Unclear risk	Not described

Zeng 2020 *(Continued)*

All outcomes		
Incomplete outcome data (attrition bias) All outcomes	Low risk	There were no losses
Selective reporting (reporting bias)	High risk	One outcome, relevant for this review, was planned but was not reported (total success rate)
Other bias	Low risk	We do not suspect any other bias related to this study

Zhefeng 2019

Study characteristics	
Methods	Single-centre prospective randomised controlled 2-arm study, with blinding not described China Duration: March 2018 to May 2018
Participants	• 77 participants randomised (experimental = 39, comparator = 38) • 77 participants analysed • mean age (years) ± SD: 46.2 ± 8.4 experimental, 49.1 ± 8.2 comparator • gender (male/female): 29/10 experimental, 26/12 comparator • severity of condition (experimental/comparator): ASA 2 24/21, ASA 3 15/17 • comorbidities (experimental/comparator): not reported • body weight (kg): 67.1 ± 9.0 experimental, 65.4 ± 9.9 comparator • height (cm): 166.1 ± 7.1 experimental, 167.2 ± 7.3 comparator • artery of interest: radial • diameter (mm), mean ± SD: 2.4 ± 0.3 experimental, 2.5 ± 0.4 comparator. Catheter size not described • catheterisation purpose (experimental/comparator): all for diagnosis (pressure monitoring or blood test, % not reported, during elective surgery) Inclusion criteria • scheduled to undergo elective hepatectomy or splenectomy with general anaesthesia • between 18 and 60 years of age • body weight 50 to 85 kg • ASA 2 or 3 Exclusion criteria • negative Allen's test • peripheral vascular disease • ulnar artery occlusion • haemorrhagic shock • atherosclerosis • morbid obesity • unstable angina • Raynaud's disease • cardiogenic shock • diabetes • hypertension

Zhefeng 2019 *(Continued)*

	• previous multiple arterial punctures
Interventions	Experimental: ultrasound-guided RA puncture (real-time; artery short axis, out-of-plane) Comparator: modified ultrasound-guided RA puncture (real-time; artery short axis, out-of-plane with add of a developing line) Level of experience of person carrying out the procedure: quote: "all radial artery punctures were performed by interns who were in the anesthesiology rotation" Concomitant medications: all participants under general anaesthesia: quote: "patients were placed in supine position and administrated 0.05 mg/kg midazolam and 0.1 μg/kg sufentanil for analgesia and sedation" and "2% lidocaine was used for local anaesthesia" Excluded medications: not reported
Outcomes	Primary (specified) • first-attempt success rate Primary (collected) • first-attempt success rate Secondary (specified) • ultrasound localisation time • puncture time • cannulation time Secondary (collected) • ultrasound localisation time • puncture time • cannulation time • complications (vasospasm, haematoma, thrombosis, occlusion, aneurysm) Time points reported: up to 1 day and up to 2 days after the procedure
Notes	Funding: quote: "supported by Beijing Municipal Science and Technology Commission (no. Z171100001017036)" Conflicts of interest: quote: "none" Protocol (ChiCTR1800015337) available

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Quote: "patients were randomly assigned to traditional ultrasound or ultrasound with developing line groups using a sealed envelope"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Quote: "the limitations of this study include the lack of a double-blind study design"

Zhefeng 2019 *(Continued)*

Blinding of outcome assessment (detection bias) All outcomes	High risk	Quote: "the limitations of this study include the lack of a double-blind study design"
Incomplete outcome data (attrition bias) All outcomes	Low risk	Quote: "there were no drop-outs during the trial"
Selective reporting (reporting bias)	Low risk	All planned outcomes were reported
Other bias	Low risk	We do not suspect any other bias related to this study

AA = axillary artery; **ABGA =** arterial blood gas analysis; **AD =** angle-distance; **ASA =** Amerian Society of Anesthesiologists physical status classification system; **BMI =** body mass index; **CA =** coronary angiography; **DNTP =** dynamic needle tip positioning; **DPA =** dorsalis pedis artery; **ENT =** ear, nose, and throat speciality; **GA =** general anaesthesia; **ICU =** intensive care unit; **INR =** international normalised ratio; **IP =** in-plane; **ITT =** intention-to-treat; **IU =** international unit; **LA =** long axis; **OA =** oblique axis; **PCI =** percutaneous coronary intervention; **PVD =** peripheral vascular disease; **RA =** radial artery; **SA =** short axis; **SD =** standard deviation; **US =** ultrasound; **VAS =** visual analogue scale.

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

Study	Reason for exclusion
Anantasit 2017	Inadequate population. RCT that included only children
Cronin 1986	Inadequate comparator. RCT that did not compare ultrasound guidance
CTRI/2018/11/016257	Inadequate comparator. RCT that used the same ultrasound guidance in both groups
Dahl 1992	Inadequate comparator. RCT that did not compare ultrasound guidance
Elmahdy 2018	Inadequate comparator. RCT that did not compare direct or indirect ultrasound guidance (ultrasound was used as a method of selection of a favourable site for puncture)
Kucuk 2014	Inadequate comparator. RCT that did not compare ultrasound guidance (same ultrasound-guided technique was used for the 5 arms)
Min 2016	Inadequate comparator. RCT that did not compare ultrasound guidance (same ultrasound-guided technique was used for both arms)
Mori 2020	Inadequate study design. Non-randomised comparative trial
NCT03537118	Inadequate population. RCT conducted with participants submitted to femoral access
NCT04001764	Inadequate comparator. RCT that considered the same ultrasound-guided short-axis out-of-plane intervention for the 3 parallel arms
NCT04077762	Inadequate comparator. RCT that did not compare ultrasound guidance
Vaquerizo 2014	Inadequate study design. Quasi-RCT. Eligible patients were randomised according to availability of staff to carry out the intervention
Wilson 2020	Inadequate study design. Quasi-RCT. Eligible patients were randomised by the last digit of their medical record number

Study	Reason for exclusion
Yao 2018	Inadequate comparator. RCT that did not compare ultrasound guidance

RCT: randomised controlled trial.

Characteristics of studies awaiting classification *[ordered by study ID]*

Flores-Arévalo 2016

Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment open-label study Ecuador Duration: July to August 2015
Participants	• 98 participants randomised • 98 analysed (experimental (ultrasound-guided) = 50, comparator (palpation) = 48), losses not described • mean age (years) ± SD: not reported • gender (male/female): not reported • severity of condition: all patients from emergency department who required blood gas analysis • comorbidities: not detailed • BMI (kg/m^2): not reported • artery of interest: not reported • diameter (cm), mean ± SD: not reported • catheterisation purpose (experimental/comparator): all for diagnosis (blood test) Inclusion criteria • both sexes • aged > 18 years • requiring blood gas analysis Exclusion criteria • haemodynamic instability • cardiorespiratory arrest • pregnant women • positive Allen's test • wrist fracture • history of arteriopathy
Interventions	Experimental: B-mode, real-time ultrasound-guided puncture (arterial axis and ultrasound plane not reported) Comparator: palpation-guided puncture Level of experience of person carrying out the procedure: not reported Concomitant medications: not reported Excluded medications: not reported
Outcomes	Primary (specified) • first-attempt success rate of puncture • time of puncture

Flores-Arévalo 2016 *(Continued)*

- adverse events

Primary (collected)

- first-attempt success rate of puncture
- time of puncture
- adverse events

Secondary (specified)

- no difference between primary and secondary outcomes

Secondary (collected)

- no difference between primary and secondary outcomes

Time points reported: until the end of the procedure

Notes	Funding: not reported Conflicts of interest: not reported Protocol not available

BMI: body mass index; **SD:** standard deviation

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

ChiCTR1800016772

Study name	Application of modified ultrasonication guidance technique in radial artery puncture: a prospective randomized controlled trial
Methods	Single-centre prospective randomised controlled 3-arm parallel-assignment study (masking not reported)
Participants	201 participants, 18 to 85 years old, female and male, radial artery Inclusion criteria • aged 18 to 85 years old, ASA physical status I to III, provided written informed consent for the research study • upper wall of the artery more than 5 mm from the skin • radial artery diameter < 2.2 mm and upper wall of the artery more than 5 mm from the skin • radial artery diameter < 2.2 mm and vascular wall too soft; mild pressure of the probe can make the vascular collapse > 70%, or even occlusion • radial artery diameter < 2.2 mm and SBP < 90 mmHg • use of traditional touch-positioning guidance techniques failing more than 3 times in radial artery puncture Exclusion criteria • inflamed skin near the puncture site • ulnar artery occlusion • history of forearm surgery • negative Allen's test results • coagulation dysfunction
Interventions	Experimental: modified ultrasound guidance

ChiCTR1800016772 *(Continued)*

	Comparator: conventional out-of-plane ultrasound guidance technique Compartaor: traditional touch positioning guidance technique
Outcomes	Primary • success rate of puncture Secondary • none described
Starting date	01 July 2018
Contact information	Jiebo Wang Fujian Medical University Union Hospital, China +86 15959004325 / 258960368@qq.com
Notes	ChiCTR1800016772 / no data provided

ChiCTR-IOR-16009966

Study name	Comparison of ultrasound-guided and traditional palpation radial artery cannulation in aged patients
Methods	Single-centre prospective randomised controlled 2-arm parallel-assignment study (masking not reported)
Participants	130 participants, 70 years of age and older, female and male, radial artery Inclusion criteria • over 70 years old • needing radial artery catheterisation before surgery • voluntarily signed informed consent • no infection or damage at puncture site Exclusion criteria • positive modified Allen's test • refusing to sign informed consent • allergic reaction to local anaesthetic • unconsciousness
Interventions	Experimental: ultrasound-guided puncture Comparator: traditional palpation puncture
Outcomes	Primary • needle manipulation time Secondary • number of first-attempt successes • number of attempts required • number of skin perforations

ChiCTR-IOR-16009966 *(Continued)*

- number of catheters used
- complications

Starting date	1 November 2016
Contact information	Jing Yu Second Affiliated Hospital of Zhejiang University School of Medicine, China +86 13758159796 / janeyu1129@163.com
Notes	ChiCTR-IOR-16009966 / no data provided

CTRI/2020/01/022989

Study name	Comparison of ultrasound-guided versus blind arterial cannulation in ICU patients: a prospective randomized study
Methods	Single-centre prospective randomised controlled 2-arm participant-blinded parallel-assignment study
Participants	188 participants, age not reported, sex not reported; radial, femoral, dorsalis pedis arteries Inclusion criteria • age ≥ 18 years • admitted to ICU requiring continuous arterial pressure monitoring Exclusion criteria • age < 18 years
Interventions	Experimental: ultrasound-guided arterial cannulation in radial, femoral, dorsalis pedis artery Comparator: arterial cannulation by digital palpation method in radial, femoral, dorsalis pedis artery
Outcomes	Primary • first-pass success rate (rate of successfully cannulating the artery in the first attempt) • time point: 1 year Secondary • total number of attempts • time taken to cannulate • any complication related to the procedure • time point: 1 year
Starting date	30 January 2020
Contact information	Dr. Afzal Azim Department of Critical Care Medicine, Sanjay Gandhi Postgraduate Institute of Medical Sciences 226014 Lucknow, Uttar Pradesh, India 8004904730 | draazim2002@gmail.com

CTRI/2020/01/022989 *(Continued)*

Notes	CTRI/2020/01/022989 | no data provided

CTRI/2020/06/025543

Study name	Radial artery cannulation
Methods	Single-centre prospective randomised controlled 2-arm open-label parallel-assignment study
Participants	80 participants, age not reported, sex not reported, radial artery Inclusion criteria • admitted to ICU and in operating room requiring radial artery cannulation Exclusion criteria • hypotension • positive Allen's test • recent cannulation in 1 month • preexisting coagulopathy • anticoagulant medications • signs of skin infection or wound near puncture site
Interventions	Experimental: ultrasound-guided arterial cannulation in radial artery Comparator: arterial cannulation by digital palpation method in radial artery
Outcomes	Primary • first-attempt success rate of radial artery cannulation at baseline Secondary • time taken to cannulate • total number of attempts • cannulation failure • any complications associated with the procedure Time point: at baseline
Starting date	15 June 2020
Contact information	CR Saravanan Room No. 201, SRM Medical College Hospital and Research Centre, SRMIST Potheri 603203 Kancheepuram, Tamil Nadu, India 9884001153 | drcrsaravanan@gmail.com
Notes	CTRI/2020/06/025543 | no data provided

CTRI/2020/08/027199

Study name	Comparing ultrasound versus palpatory method for posterior tibial artery cannulation

CTRI/2020/08/027199 *(Continued)*

Methods	Single-centre prospective randomised controlled 2-arm parallel assignment study, with participant and outcome assessment blinded
Participants	240 participants, age not reported, sex not reported, radial artery Inclusion criteria • ASA grade I to IV • undergoing major surgery requiring arterial cannulation Exclusion criteria • refusal to consent • absence of arterial pulsation • skin erosions near insertion site • undergoing surgery on lower limbs • peripheral vascular disease
Interventions	Experimental: ultrasound-guided arterial cannulation in tibial artery Comparator: arterial cannulation by digital palpation method in tibial artery
Outcomes	Primary • first-time successful cannulation Secondary • number of attempts • assessment time • cannulation time • cannulation failure • complication with multiple attempts such as spasm, thrombosis, necrosis
Starting date	20 August 2020
Contact information	Dr. Priyanka Gupta Department of Anaesthesiology, Level 6, Medical College Building, AIIMS Rishikesh 249203 Dehradun, Uttaranchal, India 9811894899 | drpriyankagupta84@gmail.com
Notes	CTRI/2020/08/027199 | no data provided

CTRI/2020/09/028136

Study name	Two methods of radial artery cannulation with sonography in low blood pressure patients
Methods	Single-centre prospective randomised controlled parallel-group interventional trial
Participants	90 participants, 18 to 80 years old, female and male Inclusion criteria • hypotensive patients (MAP < 65 mmHg) interned in the ICU

CTRI/2020/09/028136 *(Continued)*

	Exclusion criteria • h/o forearm surgery • local infection • local artery embolism • negative Allen's test • abnormal ulnar artery • had undergone arterial puncture within a 1-month period immediately preceding commencement of the trial • abnormal coagulopathy • do not give informed consent
Interventions	Intervention 1: radial artery cannulation in patients' non-dominant hand using a traditional ultrasound-guided technique Intervention 2: radial artery cannulation in patients' non-dominant hand using focused acoustic shadowing facilitated ultrasound-guided technique
Outcomes	Primary • USG localisation time • puncture time • success rate • time point: until successful radial artery cannulation Secondary • complications • time point: 24 hours
Starting date	29 September 2020
Contact information	Dr. Shikha Soni Department of Anaesthesiology and Critical Care Medical College Jodhpur Rajasthan Jodhpur Rajasthan 342001 Jodhpur, RAJASTHAN, India | telephone: 9828036002 email: doctorudsharma@gmail.com affiliation: Dr. S.N. Medical College Jodhpur Dr. U.D. Sharma Department of Anaesthesiology and Critical Care Medical College Jodhpur Rajasthan Jodhpur Rajasthan 342001 Jodhpur, RAJASTHAN, India | telephone: 9828036002 email: doctorudsharma@gmail.com affiliation: Dr. S.N. Medical College Jodhpur
Notes	CTRI/2020/09/028136 / no data provided

CTRI/2020/12/029455

Study name	Comparison of ultrasound guided versus conventional palpatory method of posterior tibial artery cannulation
Methods	Single-centre prospective randomised parallel-group trial
Participants	76 participants, 18 to 65 years old, female and male, posterior tibial artery Inclusion criteria • undergoing any head and neck surgery or faciomaxillary surgery requiring arterial cannulation for haemodynamic monitoring Exclusion criteria • refusal to participate • absence of an amplitude of PTA pulsation • skin erosions near insertion site • obesity defined by body mass index > 30 kg/m^2
Interventions	Experimental: ultrasound-guided posterior tibial artery cannulation Control: conventional palpatory method of posterior tibial artery cannulation
Outcomes	Primary • total procedure time of arterial cannulation Secondary • first-attempt success of cannulation • number of attempts to cannulate • cannulation failure • incidence of complications (ischaemia, haemorrhage, thrombosis, haematoma formation) until cannulation of the artery
Starting date	01 December 2020
Contact information	Dr. Ankur Sharma address: Room No. 3124 Medical College Building Department of Trauma & Emergency (Anesthesia) AIIMS JODHPUR BASNI, phase 2, JODHPUR 342005 Jodhpur, RAJASTHAN, India | telephone: 9654045653 | email: ankuranaesthesia@gmail.com affiliation: AIIMS JODHPUR
Notes	CTRI/2020/12/029455 / no data provided

CTRI/2021/02/031051

Study name	Comparison of USG-guided and blind techniques for radial artery cannulation by residents in a teaching institute
Methods	Randomised parallel-group active controlled interventional trial
Participants	124 participants, adults

CTRI/2021/02/031051 *(Continued)*

	Inclusion criteria • adult patients undergoing high-risk surgery for which invasive BP monitoring is needed • willing to give consent • trained postgraduate third-year (PGY-3) anaesthesiology resident (at least 5 TBP and 5 USG radial arterial catheterisations prior to the study) Exclusion criteria • American Society of Anaesthesiologist class V • not willing to give consent
Interventions	Intervention 1: ultrasound-guided radial artery cannulation Control Intervention 1: palpation technique for radial artery cannulation
Outcomes	Primary • number of patients whose arterial catheter was successfully inserted at first attempt Secondary • number of attempts needed for successful arterial catheter placement by both methods • time required for successful cannulation • number of sites used for successful cannulation • total catheters used for cannulation • rate of complications and total number of operators required for both methods
Starting date	15 February 2021
Contact information	Afroz Khan address: 6th floor Department of Anaesthesia & Critical Care, Main Building, Grant Government Medical College & Hospital, Byculla, Mumbai-08 Quarter No. 11, Panchasheel Building, JJ Hospital, Byculla, Mumbai-08 400008 Mumbai, MAHARASHTRA, India telephone: 09167296754 | email: drafrozkhan2003@gmail.com affiliation: grant government medical college
Notes	CTRI/2021/02/031051 / no data provided

KCT0004903

Study name	The efficacy of combined ultrasound-guided radial artery cannulation in adult surgical patients
Methods	Interventional primary study; parallel randomised controlled trial
Participants	120 participants, radial artery, minimum 18 years old, maximum without limit of age Inclusion criteria • adult patients scheduled for surgery under general anaesthesia • over 18 years of age • requiring invasive arterial pressure monitoring • understand and agree to the research agreement Exclusion criteria

KCT0004903 *(Continued)*

	• undergoing emergency surgery • haemorrhagic shock • obese with BMI > 30 • negative modified Allen's test • coagulation disorder • underwent arterial catheterisation on the same arm within 7 days
Interventions	1. SA group (short-axis approach group): only short-axis approach was used to confirm radial artery 2. SLA group (combined short-axis and long-axis approach group): confirm midline of the radial artery through a short-axis approach, then conduct a catheter with a long-axis approach, confirming the actual catheter approach in real time
Outcomes	Primary • first-attempt success rate for radial artery catheterisation • overall success rate for radial artery catheterisation Secondary • depth and diameter of radial artery • radial artery catheterisation attempts • radial artery catheterisation complications • radial artery catheterisation duration
Starting date	4 August 2020
Contact information	Dowon Lee address: not informed telephone: not informed email: not informed affiliation: Pusan National University Hospital
Notes	KCT0004903 / no data provided

NCT01189188

Study name	Ultrasound guidance for radial arterial blood sampling
Methods	Single-centre prospective randomised controlled 2-arm open-label parallel-assignment study
Participants	74 participants, 18 years of age and older, female and male, radial artery Inclusion criteria • signed consent • affiliated with a social security system • health status necessitating an arterial blood sample for diagnostic, prognostic, or therapeutic reasons Exclusion criteria • participating in another study • in a study exclusion period determined by a previous study

NCT01189188 *(Continued)*

	• under guardianship • refusal to sign consent • impossible to correctly inform the patient • pregnant, breastfeeding, or parturient • allergy to 1 or more of the following: methyl, propylbenzoate, propylene glycol, chlorhexidine gluconate • contraindication for an arterial puncture (at the radial artery) • cardiorespiratory arrest
Interventions	Experimental: artery puncture with ultrasound guidance Comparator: artery puncture without ultrasound guidance
Outcomes	Primary • is only 1 puncture attempt necessary to attain the radial artery? yes/no [Time Frame: maximum 2 hours] Secondary • number of puncture attempts required to attain the radial artery [Time Frame: maximum 2 hours] • visual analogue scale score for pain felt by the patient (0.0 to 10.0) [Time Frame: maximum 2 hours] • visual analogue scale score for patient satisfaction (0.0 to 10.0) [Time Frame: maximum 2 hours] • visual analogue scale score for health professional satisfaction (0.0 to 10.0) [Time Frame: maximum 2 hours] • presence/absence of a haematoma at the site of puncture [Time Frame: 2 hours] • presence/absence of other complications [Time Frame: 2 hours]
Starting date	August 2010
Contact information	Romain Genre-Grandpierre Centre Hospitalier Universitaire de Nîmes, France phone and email not provided
Notes	NCT01189188 | no data provided

NCT01561196

Study name	Conventional versus ultrasound-guided arterial cannulation, with and without local anaesthesia
Methods	Single-centre prospective randomised controlled 2-arm single-masking cross-over assignment study
Participants	20 participants, 20 to 90 years old, female and male, radial artery Inclusion criteria • age 20 to 90 years • fulfilling the criteria of an operation • routine need for an arterial needle Exclusion criteria • lack of patient consent

NCT01561196 *(Continued)*

	• ultrasound-identified plaques in the radial artery or ultrasound-verified positive Allen's test or traditional positive Allen's test
Interventions	Experimental: ultrasound-guided arterial cannulation Comparator: conventional cannulation. The arterial needle is placed using the traditional method and lidocaine

Outcomes	Primary
	
	• pain score on visual analogue scale [Time Frame: 5 minutes]
	• primary outcome is subjective feeling of pain following the 2 methods
	
	Secondary
	
	• time spent on the procedure [Time Frame: 1 day]
	  ◦ time will be measured from the point where (1) the operator starts to search for patients plus/or (2) the operator starts to examine the patient with the ultrasound machine. Time will be stopped at the time when the catheter is successfully placed
	• number of utilised needles [Time Frame: 1 day]
	• number of pricks [Time Frame: 1 day]
	  ◦ a prick is defined as eruption of the skin
	• number of withdrawals [Time Frame: 1 day]
	  ◦ a withdrawal is defined as backwards movement of needle or needle + catheter

Starting date	February 2012
Contact information	Marlene A Hansen Aarhus University Hospital, Skejby, Denmark Anæstesiologisk-Intensiv afdeling IAarhus, Jylland, Denmark, 8200 phone and email not provided
Notes	NCT01561196 | no data provided

NCT02584673

Study name	Computer-assisted instrument guidance (CAIG) for arterial line placement
Methods	Single-centre prospective randomised controlled 2-arm open-label parallel-assignment study
Participants	30 participants, 18 years of age and older, female and male, target artery not described (e.g. radial, tibial, axillary) Inclusion criteria • undergoing vessel catheterisation • able to give written informed consent Exclusion criteria • unable to give informed consent • prisoners, pregnant women, and children
Interventions	Experimental: existing ultrasound equipment with supplemental computer-assisted instrument guidance system

NCT02584673 *(Continued)*

	Comparator: traditional ultrasound methods and equipment (not described)
Outcomes	Primary • time needed to correctly insert the arterial or midline catheter [Time Frame: immediately following intervention (within 2 hours)] Secondary • clinician rating of the device [Time Frame: immediately following intervention (within 2 hours)] • number of attempts [Time Frame: immediately following intervention (within 2 hours)] • number of instrument pricks before target is reached • number of times needle needs repositioning [Time Frame: immediately following intervention (within 2 hours)]
Starting date	October 2015
Contact information	Irwin Gratz The Cooper Health System, Camden, NJ, USA phone: 856-968-8527 email: gratz-irwin@cooperhealth.edu
Notes	NCT02584673 | no data provided

NCT03144895

Study name	Arterial catheterisation by ultrasound: impact on success rates and complications in patients hospitalised in resuscitation
Methods	Single-centre prospective randomised controlled 2-arm open-label parallel-assignment study
Participants	380 participants, 18 years of age and older, female and male, radial or femoral artery Inclusion criteria • age over 18 years • hospitalisation in resuscitation • necessity for installation of an arterial catheter • signed informed consent • affiliation to a social security scheme Exclusion criteria • under tutorship or curatorship • minor age
Interventions	Experimental: laying a radial or femoral arterial catheter by anatomical placement alone Comparator: laying a radial or femoral arterial catheter by ultrasound tracking
Outcomes	Primary

NCT03144895 *(Continued)*

	• success rate of arterial or femoral catheter placement [Time Frame: 1 day] at first attempted puncture (with only 1 puncture point on the skin) Secondary • not described
Starting date	2 May 2017
Contact information	Elie Zogheib Centre Hospitalier Universitaire, Amiens, France +33322087832 | zogheib.elie@chu-amiens.fr
Notes	NCT03144895 | no data provided

NCT03995264

Study name	Ultrasound vs palpation for radial artery cannulation in patients undergoing bariatric surgery
Methods	Single-centre prospective randomised controlled 2-arm quadruple-masking (participant, care provider, investigator, outcomes assessor) parallel-assignment study
Participants	120 participants, 19 to 85 years old, female and male, radial artery Inclusion criteria • American Society of Anesthesiologists 1, 2, 3 • BMI ≥ 30 • bariatric surgery Exclusion criteria • refusal of infection or surgery history in wrist
Interventions	Experimental: ultrasound-guided radial artery cannulation Comparator: radial artery cannulation using palpation
Outcomes	Primary • success rate [Time Frame: at first attempt, as average 5 minutes] ◦ success rate at first attempt for radial artery cannulation
Starting date	1 August 2019
Contact information	Ji Eun Kim Ajou University School of Medicine, Seoul, Republic of Korea 82-31-219-5575 | beye98@aumc.ac.kr
Notes	NCT03995264 | no data provided

NCT04318990

Study name	Distal vs proximal radial artery access for cardiac catheterisation and intervention
Methods	Single-centre prospective randomised controlled 2-arm open-label parallel-assignment study
Participants	300 participants, 18 years of age and older, female and male, radial artery Inclusion criteria • age ≥ 18 years • distal and proximal radial artery must be palpable and non-occlusive flow must be confirmed by (Doppler) ultrasound • be able to comply with the protocol • written informed consent before study participation Exclusion criteria • obligatory femoral or forearm radial access • previous ipsilateral forearm radial artery occlusion • therapeutic oral anticoagulation • very large hand/wrist anatomy that will preclude using available haemostatic radial bands • enrolment in another study that competes or interferes with this study • poor clinical condition such as cardiogenic shock, which prohibits pre-procedural and post-procedural function tests • planned complex PCI or procedure necessitating multiple intervention • any other condition or comorbidity that, in the opinion of the investigator or operator, may pose a significant hazard to the subject if he or she is enrolled in the study • history of stroke with residual deficit that affects hand function • previous radial artery catheterisation within 1 year
Interventions	Experimental: distal radial artery access under ultrasound guidance Comparator: proximal radial artery access (ultrasound guidance not reported in this group)

Outcomes	Primary
	
	• Quick Disabilities of the Arm Shoulder and Hand questionnaire score (0 to 100) [Time Frame: 1 month]
	  ◦ hand function questionnaire, range: 0 (no disability) to 100 (most severe disability)
	• thumb and forefinger pinch strength test [Time Frame: 1 month]
	  ◦ hand function: thumb and forefinger pinch strength (kg)
	• hand grip strength test [Time Frame: 1 month]
	  ◦ hand grip strength test (kg)
	
	Secondary
	
	• rate of complications [Time Frame: 12 months] including occurrence of haematoma, bleeding, radial artery occlusion, and complications of vascular access

Starting date	6 March 2020
Contact information	Preethi Ravindranathan Baylor Scott & White The Heart Hospital, USA 469-814-4721 | preethi.ravindranathan@bswhealth.org
Notes	NCT04318990 | no data provided

NCT04617106

Study name	Radial artery cannulation using two different methods
Methods	Single-centre prospective randomised parallel-assignment clinical trial
Participants	52 participants, 18 years of age and older, female and male, radial artery Inclusion criteria • undergoing elective surgery • requiring arterial cannulation as determined by the consultant anaesthesiologist • 18 years of age or older Exclusion criteria • type D ulnopalmar arch patency during Barbeau test • documented history of peripheral vascular disease • infection or other soft tissue lesions at the site of cannulation • surgical procedure involving the cannulation site • receiving inotropes or vasopressors • history of radial artery cannulation within the past month at the planned cannulation site • arterial catheter in situ (any site)
Interventions	Control group • radial artery cannulation will be done by the conventional palpation method Intervention group • USG-guided dynamic needle tip positioning method will be employed
Outcomes	Primary • first-pass success rate with conventional palpation method vs USG-guided DNTP method [Time Frame: through study completion, an average of 6 months] ◦ compare successfully obtained arterial waveform vs a single skin puncture, irrespective of the number of needle re-directions needed Secondary • number of skin punctures between conventional palpation method vs USG-guided DNTP method [Time Frame: through study completion, an average of 6 months] ◦ puncture in the skin made by the cannula in an attempt to cannulate the radial artery assessed between groups • number of cannulae used for successful radial artery cannulation between conventional palpation method vs USG-guided DNTP method [Time Frame: through study completion, an average of 6 months] ◦ number of cannulae required for successful cannulation between 2 groups will be compared • time duration for successful cannulation in conventional palpation method vs USG-guided DNTP method [Time Frame: through study completion, an average of 6 months] ◦ total time (in seconds) taken from placement of USG probe on the prepped wrist or when the operator begins palpation of radial pulse to appearance of arterial waveform in the monitor will be compared between 2 groups • overall 5-minute success rate in conventional palpation method vs USG-guided DNTP method [Time Frame: through study completion, an average of 6 months] ◦ overall success between 2 groups after 5 minutes will be compared
Starting date	5 November 2020

NCT04617106 *(Continued)*

Contact information	Sujan Dhakal, MBBS, MD resident +9779851178234 | szndkl44@gmail.com Dr. Gentle Shrestha MBBS, MD +9779841248584 | gentlesunder@hotmail.com location: Nepal Tribhuwan University Teaching Hospital Bagmati, Nepal, 44600 contact: Sujan Dhakal, MBBS 9851178234 | szndkl44@gmail.com
Notes	NCT04617106 / no data provided

NCT04806932

Study name	Comparison of the modified and conventional approach of radial artery cannulation under short-axis ultrasound guidance in ICU hypotensive patients
Methods	Single-centre prospective randomised controlled parallel-assignment trial
Participants	102 participants, 18 years to 100 years old (adult, older adult), female and male, radial artery Inclusion criteria • patient in intensive care unit • need for invasive haemodynamic monitoring (arterial blood pressure and cardiac output monitoring) • need for frequent blood sampling (arterial blood gas analysis and general laboratory evaluation) • vasopressor therapy Exclusion criteria • negative Allen's test • ulnar artery occlusion • prevalent atherosclerosis • blocked or embolised target vessel determined by ultrasound assessment • Raynaud disease • infection near radial artery puncture site
Interventions	Experimental: modified approach The first 3 attempts will be performed via the modified approach. If the first 3 attempts fail, location or operator of subsequent attempts at artery puncture will be changed Comparator: conventional approach The first 3 attempts will be performed via the conventional approach. If the first 3 attempts fail, location or operator of subsequent attempts at artery puncture will be changed
Outcomes	Primary • first-pass success [Time Frame: approximately 3 minutes] - successful catheterisation on first attempt Secondary • overall success [Time Frame: within 10 minutes] - successful catheterisation without a limit on the number of punctures

NCT04806932 *(Continued)*

	• cannulation time [Time Frame: within 10 minutes] - interval between skin contact with the probe and confirmation of arterial waveform on the monitor • posterior wall puncture [Time Frame: within 10 minutes] - operator saw the needle passing the posterior wall or blood backflow appearing then disappearing while needle advancing • number of attempts [Time Frame: within 10 minutes] - number of attempts until successful cannulation • complication rate [Time Frame: Day 1] - bleeding, haematoma, thrombosis, vasospasm, occlusion, aneurysm
Starting date	11 April 2021
Contact information	Hongyu He, Ph D021-64041990 ext 692958 | he.hongyu@zs-hospital.sh.cn Shanghai Zhongshan Hospital Recruiting Shanghai, Shanghai, China, 200032 Contact: Guowei Tu, PhD +8613501996995 | tu.guowei@zs-hospital.sh.cn Contact: Zhe Luo, PhD +8613916127028 | luo.zhe@zs-hospital.sh.cn
Notes	NCT04806932 / no data provided

NTR6107

Study name	Catheterisation of the radial artery with fixated ultrasound transducer
Methods	Single-centre prospective randomised controlled 3-arm single-masking parallel-assignment study
Participants	200 participants, 18 years of age and older, female and male, radial artery. Inclusion criteria • age ≥ 18 years • written informed consent • scheduled for elective cardiothoracic or major abdominal surgery Exclusion criteria • no informed consent • emergency procedure • preexisting injury at radial artery cannulation site (e.g. haematoma, infection, previous surgery such as radial artery harvesting)
Interventions	Experimental: ultrasound-guided puncture Comparator: ultrasound with a fixated transducer-guided puncture Comparator: digital palpation puncture
Outcomes	Primary • rate of successful cannulation

NTR6107 *(Continued)*

	Secondary • total time for completion of the procedure. For the digital palpation group, this is the time from first palpation of the artery until placement of the catheter. In US groups, this is the time from first contact of the US transducer with the skin until placement of the catheter • total attempts needed to complete the procedure • total attempts per group • skin punctures • failures
Starting date	1 November 2016
Contact information	Harm Scholten Catharina Hospital Eindhoven, The Netherlands harm.scholten@cze.nl
Notes	NTR6107 | no data provided

TCTR20210202004

Study name	A comparison of success rate of radial artery cannulation between ultrasound-guided and conventional palpation technique in elderly patients
Methods	Prospective randomised interventional trial (masking not reported)
Participants	60 participants, both sexes, 65 years of age or older Inclusion criteria • older than 65 years • selective cardiovascular or thoracic surgery • indication for artery cannulation Exclusion criteria • severe peripheral vascular disease • contraindication for artery cannulation • previous artery cannulation • hypotension or shock • radial artery injury
Interventions	Experimental • radial artery cannulation by ultrasound-guided (out-of-plane) technique Comparator • palpation technique for radial artery cannulation
Outcomes	Primary • first-attempt success rate 10 minutes (%) Secondary • time to first success within 10 minutes

TCTR20210202004 *(Continued)*

	• time to success 20 minutes • failure at more than 10 minutes
Starting date	1 July 2020
Contact information	Narumon Ngorsorn address: Department of Anesthesiology, 40002 Khonkaen, Thailand telephone: 0834051482 | email: miracle_oneview@msn.com affiliation: Khon Kaen University Thanaporn Suwongkrua address: Department of Anesthesiology, 40002 Khonkaen, Thailand telephone: 0644469666 | email: por4807062@gmail.com affiliation: Khon Kaen University
Notes	TCTR20210202004 / no data reported

UMIN000020698

Study name	The disturbing factors for residents to insert arterial catheter
Methods	Single-centre prospective randomised controlled 3-arm open-label parallel-assignment study
Participants	150 participants, 20 years of age and older, female and male, target artery not described. Inclusion criteria • patient scheduled for insertion of arterial catheter under general anaesthesia Exclusion criteria • emergency surgery • younger than 20 years of age • insertion of arterial catheter before general anaesthesia • assessed as inappropriate case
Interventions	Experimental: insert arterial catheter with ultrasound scan Comparator • insert arterial catheter with sphygmo palpation • insert arterial catheter with infrared light device "MillSuss"
Outcomes	Primary • time needed to insert arterial catheter Secondary • none provided

UMIN000020698 *(Continued)*

Starting date	25 January 2016
Contact information	Irie Tomoya Yokohama City University, Japan 045-787-2918 | tomoya.irie0216@gmail.com
Notes	UMIN000020698 | no data provided

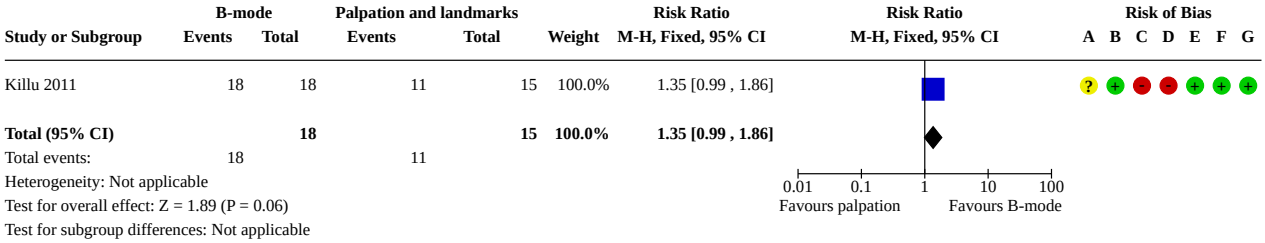
AA = axillary artery; **ABGA =** arterial blood gas analysis; **ASA =** Amerian Society of Anesthesiologists physical status classification system; **BMI =** body mass index; **CA =** coronary angiography; **DNTP =** dynamic needle tip positioning; **DPA =** dorsalis pedis artery; **ENT =** ear, nose, and throat speciality; **GA =** general anaesthesia; **ICU =** intensive care unit; **INR =** international normalised ratio; **ITT =** intention-to-treat; **IU =** international unit; **PCI =** percutaneous coronary intervention; **PVD =** peripheral vascular disease; **RA =** radial artery; **SD =** standard deviation; **VAS =** visual analogue scale.

DATA AND ANALYSES

Comparison 1. [Axillary] B-mode ultrasound guidance versus palpation and landmarks

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1.1 Overall success rate	1	33	Risk Ratio (M-H, Fixed, 95% CI)	1.35 [0.99, 1.86]
1.2 Time needed for a successful procedure	1	33	Mean Difference (IV, Fixed, 95% CI)	-2.27 [-7.36, 2.82]
1.3 Major haematoma	1	33	Risk Ratio (M-H, Fixed, 95% CI)	0.83 [0.06, 12.22]
1.4 Adverse events (venous puncture)	1	33	Risk Ratio (M-H, Fixed, 95% CI)	0.83 [0.20, 3.54]

Analysis 1.1. Comparison 1: [Axillary] B-mode ultrasound guidance versus palpation and landmarks, Outcome 1: Overall success rate

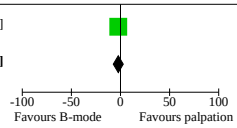


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 1.2. Comparison 1: [Axillary] B-mode ultrasound guidance versus palpation and landmarks, Outcome 2: Time needed for a successful procedure

Study or Subgroup	B-mode Mean [minutes]	B-mode SD [minutes]	B-mode Total	Palpation and landmarks Mean [minutes]	Palpation and landmarks SD [minutes]	Palpation and landmarks Total	Weight	Mean Difference IV, Fixed, 95% CI [minutes]	Risk of Bias A B C D E F G
Killu 2011	7.0156	4.4025	18	9.288	9.2255	15	100.0%	-2.27 [-7.36 , 2.82]	? + - - + + +
Total (95% CI)			**18**			**15**	**100.0%**	**-2.27 [-7.36 , 2.82]**	

Heterogeneity: Not applicable
Test for overall effect: Z = 0.87 (P = 0.38)
Test for subgroup differences: Not applicable



Risk of bias legend
(A) Random sequence generation (selection bias)
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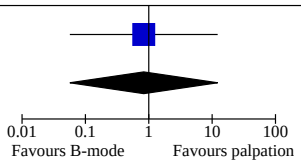
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.3. Comparison 1: [Axillary] B-mode ultrasound guidance versus palpation and landmarks, Outcome 3: Major haematoma

Study or Subgroup	B-mode Events	B-mode Total	Palpation and landmarks Events	Palpation and landmarks Total	Weight	Risk Ratio M-H, Fixed, 95% CI	Risk of Bias A B C D E F G
Killu 2011	1	18	1	15	100.0%	0.83 [0.06 , 12.22]	? + - - + + +
Total (95% CI)		**18**		**15**	**100.0%**	**0.83 [0.06 , 12.22]**	
Total events:	1		1				

Heterogeneity: Not applicable
Test for overall effect: Z = 0.13 (P = 0.89)
Test for subgroup differences: Not applicable



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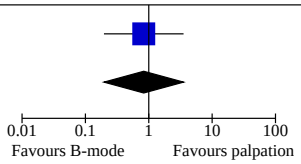
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 1.4. Comparison 1: [Axillary] B-mode ultrasound guidance versus palpation and landmarks, Outcome 4: Adverse events (venous puncture)

Study or Subgroup	B-mode Events	B-mode Total	Palpation and landmarks Events	Palpation and landmarks Total	Weight	Risk Ratio M-H, Fixed, 95% CI	Risk of Bias A B C D E F G
Killu 2011	3	18	3	15	100.0%	0.83 [0.20 , 3.54]	? + - - + + +
Total (95% CI)		**18**		**15**	**100.0%**	**0.83 [0.20 , 3.54]**	
Total events:	3		3				

Heterogeneity: Not applicable
Test for overall effect: Z = 0.25 (P = 0.80)
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

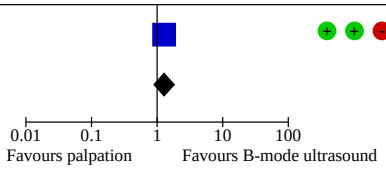
Comparison 2. [Dorsalis pedis] B-mode ultrasound guidance versus palpation and landmarks

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
2.1 First-attempt success rate	1	60	Risk Ratio (M-H, Fixed, 95% CI)	1.28 [0.90, 1.82]
2.2 Overall success rate	1	60	Risk Ratio (M-H, Fixed, 95% CI)	1.00 [0.91, 1.10]
2.3 Time needed for a successful procedure	1	60	Mean Difference (IV, Fixed, 95% CI)	-0.04 [-0.16, 0.08]

Analysis 2.1. Comparison 2: [Dorsalis pedis] B-mode ultrasound guidance versus palpation and landmarks, Outcome 1: First-attempt success rate

Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Anand 2019	23	30	18	30	100.0%	1.28 [0.90 , 1.82]
Total (95% CI)		**30**		**30**	**100.0%**	**1.28 [0.90 , 1.82]**
Total events:	23		18			

Heterogeneity: Not applicable
Test for overall effect: Z = 1.36 (P = 0.17)
Test for subgroup differences: Not applicable



Risk of bias legend
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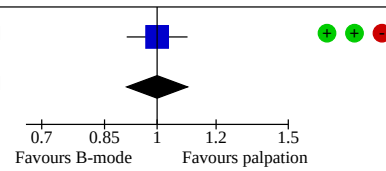
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 2.2. Comparison 2: [Dorsalis pedis] B-mode ultrasound guidance versus palpation and landmarks, Outcome 2: Overall success rate

Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Anand 2019	29	30	29	30	100.0%	1.00 [0.91 , 1.10]
Total (95% CI)		**30**		**30**	**100.0%**	**1.00 [0.91 , 1.10]**
Total events:	29		29			

Heterogeneity: Not applicable
Test for overall effect: Z = 0.00 (P = 1.00)
Test for subgroup differences: Not applicable



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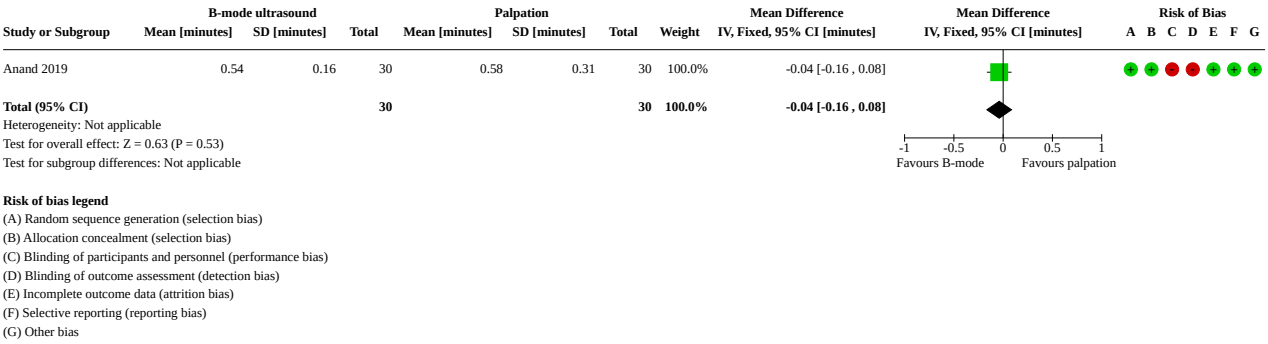
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

Analysis 2.3. Comparison 2: [Dorsalis pedis] B-mode ultrasound guidance versus palpation and landmarks, Outcome 3: Time needed for a successful procedure



Comparison 3. [Radial] B-mode ultrasound guidance versus palpation and landmarks

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
3.1 First-attempt success rate	27	4708	Risk Ratio (M-H, Random, 95% CI)	1.44 [1.29, 1.61]
3.1.1 Experienced operators	19	3384	Risk Ratio (M-H, Random, 95% CI)	1.39 [1.23, 1.58]
3.1.2 Inexperienced operators	9	1324	Risk Ratio (M-H, Random, 95% CI)	1.55 [1.31, 1.83]
3.2 First-attempt success rate - trials at low risk of bias	19	2762	Risk Ratio (M-H, Random, 95% CI)	1.46 [1.33, 1.60]
3.2.1 Experienced operators	14	2106	Risk Ratio (M-H, Random, 95% CI)	1.38 [1.26, 1.53]
3.2.2 Inexperienced operators	6	656	Risk Ratio (M-H, Random, 95% CI)	1.72 [1.39, 2.12]
3.3 First-attempt success rate - trials with individual parallel design	25	4625	Risk Ratio (M-H, Random, 95% CI)	1.42 [1.27, 1.59]
3.3.1 Experienced operators	18	3344	Risk Ratio (M-H, Random, 95% CI)	1.38 [1.21, 1.56]
3.3.2 Inexperienced operators	8	1281	Risk Ratio (M-H, Random, 95% CI)	1.53 [1.28, 1.83]
3.4 Pseudomaneurysm	1	679	Risk Ratio (M-H, Fixed, 95% CI)	2.89 [0.12, 70.63]
3.5 Overall success rate	28	4955	Risk Ratio (M-H, Random, 95% CI)	1.11 [1.06, 1.16]
3.5.1 Experienced operators	18	3132	Risk Ratio (M-H, Random, 95% CI)	1.09 [1.03, 1.14]

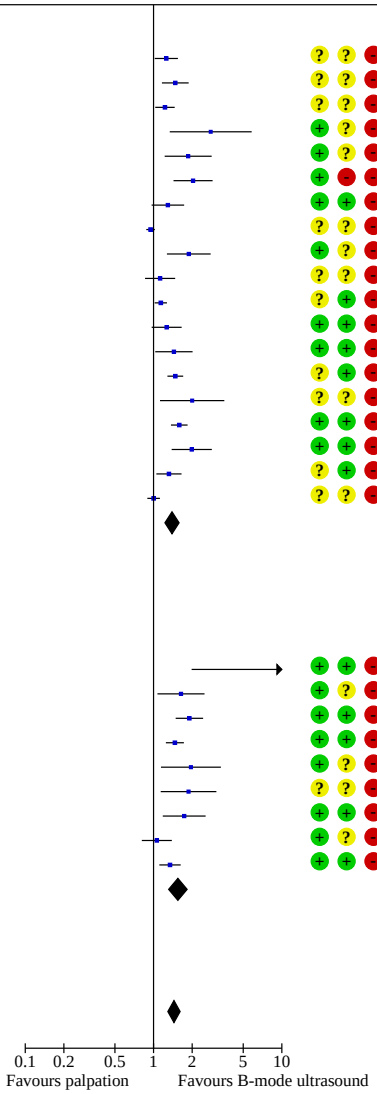
Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
3.5.2 Inexperienced operators	11	1823	Risk Ratio (M-H, Random, 95% CI)	1.17 [1.05, 1.29]
3.6 Overall success rate - trials at low risk of bias	19	2784	Risk Ratio (M-H, Random, 95% CI)	1.14 [1.07, 1.22]
3.6.1 Experienced operators	15	2178	Risk Ratio (M-H, Random, 95% CI)	1.13 [1.06, 1.21]
3.6.2 Inexperienced operators	5	606	Risk Ratio (M-H, Random, 95% CI)	1.29 [0.97, 1.72]
3.7 Overall success rate - trials with individual parallel design	26	4875	Risk Ratio (M-H, Random, 95% CI)	1.10 [1.05, 1.15]
3.7.1 Experienced operators	17	3092	Risk Ratio (M-H, Random, 95% CI)	1.08 [1.03, 1.14]
3.7.2 Inexperienced operators	10	1783	Risk Ratio (M-H, Random, 95% CI)	1.15 [1.04, 1.28]
3.8 Time needed for a successful procedure	26	4902	Mean Difference (IV, Random, 95% CI)	-0.33 [-0.54, -0.13]
3.8.1 Experienced operators	18	3430	Mean Difference (IV, Random, 95% CI)	-0.13 [-0.35, 0.08]
3.8.2 Inexperienced operators	8	1472	Mean Difference (IV, Random, 95% CI)	-1.12 [-1.69, -0.55]
3.9 Time needed for successful procedure - trials at low risk of bias	18	2671	Mean Difference (IV, Random, 95% CI)	-0.23 [-0.38, -0.08]
3.9.1 Experienced operators	14	2276	Mean Difference (IV, Random, 95% CI)	-0.19 [-0.36, -0.02]
3.9.2 Inexperienced operators	4	395	Mean Difference (IV, Random, 95% CI)	-0.92 [-1.81, -0.03]
3.10 Time needed for a successful procedure - trials with individual parallel design	24	4822	Mean Difference (IV, Random, 95% CI)	-0.30 [-0.51, -0.09]
3.10.1 Experienced operators	17	3390	Mean Difference (IV, Random, 95% CI)	-0.10 [-0.32, 0.11]
3.10.2 Inexperienced operators	7	1432	Mean Difference (IV, Random, 95% CI)	-1.18 [-1.79, -0.56]
3.11 Major haematoma	16	2504	Risk Ratio (M-H, Random, 95% CI)	0.35 [0.23, 0.56]
3.11.1 Experienced operators	10	1918	Risk Ratio (M-H, Random, 95% CI)	0.30 [0.19, 0.46]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
3.11.2 Inexperienced operators	6	586	Risk Ratio (M-H, Random, 95% CI)	0.44 [0.18, 1.09]
3.12 Major haematoma - trials at low risk of bias	12	2081	Risk Ratio (M-H, Random, 95% CI)	0.30 [0.21, 0.43]
3.12.1 Experienced operators	9	1735	Risk Ratio (M-H, Random, 95% CI)	0.30 [0.19, 0.46]
3.12.2 Inexperienced operators	3	346	Risk Ratio (M-H, Random, 95% CI)	0.32 [0.17, 0.63]
3.13 Adverse events (pain)	4	883	Mean Difference (IV, Random, 95% CI)	0.81 [-0.66, 2.28]
3.14 Adverse events (pain) - trials at low risk of bias	2	112	Mean Difference (IV, Random, 95% CI)	-0.10 [-0.95, 0.75]
3.15 Adverse events (pain) - trials with individual parallel design	3	497	Mean Difference (IV, Random, 95% CI)	1.22 [-1.19, 3.64]
3.16 Adverse events (bleeding, haematoma, ischaemia, or spasm)	3	1303	Risk Ratio (M-H, Random, 95% CI)	0.86 [0.49, 1.52]
3.16.1 Bleeding or haematoma	1	698	Risk Ratio (M-H, Random, 95% CI)	1.26 [0.34, 4.67]
3.16.2 Bleeding, haematoma, or spasm	1	100	Risk Ratio (M-H, Random, 95% CI)	0.30 [0.06, 1.36]
3.16.3 Haematoma or ischaemia	1	505	Risk Ratio (M-H, Random, 95% CI)	0.96 [0.58, 1.57]
3.17 Adverse events (local infection)	3	260	Risk Ratio (M-H, Random, 95% CI)	0.33 [0.04, 3.15]
3.18 Adverse events (local infection) - trials at low risk of bias	2	180	Risk Ratio (M-H, Random, 95% CI)	0.33 [0.01, 8.02]
3.19 Adverse events (oedema)	2	365	Risk Ratio (M-H, Random, 95% CI)	0.15 [0.04, 0.64]
3.20 Adverse events (arterial thrombosis)	5	1496	Risk Ratio (M-H, Fixed, 95% CI)	0.71 [0.14, 3.54]
3.21 Adverse events (arterial thrombosis) - trials at low risk of bias	4	1416	Risk Ratio (M-H, Fixed, 95% CI)	0.33 [0.03, 3.13]
3.22 Adverse events (death)	1	679	Risk Ratio (M-H, Fixed, 95% CI)	0.32 [0.01, 7.85]
3.23 Adverse events (spasm)	5	1525	Risk Ratio (M-H, Random, 95% CI)	1.11 [0.62, 1.97]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
3.24 Adverse events (spasm) - trials at low risk of bias	4	827	Risk Ratio (M-H, Random, 95% CI)	0.90 [0.30, 2.64]
3.25 Adverse events (posterior wall puncture)	1	196	Risk Ratio (M-H, Fixed, 95% CI)	0.41 [0.28, 0.61]
3.26 Quality of life (satisfaction)	1	72	Mean Difference (IV, Fixed, 95% CI)	0.00 [-1.07, 1.07]

Analysis 3.1. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 1: First-attempt success rate

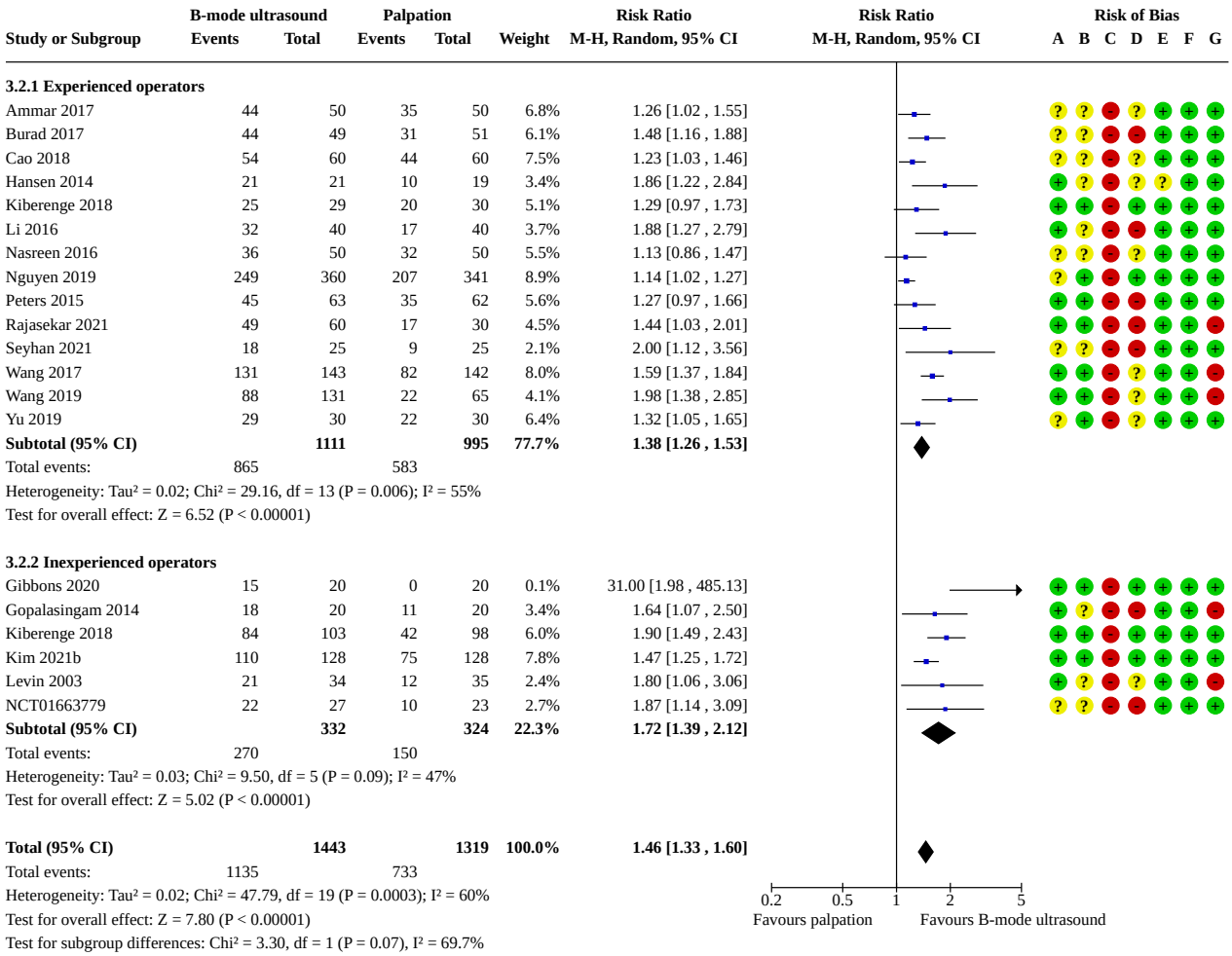
Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
3.1.1 Experienced operators						
Ammar 2017	44	50	35	50	4.3%	1.26 [1.02 , 1.55]
Burad 2017	44	49	31	51	4.1%	1.48 [1.16 , 1.88]
Cao 2018	54	60	44	60	4.5%	1.23 [1.03 , 1.46]
Grandpierre 2019	19	36	7	37	1.6%	2.79 [1.34 , 5.82]
Hansen 2014	21	21	10	19	2.9%	1.86 [1.22 , 2.84]
Khan 2018	41	49	21	51	3.3%	2.03 [1.43 , 2.89]
Kiberenge 2018	25	29	20	30	3.7%	1.29 [0.97 , 1.73]
Laursen 2015	103	115	103	109	4.9%	0.95 [0.88 , 1.02]
Li 2016	32	40	17	40	3.1%	1.88 [1.27 , 2.79]
Nasreen 2016	36	50	32	50	3.9%	1.13 [0.86 , 1.47]
Nguyen 2019	249	360	207	341	4.8%	1.14 [1.02 , 1.27]
Peters 2015	45	63	35	62	3.9%	1.27 [0.97 , 1.66]
Rajasekar 2021	49	60	17	30	3.4%	1.44 [1.03 , 2.01]
Seto 2015	225	347	154	351	4.7%	1.48 [1.28 , 1.70]
Seyhan 2021	18	25	9	25	2.1%	2.00 [1.12 , 3.56]
Wang 2017	131	143	82	142	4.6%	1.59 [1.37 , 1.84]
Wang 2019	88	131	22	65	3.3%	1.98 [1.38 , 2.85]
Yu 2019	29	30	22	30	4.2%	1.32 [1.05 , 1.65]
Zaremski 2013	80	92	79	91	4.8%	1.00 [0.89 , 1.12]
Subtotal (95% CI)		**1750**		**1634**	**72.2%**	**1.39 [1.23 , 1.58]**
Total events:	1333		947			
Heterogeneity: Tau² = 0.06; Chi² = 135.63, df = 18 (P < 0.00001); I² = 87%						
Test for overall effect: Z = 5.11 (P < 0.00001)						
3.1.2 Inexperienced operators						
Gibbons 2020	15	20	0	20	0.2%	31.00 [1.98 , 485.13]
Gopalasingam 2014	18	20	11	20	2.9%	1.64 [1.07 , 2.50]
Kiberenge 2018	84	103	42	98	4.0%	1.90 [1.49 , 2.43]
Kim 2021b	110	128	75	128	4.6%	1.47 [1.25 , 1.72]
Levin 2003	21	34	12	38	2.3%	1.96 [1.14 , 3.35]
NCT01663779	22	27	10	23	2.5%	1.87 [1.14 , 3.09]
Shiver 2006	26	30	15	30	3.1%	1.73 [1.18 , 2.55]
Tangwiwat 2016	35	50	33	50	3.9%	1.06 [0.81 , 1.39]
Ueda 2015	132	249	101	256	4.4%	1.34 [1.11 , 1.63]
Subtotal (95% CI)		**661**		**663**	**27.8%**	**1.55 [1.31 , 1.83]**
Total events:	463		299			
Heterogeneity: Tau² = 0.03; Chi² = 19.00, df = 8 (P = 0.01); I² = 58%						
Test for overall effect: Z = 5.16 (P < 0.00001)						
Total (95% CI)		**2411**		**2297**	**100.0%**	**1.44 [1.29 , 1.61]**
Total events:	1796		1246			
Heterogeneity: Tau² = 0.06; Chi² = 180.40, df = 27 (P < 0.00001); I² = 85%						
Test for overall effect: Z = 6.53 (P < 0.00001)						
Test for subgroup differences: Chi² = 0.98, df = 1 (P = 0.32), 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 3.2. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 2: First-attempt success rate - trials at low risk of bias

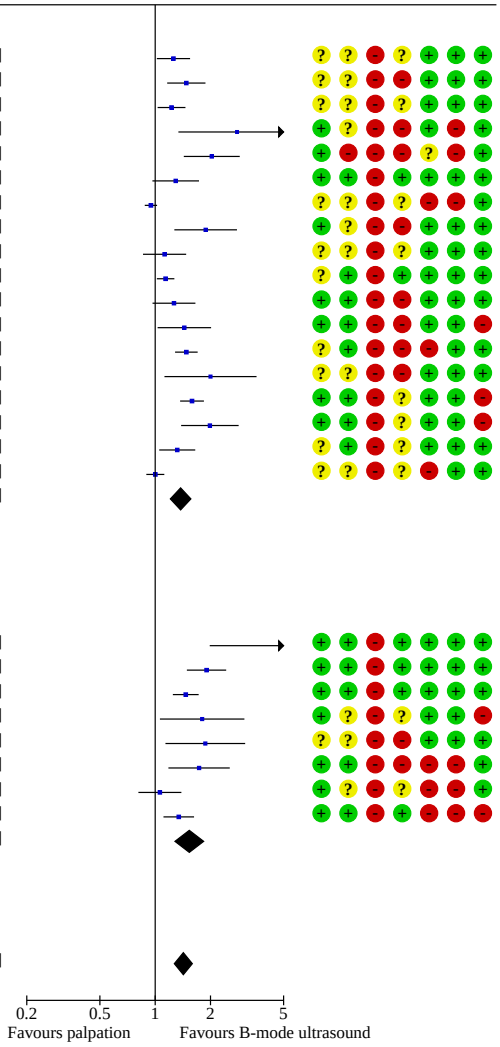


Risk of bias legend

(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 3.3. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 3: First-attempt success rate - trials with individual parallel design

Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
3.3.1 Experienced operators						
Ammar 2017	44	50	35	50	4.6%	1.26 [1.02 , 1.55]
Burad 2017	44	49	31	51	4.3%	1.48 [1.16 , 1.88]
Cao 2018	54	60	44	60	4.8%	1.23 [1.03 , 1.46]
Grandpierre 2019	19	36	7	37	1.6%	2.79 [1.34 , 5.82]
Khan 2018	41	49	21	51	3.5%	2.03 [1.43 , 2.89]
Kiberenge 2018	25	29	20	30	4.0%	1.29 [0.97 , 1.73]
Laursen 2015	103	115	103	109	5.3%	0.95 [0.88 , 1.02]
Li 2016	32	40	17	40	3.3%	1.88 [1.27 , 2.79]
Nasreen 2016	36	50	32	50	4.1%	1.13 [0.86 , 1.47]
Nguyen 2019	249	360	207	341	5.1%	1.14 [1.02 , 1.27]
Peters 2015	45	63	35	62	4.1%	1.27 [0.97 , 1.66]
Rajasekar 2021	49	60	17	30	3.7%	1.44 [1.03 , 2.01]
Seto 2015	225	347	154	351	5.0%	1.48 [1.28 , 1.70]
Seyhan 2021	18	25	9	25	2.2%	2.00 [1.12 , 3.56]
Wang 2017	131	143	82	142	4.9%	1.59 [1.37 , 1.84]
Wang 2019	88	131	22	65	3.5%	1.98 [1.38 , 2.85]
Yu 2019	29	30	22	30	4.4%	1.32 [1.05 , 1.65]
Zaremski 2013	80	92	79	91	5.1%	1.00 [0.89 , 1.12]
Subtotal (95% CI)		**1729**		**1615**	**73.5%**	**1.38 [1.21 , 1.56]**
Total events:	1312		937			
Heterogeneity: Tau² = 0.06; Chi² = 130.66, df = 17 (P < 0.00001); I² = 87%						
Test for overall effect: Z = 4.86 (P < 0.00001)						
3.3.2 Inexperienced operators						
Gibbons 2020	15	20	0	20	0.2%	31.00 [1.98 , 485.13]
Kiberenge 2018	84	103	42	98	4.3%	1.90 [1.49 , 2.43]
Kim 2021b	110	128	75	128	4.9%	1.47 [1.25 , 1.72]
Levin 2003	21	34	12	35	2.5%	1.80 [1.06 , 3.06]
NCT01663779	22	27	10	23	2.6%	1.87 [1.14 , 3.09]
Shiver 2006	26	30	15	30	3.3%	1.73 [1.18 , 2.55]
Tangwiwat 2016	35	50	33	50	4.1%	1.06 [0.81 , 1.39]
Ueda 2015	132	249	101	256	4.7%	1.34 [1.11 , 1.63]
Subtotal (95% CI)		**641**		**640**	**26.5%**	**1.53 [1.28 , 1.83]**
Total events:	445		288			
Heterogeneity: Tau² = 0.03; Chi² = 18.30, df = 7 (P = 0.01); I² = 62%						
Test for overall effect: Z = 4.67 (P < 0.00001)						
Total (95% CI)		**2370**		**2255**	**100.0%**	**1.42 [1.27 , 1.59]**
Total events:	1757		1225			
Heterogeneity: Tau² = 0.06; Chi² = 173.49, df = 25 (P < 0.00001); I² = 86%						
Test for overall effect: Z = 6.13 (P < 0.00001)						
Test for subgroup differences: Chi² = 0.93, df = 1 (P = 0.33), I² = 0%						

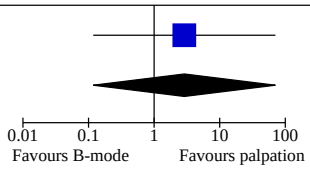


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 3.4. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 4: Pseudomaneurysm

Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI	Risk of Bias A B C D E F G
Nguyen 2019	1	346	0	333	100.0%	2.89 [0.12 , 70.63]	? + - + + + +
Total (95% CI)		**346**		**333**	**100.0%**	**2.89 [0.12 , 70.63]**	
Total events:	1		0				

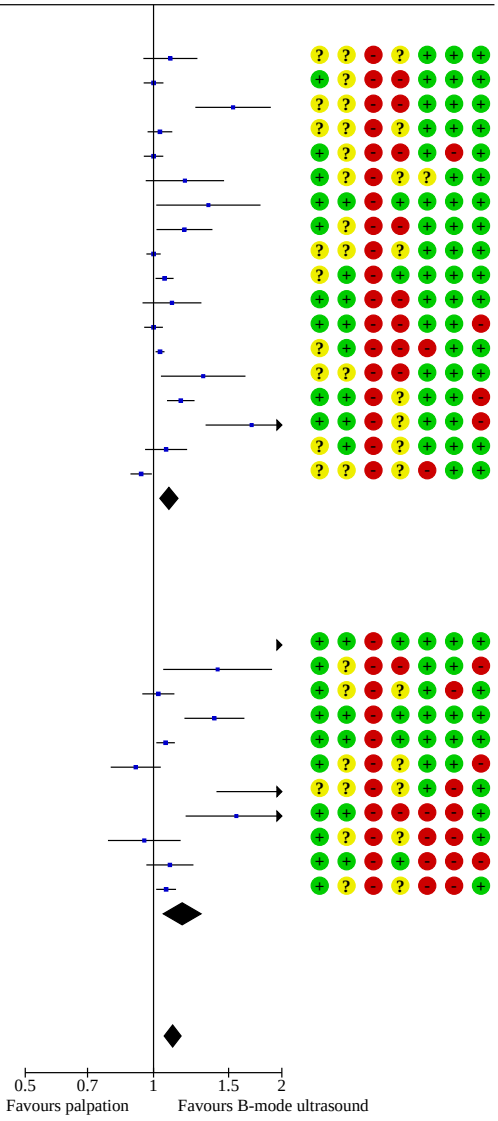
Heterogeneity: Not applicable
Test for overall effect: Z = 0.65 (P = 0.52)
Test for subgroup differences: Not applicable



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 3.5. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 5: Overall success rate

Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
3.5.1 Experienced operators						
Ammar 2017	46	50	42	50	3.4%	1.10 [0.95 , 1.27]
Bobbia 2013	37	37	35	35	4.8%	1.00 [0.95 , 1.05]
Burad 2017	49	49	33	51	2.5%	1.54 [1.25 , 1.88]
Cao 2018	59	60	57	60	4.7%	1.04 [0.97 , 1.11]
Grandpierre 2019	36	36	37	37	4.8%	1.00 [0.95 , 1.05]
Hansen 2014	21	21	16	19	2.4%	1.18 [0.96 , 1.46]
Kiberenge 2018	26	29	20	30	1.7%	1.34 [1.01 , 1.78]
Li 2016	39	40	33	40	3.3%	1.18 [1.02 , 1.37]
Nasreen 2016	50	50	50	50	5.0%	1.00 [0.96 , 1.04]
Nguyen 2019	335	360	299	341	4.9%	1.06 [1.01 , 1.11]
Peters 2015	55	63	49	62	3.2%	1.10 [0.94 , 1.30]
Rajasekar 2021	60	60	30	30	4.9%	1.00 [0.95 , 1.05]
Seto 2015	344	347	336	351	5.1%	1.04 [1.01 , 1.06]
Seyhan 2021	25	25	19	25	2.3%	1.31 [1.04 , 1.64]
Wang 2017	140	143	120	142	4.5%	1.16 [1.08 , 1.25]
Wang 2019	113	131	33	65	2.0%	1.70 [1.32 , 2.18]
Yu 2019	30	30	28	30	3.9%	1.07 [0.96 , 1.20]
Zaremski 2013	86	92	91	91	4.8%	0.94 [0.88 , 0.99]
Subtotal (95% CI)		**1623**		**1509**	**68.2%**	**1.09 [1.03 , 1.14]**
Total events:	1551		1328			
Heterogeneity: Tau² = 0.01; Chi² = 137.55, df = 17 (P < 0.00001); I² = 88%						
Test for overall effect: Z = 3.32 (P = 0.0009)						
3.5.2 Inexperienced operators						
Gibbons 2020	20	20	3	20	0.2%	5.86 [2.25 , 15.28]
Gopalasingam 2014	20	20	14	20	1.6%	1.41 [1.05 , 1.90]
Goswami 2020	39	40	38	40	4.4%	1.03 [0.94 , 1.12]
Kiberenge 2018	92	103	63	98	3.1%	1.39 [1.18 , 1.63]
Kim 2021b	127	128	119	128	4.9%	1.07 [1.02 , 1.12]
Levin 2003	30	34	34	35	3.6%	0.91 [0.79 , 1.04]
Rose 2018	29	30	14	30	1.1%	2.07 [1.40 , 3.05]
Shiver 2006	30	30	19	30	1.8%	1.56 [1.19 , 2.06]
Tangwiwat 2016	39	50	41	50	2.6%	0.95 [0.78 , 1.16]
Ueda 2015	170	249	160	256	3.7%	1.09 [0.96 , 1.24]
Yeap 2019	198	206	185	206	4.8%	1.07 [1.01 , 1.13]
Subtotal (95% CI)		**910**		**913**	**31.8%**	**1.17 [1.05 , 1.29]**
Total events:	794		690			
Heterogeneity: Tau² = 0.02; Chi² = 71.33, df = 10 (P < 0.00001); I² = 86%						
Test for overall effect: Z = 2.97 (P = 0.003)						
Total (95% CI)		**2533**		**2422**	**100.0%**	**1.11 [1.06 , 1.16]**
Total events:	2345		2018			
Heterogeneity: Tau² = 0.01; Chi² = 240.35, df = 28 (P < 0.00001); I² = 88%						
Test for overall effect: Z = 4.43 (P < 0.00001)						
Test for subgroup differences: Chi² = 1.54, df = 1 (P = 0.21), I² = 35.0%						

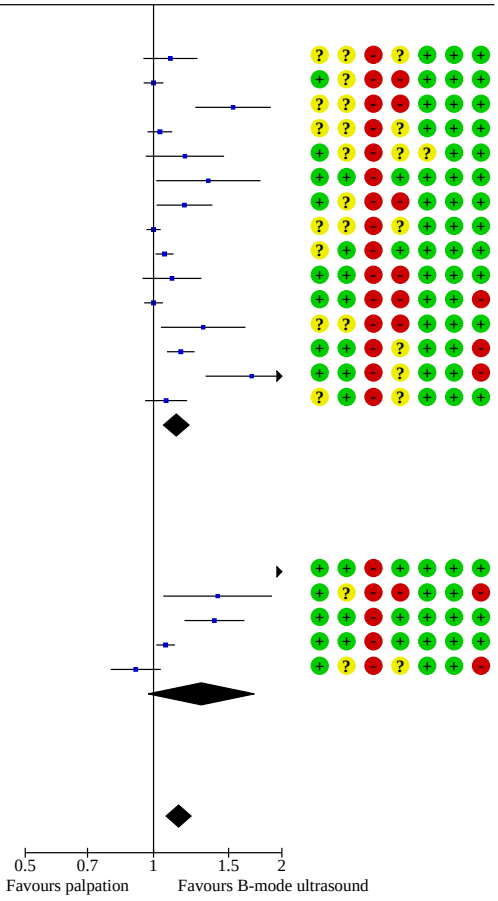


Risk of bias legend

(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 3.6. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 6: Overall success rate - trials at low risk of bias

Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
3.6.1 Experienced operators						
Ammar 2017	46	50	42	50	5.2%	1.10 [0.95 , 1.27]
Bobbia 2013	37	37	35	35	6.6%	1.00 [0.95 , 1.05]
Burad 2017	49	49	33	51	4.2%	1.54 [1.25 , 1.88]
Cao 2018	59	60	57	60	6.5%	1.04 [0.97 , 1.11]
Hansen 2014	21	21	16	19	4.1%	1.18 [0.96 , 1.46]
Kiberenge 2018	26	29	20	30	3.1%	1.34 [1.01 , 1.78]
Li 2016	39	40	33	40	5.1%	1.18 [1.02 , 1.37]
Nasreen 2016	50	50	50	50	6.8%	1.00 [0.96 , 1.04]
Nguyen 2019	335	360	299	341	6.7%	1.06 [1.01 , 1.11]
Peters 2015	55	63	49	62	5.0%	1.10 [0.94 , 1.30]
Rajasekar 2021	60	60	30	30	6.7%	1.00 [0.95 , 1.05]
Seyhan 2021	25	25	19	25	3.9%	1.31 [1.04 , 1.64]
Wang 2017	140	143	120	142	6.4%	1.16 [1.08 , 1.25]
Wang 2019	113	131	33	65	3.6%	1.70 [1.32 , 2.18]
Yu 2019	30	30	28	30	5.8%	1.07 [0.96 , 1.20]
Subtotal (95% CI)		**1148**		**1030**	**79.6%**	**1.13 [1.06 , 1.21]**
Total events:	1085		864			
Heterogeneity: Tau² = 0.01; Chi² = 125.58, df = 14 (P < 0.00001); I² = 89%						
Test for overall effect: Z = 3.49 (P = 0.0005)						
3.6.2 Inexperienced operators						
Gibbons 2020	20	20	3	20	0.5%	5.86 [2.25 , 15.28]
Gopalasingam 2014	20	20	14	20	3.0%	1.41 [1.05 , 1.90]
Kiberenge 2018	92	103	63	98	4.9%	1.39 [1.18 , 1.63]
Kim 2021b	127	128	119	128	6.7%	1.07 [1.02 , 1.12]
Levin 2003	30	34	34	35	5.4%	0.91 [0.79 , 1.04]
Subtotal (95% CI)		**305**		**301**	**20.4%**	**1.29 [0.97 , 1.72]**
Total events:	289		233			
Heterogeneity: Tau² = 0.08; Chi² = 61.70, df = 4 (P < 0.00001); I² = 94%						
Test for overall effect: Z = 1.76 (P = 0.08)						
Total (95% CI)		**1453**		**1331**	**100.0%**	**1.14 [1.07 , 1.22]**
Total events:	1374		1097			
Heterogeneity: Tau² = 0.02; Chi² = 194.07, df = 19 (P < 0.00001); I² = 90%						
Test for overall effect: Z = 3.93 (P < 0.0001)						
Test for subgroup differences: Chi² = 0.81, df = 1 (P = 0.37), I² = 0%						

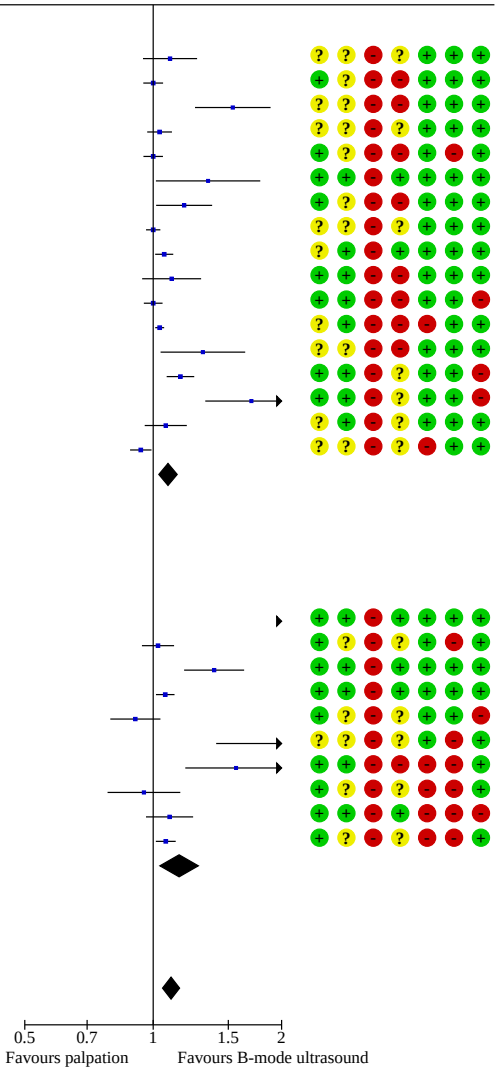


Risk of bias legend

(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 3.7. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 7: Overall success rate - trials with individual parallel design

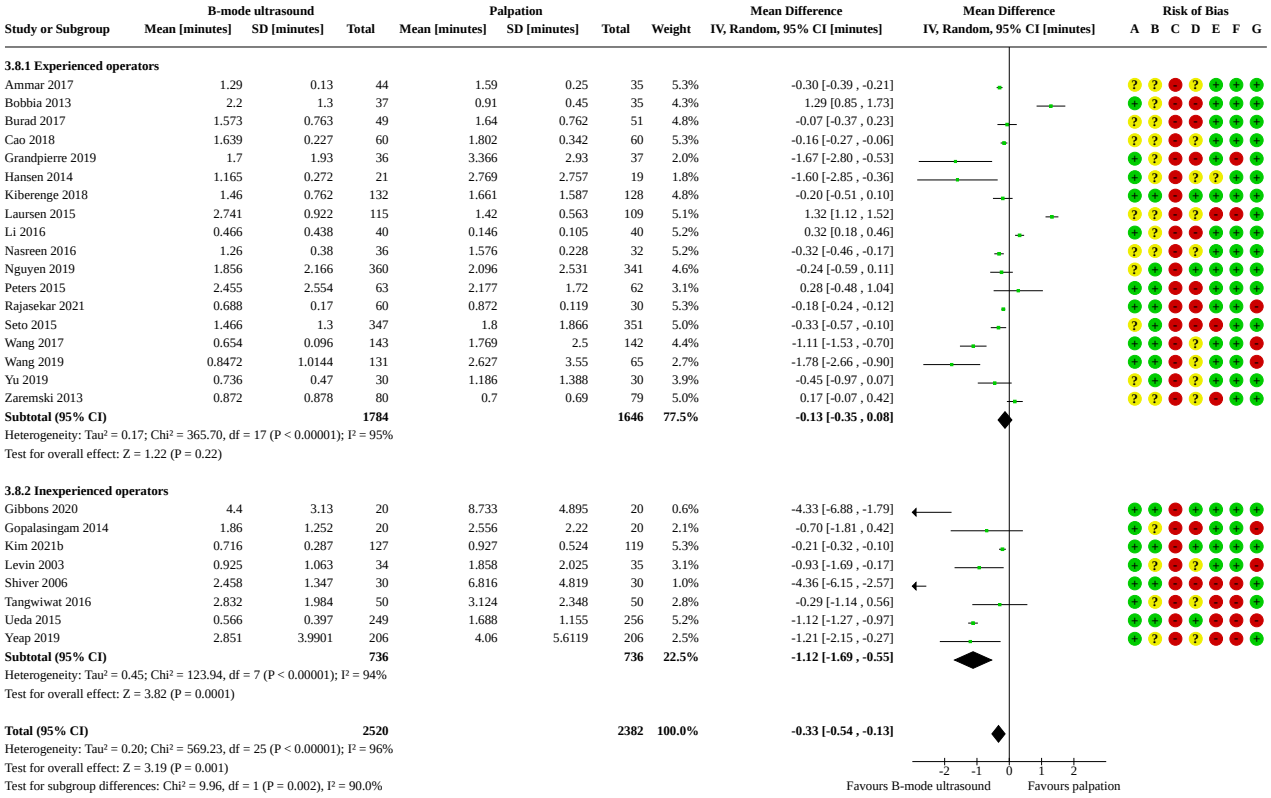
Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
3.7.1 Experienced operators						
Ammar 2017	46	50	42	50	3.5%	1.10 [0.95 , 1.27]
Bobbia 2013	37	37	35	35	5.1%	1.00 [0.95 , 1.05]
Burad 2017	49	49	33	51	2.6%	1.54 [1.25 , 1.88]
Cao 2018	59	60	57	60	4.9%	1.04 [0.97 , 1.11]
Grandpierre 2019	36	36	37	37	5.1%	1.00 [0.95 , 1.05]
Kiberenge 2018	26	29	20	30	1.8%	1.34 [1.01 , 1.78]
Li 2016	39	40	33	40	3.4%	1.18 [1.02 , 1.37]
Nasreen 2016	50	50	50	50	5.2%	1.00 [0.96 , 1.04]
Nguyen 2019	335	360	299	341	5.1%	1.06 [1.01 , 1.11]
Peters 2015	55	63	49	62	3.3%	1.10 [0.94 , 1.30]
Rajasekar 2021	60	60	30	30	5.1%	1.00 [0.95 , 1.05]
Seto 2015	344	347	336	351	5.3%	1.04 [1.01 , 1.06]
Seyhan 2021	25	25	19	25	2.3%	1.31 [1.04 , 1.64]
Wang 2017	140	143	120	142	4.7%	1.16 [1.08 , 1.25]
Wang 2019	113	131	33	65	2.1%	1.70 [1.32 , 2.18]
Yu 2019	30	30	28	30	4.1%	1.07 [0.96 , 1.20]
Zaremski 2013	86	92	91	91	5.0%	0.94 [0.88 , 0.99]
Subtotal (95% CI)		**1602**		**1490**	**68.6%**	**1.08 [1.03 , 1.14]**
Total events:	1530		1312			
Heterogeneity: Tau² = 0.01; Chi² = 134.64, df = 16 (P < 0.00001); I² = 88%						
Test for overall effect: Z = 3.16 (P = 0.002)						
3.7.2 Inexperienced operators						
Gibbons 2020	20	20	3	20	0.2%	5.86 [2.25 , 15.28]
Goswami 2020	39	40	38	40	4.5%	1.03 [0.94 , 1.12]
Kiberenge 2018	92	103	63	98	3.2%	1.39 [1.18 , 1.63]
Kim 2021b	127	128	119	128	5.1%	1.07 [1.02 , 1.12]
Levin 2003	30	34	34	35	3.7%	0.91 [0.79 , 1.04]
Rose 2018	29	30	14	30	1.1%	2.07 [1.40 , 3.05]
Shiver 2006	30	30	19	30	1.9%	1.56 [1.19 , 2.06]
Tangwiwat 2016	39	50	41	50	2.7%	0.95 [0.78 , 1.16]
Ueda 2015	170	249	160	256	3.8%	1.09 [0.96 , 1.24]
Yeap 2019	198	206	185	206	5.1%	1.07 [1.01 , 1.13]
Subtotal (95% CI)		**890**		**893**	**31.4%**	**1.15 [1.04 , 1.28]**
Total events:	774		676			
Heterogeneity: Tau² = 0.02; Chi² = 66.71, df = 9 (P < 0.00001); I² = 87%						
Test for overall effect: Z = 2.64 (P = 0.008)						
Total (95% CI)		**2492**		**2383**	**100.0%**	**1.10 [1.05 , 1.15]**
Total events:	2304		1988			
Heterogeneity: Tau² = 0.01; Chi² = 229.66, df = 26 (P < 0.00001); I² = 89%						
Test for overall effect: Z = 4.11 (P < 0.0001)						
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

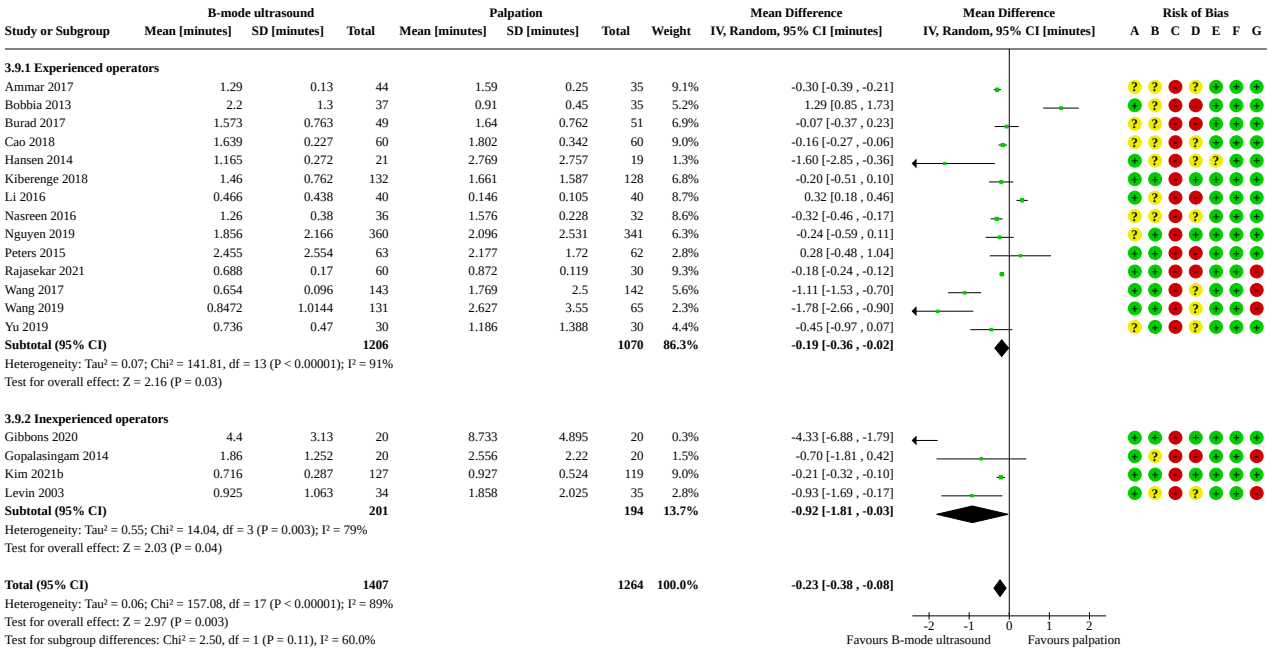
Analysis 3.8. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 8: Time needed for a successful procedure



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 3.9. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 9: Time needed for successful procedure - trials at low risk of bias

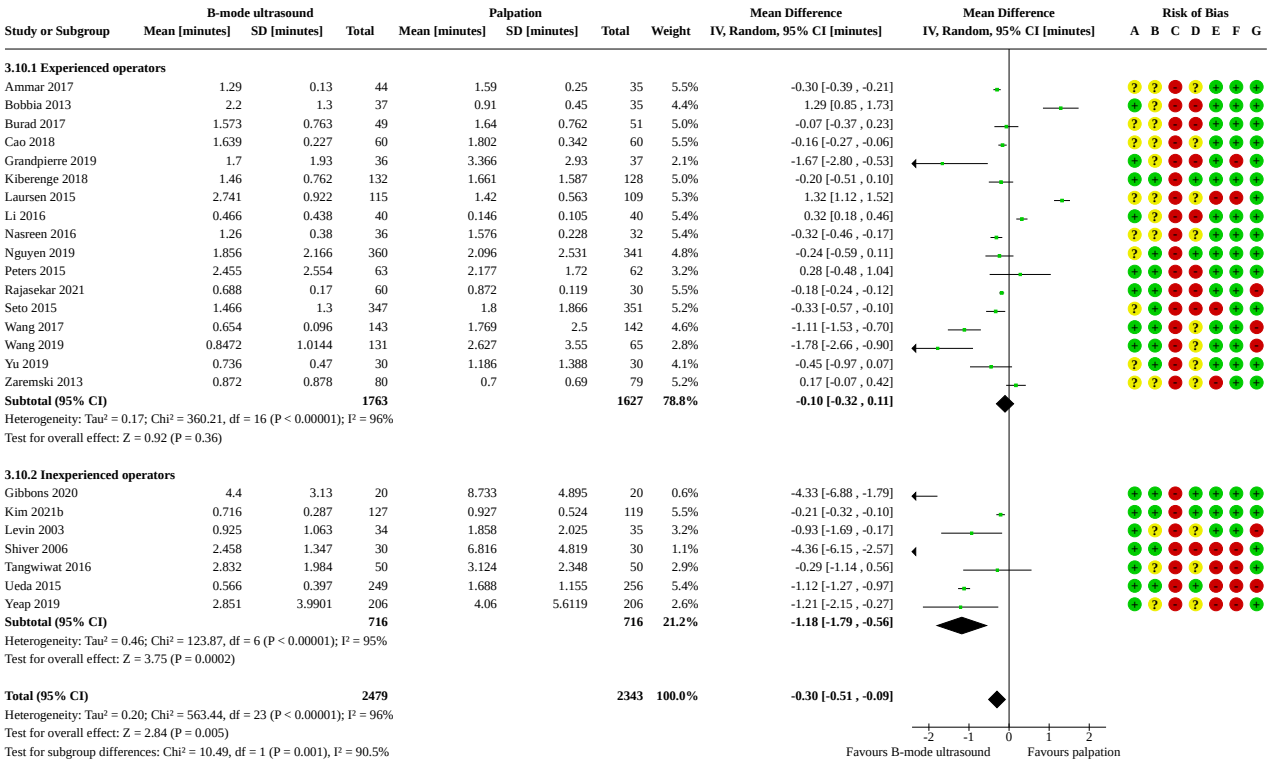


Study or Subgroup	B-mode ultrasound Mean [minutes]	SD [minutes]	Total	Palpation Mean [minutes]	SD [minutes]	Total	Weight	Mean Difference IV, Random, 95% CI [minutes]	Risk of Bias A B C D E F G
3.9.1 Experienced operators									
Ammar 2017	1.29	0.13	44	1.59	0.25	35	9.1%	-0.30 [-0.39 , -0.21]	? ? - ? + + +
Bobbia 2013	2.2	1.3	37	0.91	0.45	35	5.2%	1.29 [0.85 , 1.73]	+ ? - - + + +
Burad 2017	1.573	0.763	49	1.64	0.762	51	6.9%	-0.07 [-0.37 , 0.23]	? ? - - + + +
Cao 2018	1.639	0.227	60	1.802	0.342	60	9.0%	-0.16 [-0.27 , -0.06]	? ? - ? + + +
Hansen 2014	1.165	0.272	21	2.769	2.757	19	1.3%	-1.60 [-2.85 , -0.36]	+ ? - ? ? + +
Kiberenge 2018	1.46	0.762	132	1.661	1.587	128	6.8%	-0.20 [-0.51 , 0.10]	+ + - + + + +
Li 2016	0.466	0.438	40	0.146	0.105	40	8.7%	0.32 [0.18 , 0.46]	+ ? - - + + +
Nasreen 2016	1.26	0.38	36	1.576	0.228	32	8.6%	-0.32 [-0.46 , -0.17]	? ? - ? + + +
Nguyen 2019	1.856	2.166	360	2.096	2.531	341	6.3%	-0.24 [-0.59 , 0.11]	? + - + + + +
Peters 2015	2.455	2.554	63	2.177	1.72	62	2.8%	0.28 [-0.48 , 1.04]	+ + - - + + +
Rajasekar 2021	0.688	0.17	60	0.872	0.119	30	9.3%	-0.18 [-0.24 , -0.12]	+ + - - + + -
Wang 2017	0.654	0.096	143	1.769	2.5	142	5.6%	-1.11 [-1.53 , -0.70]	+ + - ? + + -
Wang 2019	0.8472	1.0144	131	2.627	3.55	65	2.3%	-1.78 [-2.66 , -0.90]	+ + - ? + + -
Yu 2019	0.736	0.47	30	1.186	1.388	30	4.4%	-0.45 [-0.97 , 0.07]	? + - ? + + +
Subtotal (95% CI)			**1206**			**1070**	**86.3%**	**-0.19 [-0.36 , -0.02]**	
Heterogeneity: Tau² = 0.07; Chi² = 141.81, df = 13 (P < 0.00001); I² = 91%									
Test for overall effect: Z = 2.16 (P = 0.03)									
3.9.2 Inexperienced operators									
Gibbons 2020	4.4	3.13	20	8.733	4.895	20	0.3%	-4.33 [-6.88 , -1.79]	+ + - + + + +
Gopalasingam 2014	1.86	1.252	20	2.556	2.22	20	1.5%	-0.70 [-1.81 , 0.42]	+ ? - - + + -
Kim 2021b	0.716	0.287	127	0.927	0.524	119	9.0%	-0.21 [-0.32 , -0.10]	+ + - + + + +
Levin 2003	0.925	1.063	34	1.858	2.025	35	2.8%	-0.93 [-1.69 , -0.17]	+ ? - ? + + -
Subtotal (95% CI)			**201**			**194**	**13.7%**	**-0.92 [-1.81 , -0.03]**	
Heterogeneity: Tau² = 0.55; Chi² = 14.04, df = 3 (P = 0.003); I² = 79%									
Test for overall effect: Z = 2.03 (P = 0.04)									
Total (95% CI)			**1407**			**1264**	**100.0%**	**-0.23 [-0.38 , -0.08]**	
Heterogeneity: Tau² = 0.06; Chi² = 157.08, df = 17 (P < 0.00001); I² = 89%									
Test for overall effect: Z = 2.97 (P = 0.003)									
Test for subgroup differences: Chi² = 2.50, df = 1 (P = 0.11), I² = 60.0%									

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

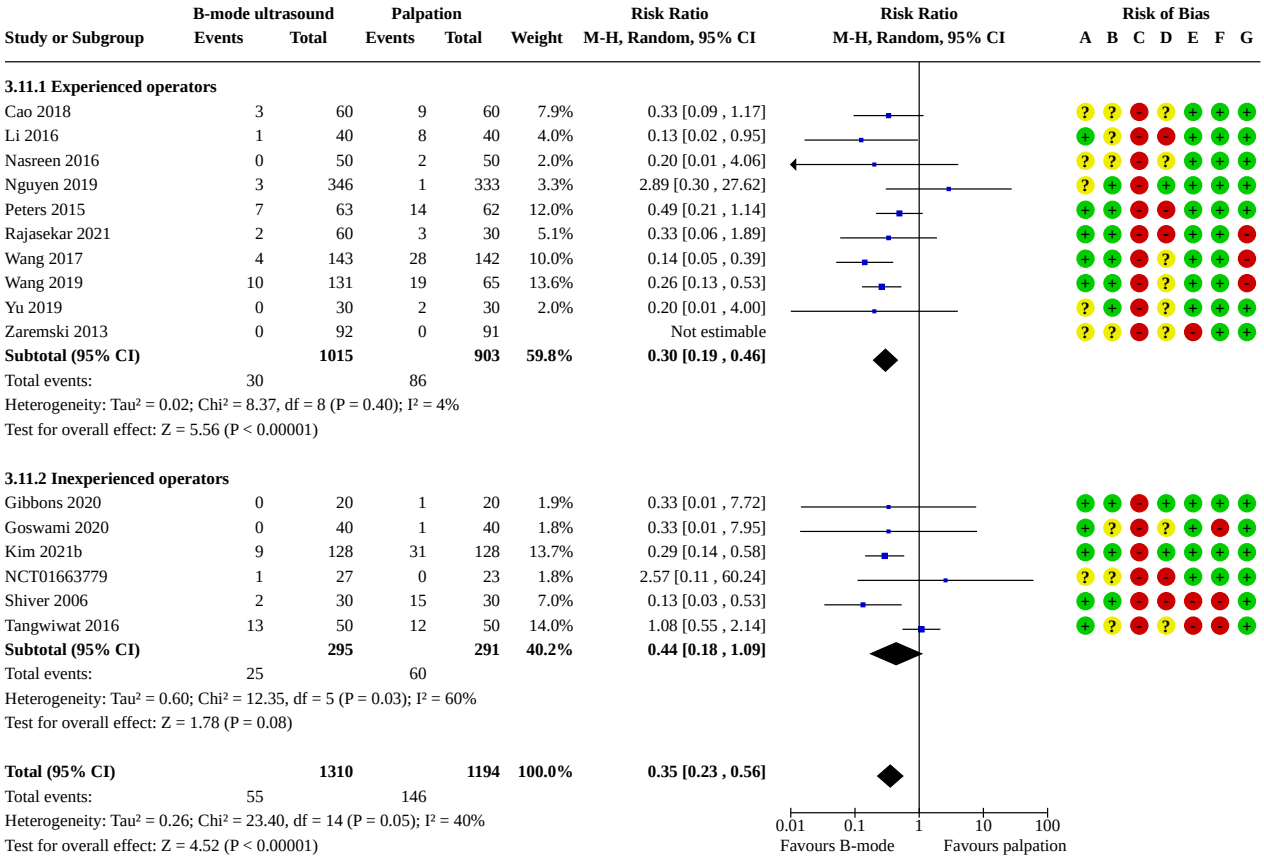
Analysis 3.10. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 10: Time needed for a successful procedure - trials with individual parallel design



Study or Subgroup	B-mode ultrasound Mean [minutes]	SD [minutes]	Total	Palpation Mean [minutes]	SD [minutes]	Total	Weight	Mean Difference IV, Random, 95% CI [minutes]
3.10.1 Experienced operators								
Ammar 2017	1.29	0.13	44	1.59	0.25	35	5.5%	-0.30 [-0.39 , -0.21]
Bobbia 2013	2.2	1.3	37	0.91	0.45	35	4.4%	1.29 [0.85 , 1.73]
Burad 2017	1.573	0.763	49	1.64	0.762	51	5.0%	-0.07 [-0.37 , 0.23]
Cao 2018	1.639	0.227	60	1.802	0.342	60	5.5%	-0.16 [-0.27 , -0.06]
Grandpierre 2019	1.7	1.93	36	3.366	2.93	37	2.1%	-1.67 [-2.80 , -0.53]
Kiberenge 2018	1.46	0.762	132	1.661	1.587	128	5.0%	-0.20 [-0.51 , 0.10]
Laursen 2015	2.741	0.922	115	1.42	0.563	109	5.3%	1.32 [1.12 , 1.52]
Li 2016	0.466	0.438	40	0.146	0.105	40	5.4%	0.32 [0.18 , 0.46]
Nasreen 2016	1.26	0.38	36	1.576	0.228	32	5.4%	-0.32 [-0.46 , -0.17]
Nguyen 2019	1.856	2.166	360	2.096	2.531	341	4.8%	-0.24 [-0.59 , 0.11]
Peters 2015	2.455	2.554	63	2.177	1.72	62	3.2%	0.28 [-0.48 , 1.04]
Rajasekar 2021	0.688	0.17	60	0.872	0.119	30	5.5%	-0.18 [-0.24 , -0.12]
Seto 2015	1.466	1.3	347	1.8	1.866	351	5.2%	-0.33 [-0.57 , -0.10]
Wang 2017	0.654	0.096	143	1.769	2.5	142	4.6%	-1.11 [-1.53 , -0.70]
Wang 2019	0.8472	1.0144	131	2.627	3.55	65	2.8%	-1.78 [-2.66 , -0.90]
Yu 2019	0.736	0.47	30	1.186	1.388	30	4.1%	-0.45 [-0.97 , 0.07]
Zaremski 2013	0.872	0.878	80	0.7	0.69	79	5.2%	0.17 [-0.07 , 0.42]
Subtotal (95% CI)			**1763**			**1627**	**78.8%**	**-0.10 [-0.32 , 0.11]**
Heterogeneity: Tau² = 0.17; Chi² = 360.21, df = 16 (P < 0.00001); I² = 96%								
Test for overall effect: Z = 0.92 (P = 0.36)								
3.10.2 Inexperienced operators								
Gibbons 2020	4.4	3.13	20	8.733	4.895	20	0.6%	-4.33 [-6.88 , -1.79]
Kim 2021b	0.716	0.287	127	0.927	0.524	119	5.5%	-0.21 [-0.32 , -0.10]
Levin 2003	0.925	1.063	34	1.858	2.025	35	3.2%	-0.93 [-1.69 , -0.17]
Shiver 2006	2.458	1.347	30	6.816	4.819	30	1.1%	-4.36 [-6.15 , -2.57]
Tangwiwat 2016	2.832	1.984	50	3.124	2.348	50	2.9%	-0.29 [-1.14 , 0.56]
Ueda 2015	0.566	0.397	249	1.688	1.155	256	5.4%	-1.12 [-1.27 , -0.97]
Yeap 2019	2.851	3.9901	206	4.06	5.6119	206	2.6%	-1.21 [-2.15 , -0.27]
Subtotal (95% CI)			**716**			**716**	**21.2%**	**-1.18 [-1.79 , -0.56]**
Heterogeneity: Tau² = 0.46; Chi² = 123.87, df = 6 (P < 0.00001); I² = 95%								
Test for overall effect: Z = 3.75 (P = 0.0002)								
Total (95% CI)			**2479**			**2343**	**100.0%**	**-0.30 [-0.51 , -0.09]**
Heterogeneity: Tau² = 0.20; Chi² = 563.44, df = 23 (P < 0.00001); I² = 96%								
Test for overall effect: Z = 2.84 (P = 0.005)								
Test for subgroup differences: Chi² = 10.49, df = 1 (P = 0.001), I² = 90.5%								

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

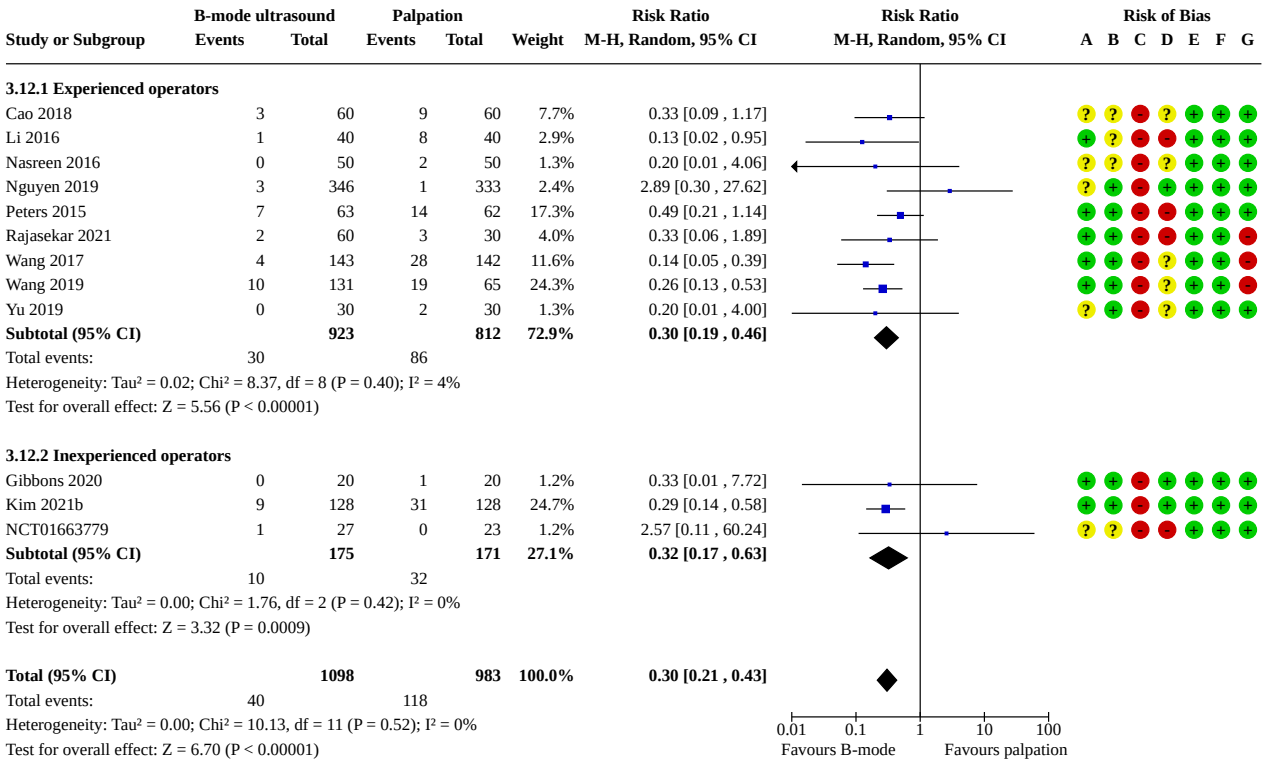
Analysis 3.11. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 11: Major haematoma



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

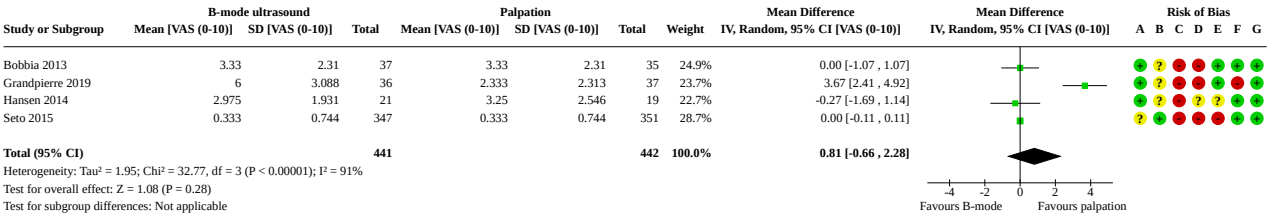
Analysis 3.12. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 12: Major haematoma - trials at low risk of bias



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 3.13. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 13: Adverse events (pain)



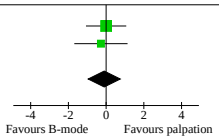
Risk of bias legend

(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 3.14. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 14: Adverse events (pain) - trials at low risk of bias

Study or Subgroup	B-mode ultrasound Mean [VAS (0-10)]	B-mode ultrasound SD [VAS (0-10)]	B-mode ultrasound Total	Palpation Mean [VAS (0-10)]	Palpation SD [VAS (0-10)]	Palpation Total	Weight	Mean Difference IV, Random, 95% CI [VAS (0-10)]
Bobbia 2013	3.33	2.31	37	3.33	2.31	35	63.6%	0.00 [-1.07 , 1.07]
Hansen 2014	2.975	1.931	21	3.25	2.546	19	36.4%	-0.27 [-1.69 , 1.14]
Total (95% CI)			**58**			**54**	**100.0%**	**-0.10 [-0.95 , 0.75]**

Heterogeneity: Tau² = 0.00; Chi² = 0.09, df = 1 (P = 0.76); I² = 0%
Test for overall effect: Z = 0.23 (P = 0.82)
Test for subgroup differences: Not applicable

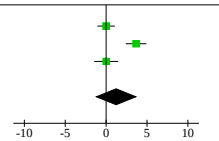


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 3.15. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 15: Adverse events (pain) - trials with individual parallel design

Study or Subgroup	B-mode ultrasound Mean [VAS (0-10)]	B-mode ultrasound SD [VAS (0-10)]	B-mode ultrasound Total	Palpation Mean [VAS (0-10)]	Palpation SD [VAS (0-10)]	Palpation Total	Weight	Mean Difference IV, Random, 95% CI [VAS (0-10)]
Bobbia 2013	3.33	2.31	37	3.33	2.31	35	34.2%	0.00 [-1.07 , 1.07]
Grandpierre 2019	6	3.088	36	2.333	2.313	37	33.4%	3.67 [2.41 , 4.92]
Seto 2015	0.333	0.744	1	0.333	0.744	351	32.4%	0.00 [-1.46 , 1.46]
Total (95% CI)			**74**			**423**	**100.0%**	**1.22 [-1.19 , 3.64]**

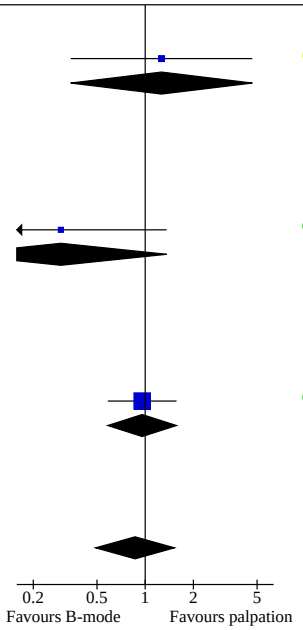
Heterogeneity: Tau² = 4.13; Chi² = 22.31, df = 2 (P < 0.0001); I² = 91%
Test for overall effect: Z = 0.99 (P = 0.32)
Test for subgroup differences: Not applicable



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 3.16. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 16: Adverse events (bleeding, haematoma, ischaemia, or spasm)

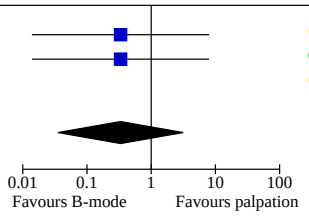
Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
3.16.1 Bleeding or haematoma							
Seto 2015	5	347	4	351	16.8%	1.26 [0.34 , 4.67]	? + - - - + +
Subtotal (95% CI)		**347**		**351**	**16.8%**	**1.26 [0.34 , 4.67]**	
Total events:	5		4				
Heterogeneity: Not applicable							
Test for overall effect: Z = 0.35 (P = 0.72)							
3.16.2 Bleeding, haematoma, or spasm							
Khan 2018	2	49	7	51	12.7%	0.30 [0.06 , 1.36]	+ - - - ? - +
Subtotal (95% CI)		**49**		**51**	**12.7%**	**0.30 [0.06 , 1.36]**	
Total events:	2		7				
Heterogeneity: Not applicable							
Test for overall effect: Z = 1.56 (P = 0.12)							
3.16.3 Haematoma or ischaemia							
Ueda 2015	27	249	29	256	70.5%	0.96 [0.58 , 1.57]	+ + - + - - -
Subtotal (95% CI)		**249**		**256**	**70.5%**	**0.96 [0.58 , 1.57]**	
Total events:	27		29				
Heterogeneity: Not applicable							
Test for overall effect: Z = 0.17 (P = 0.86)							
Total (95% CI)		**645**		**658**	**100.0%**	**0.86 [0.49 , 1.52]**	
Total events:	34		40				
Heterogeneity: Tau² = 0.06; Chi² = 2.37, df = 2 (P = 0.31); I² = 15%							
Test for overall effect: Z = 0.50 (P = 0.61)							
Test for subgroup differences: Chi² = 2.35, df = 2 (P = 0.31), I² = 15.0%							



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 3.17. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 17: Adverse events (local infection)

Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Cao 2018	0	60	1	60	49.8%	0.33 [0.01 , 8.02]	? ? - ? + + +
Goswami 2020	0	40	1	40	50.2%	0.33 [0.01 , 7.95]	+ ? - ? + - +
Yu 2019	0	30	0	30		Not estimable	? + - ? + + +
Total (95% CI)		**130**		**130**	**100.0%**	**0.33 [0.04 , 3.15]**	
Total events:	0		2				
Heterogeneity: Tau² = 0.00; Chi² = 0.00, df = 1 (P = 1.00); I² = 0%							
Test for overall effect: Z = 0.96 (P = 0.34)							
Test for subgroup differences: Not applicable							

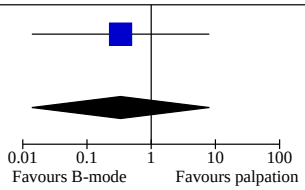


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 3.18. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 18: Adverse events (local infection) - trials at low risk of bias

Study or Subgroup	B-mode ultrasound Events	B-mode ultrasound Total	Palpation Events	Palpation Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk of Bias A	B	C	D	E	F	G
Cao 2018	0	60	1	60	100.0%	0.33 [0.01 , 8.02]	?	?	-	?	+	+	+
Yu 2019	0	30	0	30		Not estimable	?	+	-	?	+	+	+
Total (95% CI)		**90**		**90**	**100.0%**	**0.33 [0.01 , 8.02]**							
Total events:	0		1										

Heterogeneity: Not applicable
Test for overall effect: Z = 0.68 (P = 0.50)
Test for subgroup differences: Not applicable

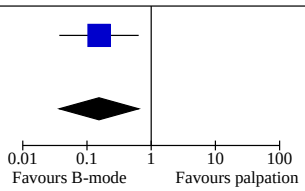


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 3.19. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 19: Adverse events (oedema)

Study or Subgroup	B-mode ultrasound Events	B-mode ultrasound Total	Palpation Events	Palpation Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk of Bias A	B	C	D	E	F	G
Li 2016	2	40	13	40	100.0%	0.15 [0.04 , 0.64]	+	?	-	-	+	+	+
Wang 2017	0	143	0	142		Not estimable	+	+	-	?	+	+	-
Total (95% CI)		**183**		**182**	**100.0%**	**0.15 [0.04 , 0.64]**							
Total events:	2		13										

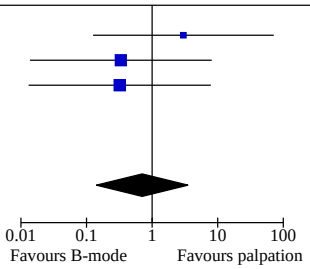
Heterogeneity: Not applicable
Test for overall effect: Z = 2.58 (P = 0.010)
Test for subgroup differences: Not applicable

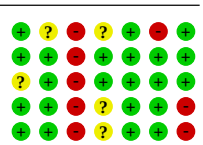


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 3.20. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 20: Adverse events (arterial thrombosis)

Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Goswami 2020	1	40	0	40	14.2%	3.00 [0.13 , 71.51]
Kim 2021b	0	128	1	128	42.5%	0.33 [0.01 , 8.11]
Nguyen 2019	0	346	1	333	43.3%	0.32 [0.01 , 7.85]
Wang 2017	0	143	0	142		Not estimable
Wang 2019	0	131	0	65		Not estimable
Total (95% CI)		**788**		**708**	**100.0%**	**0.71 [0.14 , 3.54]**
Total events:	1		2			



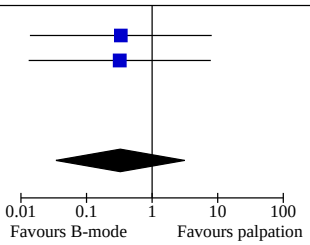


Heterogeneity: Chi² = 1.25, df = 2 (P = 0.54); I² = 0%
Test for overall effect: Z = 0.42 (P = 0.67)
Test for subgroup differences: Not applicable

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 3.21. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 21: Adverse events (arterial thrombosis) - trials at low risk of bias

Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Kim 2021b	0	128	1	128	49.5%	0.33 [0.01 , 8.11]
Nguyen 2019	0	346	1	333	50.5%	0.32 [0.01 , 7.85]
Wang 2017	0	143	0	142		Not estimable
Wang 2019	0	131	0	65		Not estimable
Total (95% CI)		**748**		**668**	**100.0%**	**0.33 [0.03 , 3.13]**
Total events:	0		2			



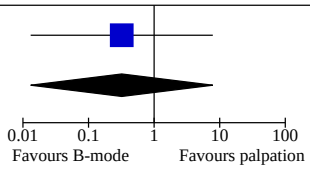
Heterogeneity: Chi² = 0.00, df = 1 (P = 0.99); I² = 0%
Test for overall effect: Z = 0.97 (P = 0.33)
Test for subgroup differences: Not applicable

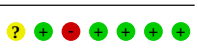
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 3.22. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 22: Adverse events (death)

Study or Subgroup	B-mode ultrasound Events	B-mode ultrasound Total	Palpation Events	Palpation Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Nguyen 2019	0	346	1	333	100.0%	0.32 [0.01 , 7.85]
Total (95% CI)		**346**		**333**	**100.0%**	**0.32 [0.01 , 7.85]**
Total events:	0		1			

Heterogeneity: Not applicable
Test for overall effect: Z = 0.70 (P = 0.49)
Test for subgroup differences: Not applicable



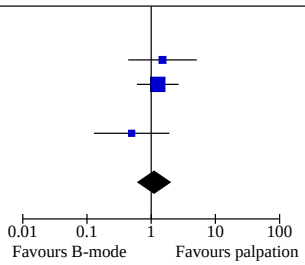


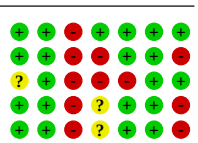
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 3.23. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 23: Adverse events (spasm)

Study or Subgroup	B-mode ultrasound Events	B-mode ultrasound Total	Palpation Events	Palpation Total	Weight	Risk Ratio M-H, Random, 95% CI
Kim 2021b	0	128	0	128		Not estimable
Rajasekar 2021	9	60	3	30	21.9%	1.50 [0.44 , 5.14]
Seto 2015	15	347	12	351	59.9%	1.26 [0.60 , 2.66]
Wang 2017	0	143	0	142		Not estimable
Wang 2019	4	131	4	65	18.1%	0.50 [0.13 , 1.92]
Total (95% CI)		**809**		**716**	**100.0%**	**1.11 [0.62 , 1.97]**
Total events:	28		19			

Heterogeneity: Tau² = 0.00; Chi² = 1.71, df = 2 (P = 0.43); I² = 0%
Test for overall effect: Z = 0.35 (P = 0.73)
Test for subgroup differences: Not applicable



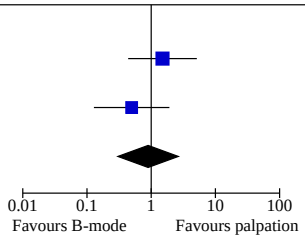


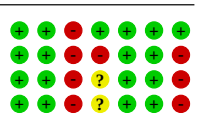
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 3.24. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 24: Adverse events (spasm) - trials at low risk of bias

Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Kim 2021b	0	128	0	128		Not estimable
Rajasekar 2021	9	60	3	30	53.4%	1.50 [0.44 , 5.14]
Wang 2017	0	143	0	142		Not estimable
Wang 2019	4	131	4	65	46.6%	0.50 [0.13 , 1.92]
Total (95% CI)		**462**		**365**	**100.0%**	**0.90 [0.30 , 2.64]**
Total events:	13		7			

Heterogeneity: Tau² = 0.18; Chi² = 1.41, df = 1 (P = 0.24); I² = 29%
Test for overall effect: Z = 0.20 (P = 0.84)
Test for subgroup differences: Not applicable



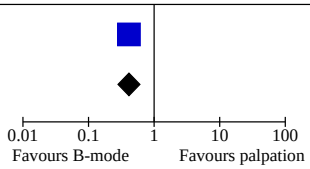


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 3.25. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 25: Adverse events (posterior wall puncture)

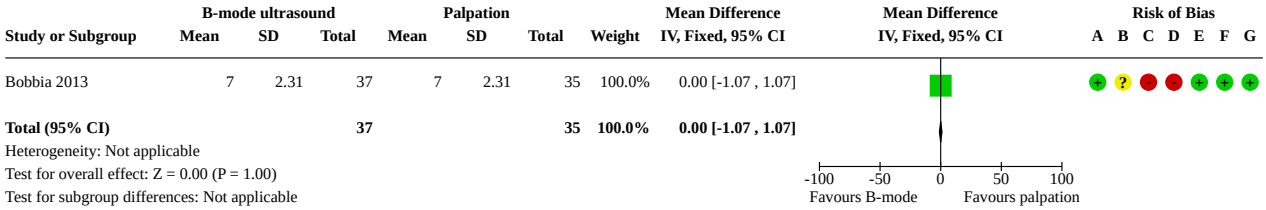
Study or Subgroup	B-mode ultrasound Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Wang 2019	30	131	36	65	100.0%	0.41 [0.28 , 0.61]
Total (95% CI)		**131**		**65**	**100.0%**	**0.41 [0.28 , 0.61]**
Total events:	30		36			

Heterogeneity: Not applicable
Test for overall effect: Z = 4.52 (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 3.26. Comparison 3: [Radial] B-mode ultrasound guidance versus palpation and landmarks, Outcome 26: Quality of life (satisfaction)

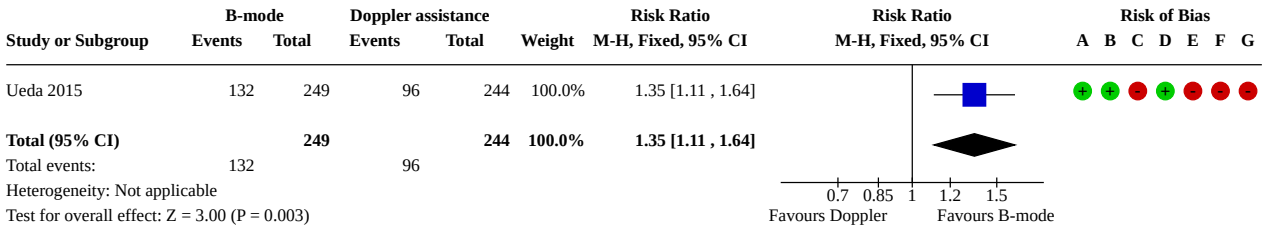


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Comparison 4. [Radial] B-mode ultrasound versus Doppler assistance

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
4.1 First-attempt success rate	1	493	Risk Ratio (M-H, Fixed, 95% CI)	1.35 [1.11, 1.64]
4.2 Overall success rate	1	493	Risk Ratio (M-H, Fixed, 95% CI)	1.13 [0.99, 1.29]
4.3 Time needed for a successful procedure	1	493	Mean Difference (IV, Fixed, 95% CI)	-1.57 [-1.78, -1.36]
4.4 Adverse events (haematoma or ischaemia)	1	493	Risk Ratio (M-H, Fixed, 95% CI)	1.20 [0.70, 2.05]

Analysis 4.1. Comparison 4: [Radial] B-mode ultrasound versus Doppler assistance, Outcome 1: First-attempt success rate

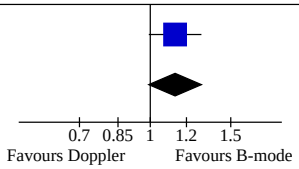


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 4.2. Comparison 4: [Radial] B-mode ultrasound versus Doppler assistance, Outcome 2: Overall success rate

Study or Subgroup	B-mode Events	B-mode Total	Doppler assistance Events	Doppler assistance Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Ueda 2015	170	249	147	244	100.0%	1.13 [0.99 , 1.29]
Total (95% CI)		**249**		**244**	**100.0%**	**1.13 [0.99 , 1.29]**
Total events:	170		147			

Heterogeneity: Not applicable
Test for overall effect: Z = 1.85 (P = 0.06)
Test for subgroup differences: Not applicable

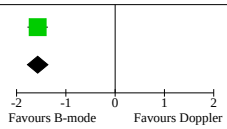


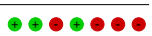
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 4.3. Comparison 4: [Radial] B-mode ultrasound versus Doppler assistance, Outcome 3: Time needed for a successful procedure

Study or Subgroup	B-mode Mean [minutes]	B-mode SD [minutes]	B-mode Total	Doppler assistance Mean [minutes]	Doppler assistance SD [minutes]	Doppler assistance Total	Weight	Mean Difference IV, Fixed, 95% CI [minutes]
Ueda 2015	0.566	0.397	249	2.138	1.603	244	100.0%	-1.57 [-1.78 , -1.36]
Total (95% CI)			**249**			**244**	**100.0%**	**-1.57 [-1.78 , -1.36]**

Heterogeneity: Not applicable
Test for overall effect: Z = 14.88 (P < 0.00001)
Test for subgroup differences: Not applicable



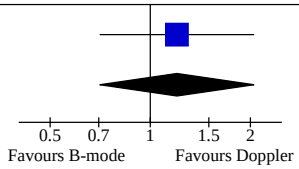


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 4.4. Comparison 4: [Radial] B-mode ultrasound versus Doppler assistance, Outcome 4: Adverse events (haematoma or ischaemia)

Study or Subgroup	B-mode Events	B-mode Total	Doppler assistance Events	Doppler assistance Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Ueda 2015	27	249	22	244	100.0%	1.20 [0.70 , 2.05]
Total (95% CI)		**249**		**244**	**100.0%**	**1.20 [0.70 , 2.05]**
Total events:	27		22			

Heterogeneity: Not applicable
Test for overall effect: Z = 0.68 (P = 0.50)
Test for subgroup differences: Not applicable



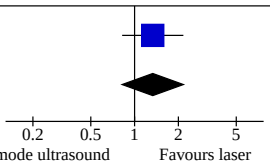
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Comparison 5. [Radial] B-mode ultrasound versus near-infrared laser guidance

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
5.1 First-attempt success rate	1	72	Risk Ratio (M-H, Fixed, 95% CI)	1.33 [0.82, 2.16]
5.2 Overall success rate	1	72	Risk Ratio (M-H, Fixed, 95% CI)	1.50 [0.27, 8.45]
5.3 Time needed for a successful procedure	1	72	Mean Difference (IV, Fixed, 95% CI)	0.20 [0.09, 0.31]

Analysis 5.1. Comparison 5: [Radial] B-mode ultrasound versus near-infrared laser guidance, Outcome 1: First-attempt success rate

Study or Subgroup	B-mode ultrasound Events	Total	Laser Events	Total	Weight	Risk Ratio (Non-event) M-H, Fixed, 95% CI	Risk Ratio (Non-event) M-H, Fixed, 95% CI	Risk of Bias A B C D E F G
Osuda 2020	16	36	21	36	100.0%	1.33 [0.82 , 2.16]		? ? - ? + + +
Total (95% CI)		**36**		**36**	**100.0%**	**1.33 [0.82 , 2.16]**		
Total events:	16		21					

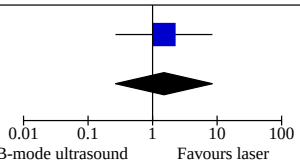


Heterogeneity: Not applicable
Test for overall effect: Z = 1.16 (P = 0.24)
Test for subgroup differences: Not applicable

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 5.2. Comparison 5: [Radial] B-mode ultrasound versus near-infrared laser guidance, Outcome 2: Overall success rate

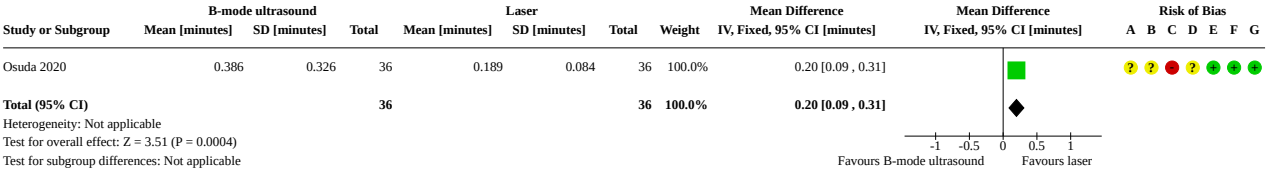
Study or Subgroup	B-mode ultrasound Events	Total	Laser Events	Total	Weight	Risk Ratio (Non-event) M-H, Fixed, 95% CI	Risk Ratio (Non-event) M-H, Fixed, 95% CI	Risk of Bias A B C D E F G
Osuda 2020	33	36	34	36	100.0%	1.50 [0.27 , 8.45]		? ? - ? + + +
Total (95% CI)		**36**		**36**	**100.0%**	**1.50 [0.27 , 8.45]**		
Total events:	33		34					



Heterogeneity: Not applicable
Test for overall effect: Z = 0.46 (P = 0.65)
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 5.3. Comparison 5: [Radial] B-mode ultrasound versus near-infrared laser guidance, Outcome 3: Time needed for a successful procedure

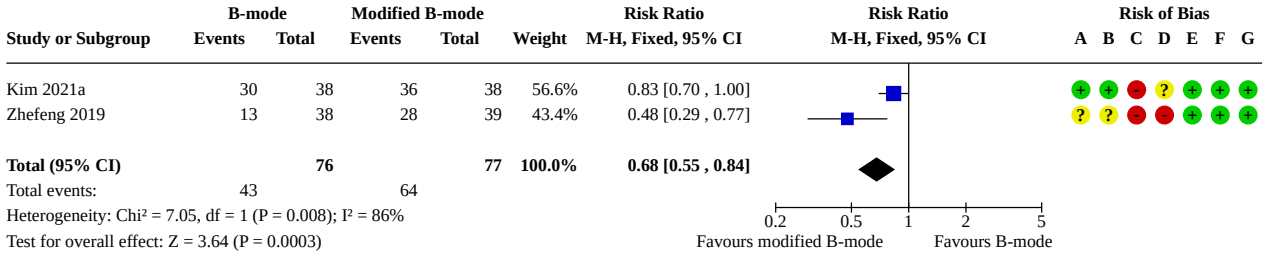


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Comparison 6. [Radial] B-mode ultrasound versus modified B-mode ultrasound

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
6.1 First-attempt success rate	2	153	Risk Ratio (M-H, Fixed, 95% CI)	0.68 [0.55, 0.84]
6.2 Overall success rate	2	153	Risk Ratio (M-H, Fixed, 95% CI)	0.93 [0.86, 1.01]
6.3 Time needed for a successful procedure	2	153	Mean Difference (IV, Fixed, 95% CI)	0.04 [-0.01, 0.09]
6.4 Major haematoma	2	153	Risk Ratio (M-H, Fixed, 95% CI)	3.23 [1.37, 7.60]
6.5 Adverse events (spasm)	1	77	Risk Ratio (M-H, Fixed, 95% CI)	1.39 [0.89, 2.16]
6.6 Adverse events (posterior wall puncture)	1	76	Risk Ratio (M-H, Fixed, 95% CI)	8.00 [1.05, 60.89]

Analysis 6.1. Comparison 6: [Radial] B-mode ultrasound versus modified B-mode ultrasound, Outcome 1: First-attempt success rate

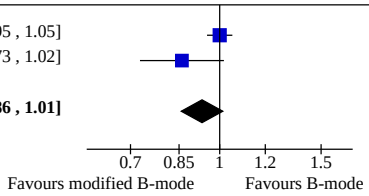


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 6.2. Comparison 6: [Radial] B-mode ultrasound versus modified B-mode ultrasound, Outcome 2: Overall success rate

Study or Subgroup	B-mode Events	B-mode Total	Modified B-mode Events	Modified B-mode Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Kim 2021a	38	38	38	38	51.3%	1.00 [0.95 , 1.05]
Zhefeng 2019	31	38	37	39	48.7%	0.86 [0.73 , 1.02]
Total (95% CI)		**76**		**77**	**100.0%**	**0.93 [0.86 , 1.01]**
Total events:	69		75			

Heterogeneity: Chi² = 8.37, df = 1 (P = 0.004); I² = 88%
Test for overall effect: Z = 1.67 (P = 0.10)
Test for subgroup differences: Not applicable

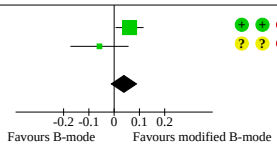


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 6.3. Comparison 6: [Radial] B-mode ultrasound versus modified B-mode ultrasound, Outcome 3: Time needed for a successful procedure

Study or Subgroup	B-mode Mean [minutes]	B-mode SD [minutes]	B-mode Total	Modified B-mode Mean [minutes]	Modified B-mode SD [minutes]	Modified B-mode Total	Weight	Mean Difference IV, Fixed, 95% CI [minutes]
Kim 2021a	0.311	0.141	38	0.25	0.102	38	81.2%	0.06 [0.01 , 0.12]
Zhefeng 2019	0.46	0.21	38	0.518	0.298	39	18.8%	-0.06 [-0.17 , 0.06]
Total (95% CI)			**76**			**77**	**100.0%**	**0.04 [-0.01 , 0.09]**

Heterogeneity: Chi² = 3.34, df = 1 (P = 0.07); I² = 70%
Test for overall effect: Z = 1.52 (P = 0.13)
Test for subgroup differences: Not applicable

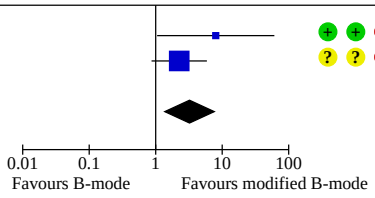


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 6.4. Comparison 6: [Radial] B-mode ultrasound versus modified B-mode ultrasound, Outcome 4: Major haematoma

Study or Subgroup	B-mode Events	B-mode Total	Modified B-mode Events	Modified B-mode Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Kim 2021a	8	38	1	38	16.8%	8.00 [1.05 , 60.89]
Zhefeng 2019	11	38	5	39	83.2%	2.26 [0.87 , 5.89]
Total (95% CI)		**76**		**77**	**100.0%**	**3.23 [1.37 , 7.60]**
Total events:	19		6			

Heterogeneity: Chi² = 1.30, df = 1 (P = 0.25); I² = 23%
Test for overall effect: Z = 2.68 (P = 0.007)
Test for subgroup differences: Not applicable

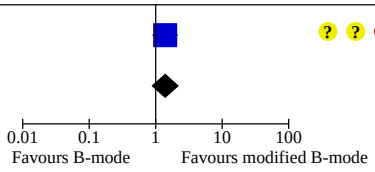


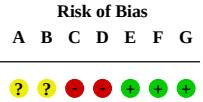
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 6.5. Comparison 6: [Radial] B-mode ultrasound versus modified B-mode ultrasound, Outcome 5: Adverse events (spasm)

Study or Subgroup	B-mode Events	B-mode Total	Modified B-mode Events	Modified B-mode Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Zhefeng 2019	23	38	17	39	100.0%	1.39 [0.89 , 2.16]
Total (95% CI)		**38**		**39**	**100.0%**	**1.39 [0.89 , 2.16]**
Total events:	23		17			

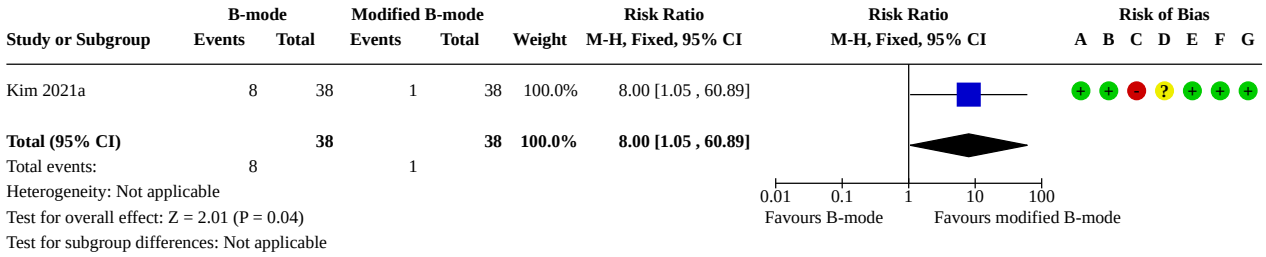
Heterogeneity: Not applicable
Test for overall effect: Z = 1.46 (P = 0.14)
Test for subgroup differences: Not applicable





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 6.6. Comparison 6: [Radial] B-mode ultrasound versus modified B-mode ultrasound, Outcome 6: Adverse events (posterior wall puncture)



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

Comparison 7. [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound

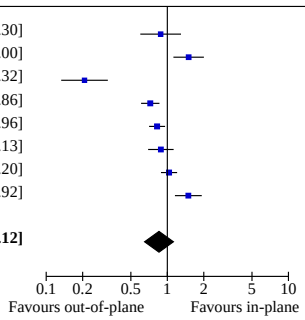
Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
7.1 First-attempt success rate	8	1051	Risk Ratio (M-H, Random, 95% CI)	0.85 [0.65, 1.12]
7.2 First-attempt success rate - trials at low risk of bias	5	616	Risk Ratio (M-H, Random, 95% CI)	0.92 [0.73, 1.17]
7.3 Overall success rate	8	1051	Risk Ratio (M-H, Random, 95% CI)	1.00 [0.96, 1.05]
7.4 Overall success rate - trials at low risk of bias	5	616	Risk Ratio (M-H, Random, 95% CI)	1.05 [0.95, 1.16]
7.5 Time needed for a successful procedure	9	1134	Mean Difference (IV, Random, 95% CI)	-0.06 [-0.16, 0.05]
7.6 Time needed for a successful procedure - trials at low risk of bias	6	699	Mean Difference (IV, Random, 95% CI)	-0.05 [-0.23, 0.12]
7.7 Major haematoma	9	1159	Risk Ratio (M-H, Random, 95% CI)	0.49 [0.22, 1.08]
7.8 Major haematoma - trials at low risk of bias	6	724	Risk Ratio (M-H, Random, 95% CI)	0.59 [0.23, 1.54]
7.9 Adverse events (thrombosis)	5	688	Risk Ratio (M-H, Random, 95% CI)	3.18 [0.13, 76.69]
7.10 Adverse events (thrombosis) - trials at low risk of bias	4	538	Risk Ratio (M-H, Random, 95% CI)	3.18 [0.13, 76.69]
7.11 Adverse events (oedema)	3	421	Risk Ratio (M-H, Random, 95% CI)	0.07 [0.00, 1.14]

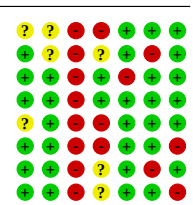
Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
7.12 Adverse events (oedema) - trials at low risk of bias	2	271	Risk Ratio (M-H, Random, 95% CI)	0.07 [0.00, 1.14]
7.13 Adverse events (vasospasm)	6	748	Risk Ratio (M-H, Random, 95% CI)	0.80 [0.24, 2.69]
7.14 Adverse events (vasospasm) - trials at low risk of bias	5	598	Risk Ratio (M-H, Random, 95% CI)	0.95 [0.25, 3.54]
7.15 Adverse events (posterior wall damage)	3	375	Risk Ratio (M-H, Random, 95% CI)	0.45 [0.10, 1.97]
7.16 Adverse events (ischaemia)	2	327	Risk Ratio (M-H, Fixed, 95% CI)	0.27 [0.05, 1.42]

Analysis 7.1. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 1: First-attempt success rate

Study or Subgroup	In-plane B-mode US Events	In-plane B-mode US Total	Out-of-plane B-mode US Events	Out-of-plane B-mode US Total	Weight	Risk Ratio M-H, Random, 95% CI
Abdalla 2017	37	84	21	42	11.1%	0.88 [0.60 , 1.30]
Arora 2021	36	42	24	42	12.3%	1.50 [1.12 , 2.00]
Cao 2020	19	131	49	70	10.4%	0.21 [0.13 , 0.32]
Nam 2020	45	66	66	70	13.5%	0.72 [0.61 , 0.86]
Quan 2014	60	82	72	81	13.6%	0.82 [0.71 , 0.96]
Rajasekar 2021	23	30	26	30	12.8%	0.88 [0.69 , 1.13]
Sethi 2017	62	75	60	75	13.6%	1.03 [0.89 , 1.20]
Wang 2019	53	66	35	65	12.7%	1.49 [1.16 , 1.92]
Total (95% CI)		**576**		**475**	**100.0%**	**0.85 [0.65 , 1.12]**
Total events:	335		353			

Heterogeneity: Tau² = 0.14; Chi² = 82.32, df = 7 (P < 0.00001); I² = 91%
Test for overall effect: Z = 1.13 (P = 0.26)
Test for subgroup differences: Not applicable



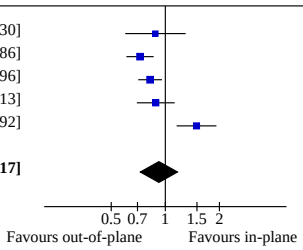


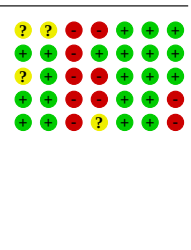
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.2. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 2: First-attempt success rate - trials at low risk of bias

Study or Subgroup	In-plane B-mode US Events	Total	Out-of-plane B-mode US Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Abdalla 2017	37	84	21	42	15.2%	0.88 [0.60 , 1.30]
Nam 2020	45	66	66	70	22.3%	0.72 [0.61 , 0.86]
Quan 2014	60	82	72	81	22.9%	0.82 [0.71 , 0.96]
Rajasekar 2021	23	30	26	30	20.0%	0.88 [0.69 , 1.13]
Wang 2019	53	66	35	65	19.6%	1.49 [1.16 , 1.92]
Total (95% CI)		**328**		**288**	**100.0%**	**0.92 [0.73 , 1.17]**
Total events:	218		220			

Heterogeneity: Tau² = 0.06; Chi² = 22.99, df = 4 (P = 0.0001); I² = 83%
Test for overall effect: Z = 0.68 (P = 0.50)
Test for subgroup differences: Not applicable



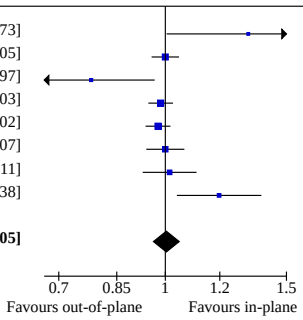


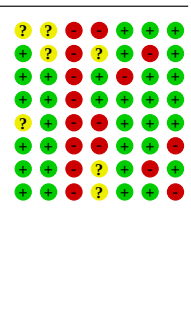
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.3. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 3: Overall success rate

Study or Subgroup	In-plane B-mode US Events	Total	Out-of-plane B-mode US Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Abdalla 2017	66	84	25	42	2.3%	1.32 [1.00 , 1.73]
Arora 2021	42	42	42	42	19.3%	1.00 [0.96 , 1.05]
Cao 2020	73	131	50	70	3.5%	0.78 [0.63 , 0.97]
Nam 2020	65	66	70	70	20.1%	0.98 [0.94 , 1.03]
Quan 2014	80	82	81	81	20.1%	0.98 [0.94 , 1.02]
Rajasekar 2021	30	30	30	30	16.0%	1.00 [0.94 , 1.07]
Sethi 2017	70	75	69	75	11.9%	1.01 [0.93 , 1.11]
Wang 2019	62	66	51	65	6.8%	1.20 [1.04 , 1.38]
Total (95% CI)		**576**		**475**	**100.0%**	**1.00 [0.96 , 1.05]**
Total events:	488		418			

Heterogeneity: Tau² = 0.00; Chi² = 19.31, df = 7 (P = 0.007); I² = 64%
Test for overall effect: Z = 0.15 (P = 0.88)
Test for subgroup differences: Not applicable



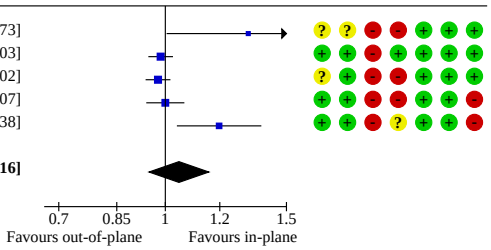


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.4. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 4: Overall success rate - trials at low risk of bias

Study or Subgroup	In-plane B-mode US Events	In-plane B-mode US Total	Out-of-plane B-mode US Events	Out-of-plane B-mode US Total	Weight	Risk Ratio M-H, Random, 95% CI
Abdalla 2017	66	84	25	42	8.9%	1.32 [1.00 , 1.73]
Nam 2020	65	66	70	70	25.1%	0.98 [0.94 , 1.03]
Quan 2014	80	82	81	81	25.1%	0.98 [0.94 , 1.02]
Rajasekar 2021	30	30	30	30	23.7%	1.00 [0.94 , 1.07]
Wang 2019	62	66	51	65	17.2%	1.20 [1.04 , 1.38]
Total (95% CI)		**328**		**288**	**100.0%**	**1.05 [0.95 , 1.16]**
Total events:	303		257			

Heterogeneity: Tau² = 0.01; Chi² = 41.17, df = 4 (P < 0.00001); I² = 90%
Test for overall effect: Z = 0.89 (P = 0.37)
Test for subgroup differences: Not applicable

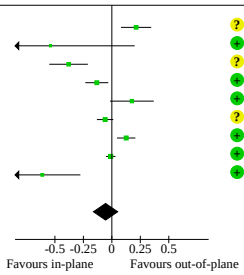


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.5. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 5: Time needed for a successful procedure

Study or Subgroup	In-plane B-mode US Mean [minutes]	In-plane B-mode US SD [minutes]	In-plane B-mode US Total	Out-of-plane B-mode US Mean [minutes]	Out-of-plane B-mode US SD [minutes]	Out-of-plane B-mode US Total	Weight	Mean Difference IV, Random, 95% CI [minutes]
Abdalla 2017	0.683	0.4313	84	0.47	0.3161	42	12.6%	0.21 [0.08 , 0.35]
Arora 2021	1.265	0.8675	42	1.8035	2.2851	42	1.8%	-0.54 [-1.28 , 0.20]
Berk 2013	0.4	0.28	54	0.78	0.57	54	11.2%	-0.38 [-0.55 , -0.21]
Cao 2020	0.2008	0.4008	131	0.333	0.316	70	13.7%	-0.13 [-0.23 , -0.03]
Nam 2020	0.989	0.617	45	0.813	0.277	66	10.3%	0.18 [-0.02 , 0.37]
Quan 2014	0.436	0.163	82	0.495	0.286	81	14.6%	-0.06 [-0.13 , 0.01]
Rajasekar 2021	0.751	0.138	30	0.625	0.179	30	14.3%	0.13 [0.05 , 0.21]
Sethi 2017	0.46	0.126	75	0.47	0.136	75	15.3%	-0.01 [-0.05 , 0.03]
Wang 2019	0.544	0.265	66	1.155	1.352	65	6.1%	-0.61 [-0.95 , -0.28]
Total (95% CI)			**609**			**525**	**100.0%**	**-0.06 [-0.16 , 0.05]**

Heterogeneity: Tau² = 0.02; Chi² = 65.36, df = 8 (P < 0.00001); I² = 88%
Test for overall effect: Z = 1.01 (P = 0.31)
Test for subgroup differences: Not applicable

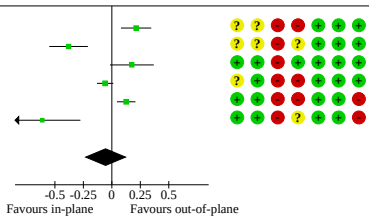


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.6. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 6: Time needed for a successful procedure - trials at low risk of bias

Study or Subgroup	In-plane B-mode US Mean [minutes]	SD [minutes]	Total	Out-of-plane B-mode US Mean [minutes]	SD [minutes]	Total	Weight	Mean Difference IV, Random, 95% CI [minutes]
Abdalla 2017	0.683	0.4313	84	0.47	0.3161	42	17.8%	0.21 [0.08 , 0.35]
Berk 2013	0.4	0.28	54	0.78	0.57	54	16.7%	-0.38 [-0.55 , -0.21]
Nam 2020	0.989	0.617	45	0.813	0.277	66	16.0%	0.18 [-0.02 , 0.37]
Quan 2014	0.436	0.163	82	0.495	0.286	81	19.1%	-0.06 [-0.13 , 0.01]
Rajasekar 2021	0.751	0.138	30	0.625	0.179	30	19.0%	0.13 [0.05 , 0.21]
Wang 2019	0.544	0.265	66	1.155	1.352	65	11.5%	-0.61 [-0.95 , -0.28]
Total (95% CI)			**361**			**338**	**100.0%**	**-0.05 [-0.23 , 0.12]**

Heterogeneity: Tau² = 0.04; Chi² = 56.87, df = 5 (P < 0.00001); I² = 91%
Test for overall effect: Z = 0.62 (P = 0.54)
Test for subgroup differences: Not applicable

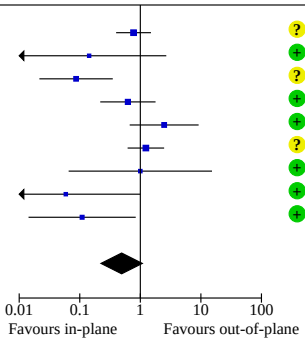


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.7. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 7: Major haematoma

Study or Subgroup	In-plane B-mode US Events	Total	Out-of-plane B-mode US Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Abdalla 2017	17	84	11	42	17.6%	0.77 [0.40 , 1.50]
Arora 2021	0	42	3	42	5.3%	0.14 [0.01 , 2.68]
Berk 2013	2	54	23	54	12.3%	0.09 [0.02 , 0.35]
Cao 2020	7	131	6	70	14.8%	0.62 [0.22 , 1.78]
Nam 2020	7	66	3	70	12.9%	2.47 [0.67 , 9.17]
Quan 2014	15	82	12	81	17.3%	1.23 [0.62 , 2.47]
Rajasekar 2021	1	30	1	30	5.9%	1.00 [0.07 , 15.26]
Sethi 2017	0	75	8	75	5.5%	0.06 [0.00 , 1.00]
Wang 2019	1	66	9	65	8.5%	0.11 [0.01 , 0.84]
Total (95% CI)		**630**		**529**	**100.0%**	**0.49 [0.22 , 1.08]**
Total events:	50		76			

Heterogeneity: Tau² = 0.80; Chi² = 24.55, df = 8 (P = 0.002); I² = 67%
Test for overall effect: Z = 1.77 (P = 0.08)
Test for subgroup differences: Not applicable

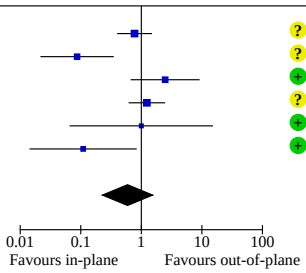


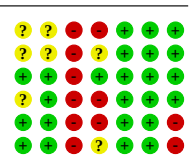
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.8. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 8: Major haematoma - trials at low risk of bias

Study or Subgroup	In-plane B-mode US Events	Total	Out-of-plane B-mode US Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Abdalla 2017	17	84	11	42	23.0%	0.77 [0.40 , 1.50]
Berk 2013	2	54	23	54	16.7%	0.09 [0.02 , 0.35]
Nam 2020	7	66	3	70	17.4%	2.47 [0.67 , 9.17]
Quan 2014	15	82	12	81	22.7%	1.23 [0.62 , 2.47]
Rajasekar 2021	1	30	1	30	8.3%	1.00 [0.07 , 15.26]
Wang 2019	1	66	9	65	11.9%	0.11 [0.01 , 0.84]
Total (95% CI)		**382**		**342**	**100.0%**	**0.59 [0.23 , 1.54]**
Total events:	43		59			

Heterogeneity: Tau² = 0.92; Chi² = 19.45, df = 5 (P = 0.002); I² = 74%
Test for overall effect: Z = 1.07 (P = 0.28)
Test for subgroup differences: Not applicable



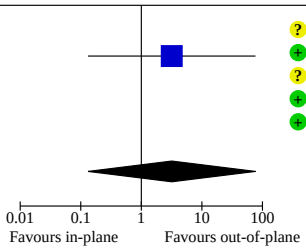


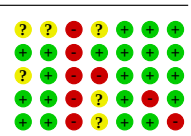
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.9. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 9: Adverse events (thrombosis)

Study or Subgroup	In-plane B-mode US Events	Total	Out-of-plane B-mode US Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Berk 2013	0	54	0	54		Not estimable
Nam 2020	1	66	0	70	100.0%	3.18 [0.13 , 76.69]
Quan 2014	0	82	0	81		Not estimable
Sethi 2017	0	75	0	75		Not estimable
Wang 2019	0	66	0	65		Not estimable
Total (95% CI)		**343**		**345**	**100.0%**	**3.18 [0.13 , 76.69]**
Total events:	1		0			

Heterogeneity: Not applicable
Test for overall effect: Z = 0.71 (P = 0.48)
Test for subgroup differences: Not applicable



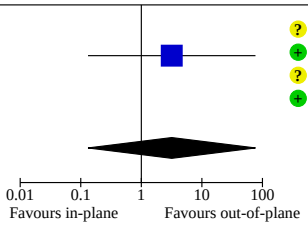


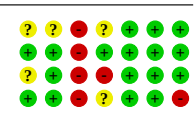
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.10. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 10: Adverse events (thrombosis) - trials at low risk of bias

Study or Subgroup	In-plane B-mode US Events	In-plane B-mode US Total	Out-of-plane B-mode US Events	Out-of-plane B-mode US Total	Weight	Risk Ratio M-H, Random, 95% CI
Berk 2013	0	54	0	54		Not estimable
Nam 2020	1	66	0	70	100.0%	3.18 [0.13 , 76.69]
Quan 2014	0	82	0	81		Not estimable
Wang 2019	0	66	0	65		Not estimable
Total (95% CI)		**268**		**270**	**100.0%**	**3.18 [0.13 , 76.69]**
Total events:	1		0			

Heterogeneity: Not applicable
Test for overall effect: Z = 0.71 (P = 0.48)
Test for subgroup differences: Not applicable



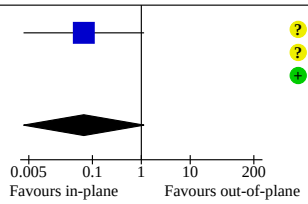


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.11. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 11: Adverse events (oedema)

Study or Subgroup	In-plane B-mode US Events	In-plane B-mode US Total	Out-of-plane B-mode US Events	Out-of-plane B-mode US Total	Weight	Risk Ratio M-H, Random, 95% CI
Berk 2013	0	54	7	54	100.0%	0.07 [0.00 , 1.14]
Quan 2014	0	82	0	81		Not estimable
Sethi 2017	0	75	0	75		Not estimable
Total (95% CI)		**211**		**210**	**100.0%**	**0.07 [0.00 , 1.14]**
Total events:	0		7			

Heterogeneity: Not applicable
Test for overall effect: Z = 1.87 (P = 0.06)
Test for subgroup differences: Not applicable

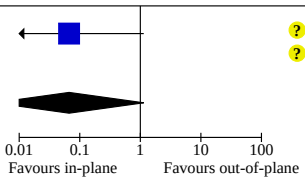


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.12. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 12: Adverse events (oedema) - trials at low risk of bias

Study or Subgroup	In-plane B-mode US Events	In-plane B-mode US Total	Out-of-plane B-mode US Events	Out-of-plane B-mode US Total	Weight	Risk Ratio M-H, Random, 95% CI
Berk 2013	0	54	7	54	100.0%	0.07 [0.00 , 1.14]
Quan 2014	0	82	0	81		Not estimable
Total (95% CI)		**136**		**135**	**100.0%**	**0.07 [0.00 , 1.14]**
Total events:	0		7			

Heterogeneity: Not applicable
Test for overall effect: Z = 1.87 (P = 0.06)
Test for subgroup differences: Not applicable

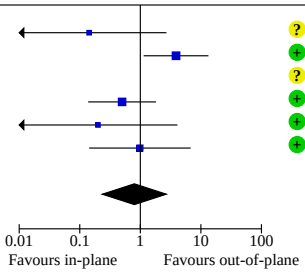


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.13. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 13: Adverse events (vasospasm)

Study or Subgroup	In-plane B-mode US Events	In-plane B-mode US Total	Out-of-plane B-mode US Events	Out-of-plane B-mode US Total	Weight	Risk Ratio M-H, Random, 95% CI
Berk 2013	0	54	3	54	12.0%	0.14 [0.01 , 2.70]
Nam 2020	11	66	3	70	28.6%	3.89 [1.13 , 13.32]
Quan 2014	0	82	0	81		Not estimable
Rajasekar 2021	3	30	6	30	27.8%	0.50 [0.14 , 1.82]
Sethi 2017	0	75	2	75	11.6%	0.20 [0.01 , 4.10]
Wang 2019	2	66	2	65	20.0%	0.98 [0.14 , 6.78]
Total (95% CI)		**373**		**375**	**100.0%**	**0.80 [0.24 , 2.69]**
Total events:	16		16			

Heterogeneity: Tau² = 0.95; Chi² = 8.55, df = 4 (P = 0.07); I² = 53%
Test for overall effect: Z = 0.37 (P = 0.71)
Test for subgroup differences: Not applicable

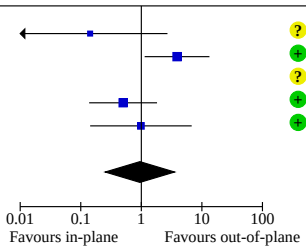


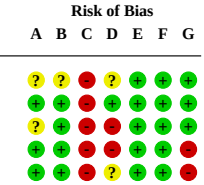
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.14. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 14: Adverse events (vasospasm) - trials at low risk of bias

Study or Subgroup	In-plane B-mode US Events	In-plane B-mode US Total	Out-of-plane B-mode US Events	Out-of-plane B-mode US Total	Weight	Risk Ratio M-H, Random, 95% CI
Berk 2013	0	54	3	54	13.9%	0.14 [0.01 , 2.70]
Nam 2020	11	66	3	70	32.1%	3.89 [1.13 , 13.32]
Quan 2014	0	82	0	81		Not estimable
Rajasekar 2021	3	30	6	30	31.2%	0.50 [0.14 , 1.82]
Wang 2019	2	66	2	65	22.8%	0.98 [0.14 , 6.78]
Total (95% CI)		**298**		**300**	**100.0%**	**0.95 [0.25 , 3.54]**
Total events:	16		14			

Heterogeneity: Tau² = 1.01; Chi² = 7.32, df = 3 (P = 0.06); I² = 59%
Test for overall effect: Z = 0.08 (P = 0.94)
Test for subgroup differences: Not applicable



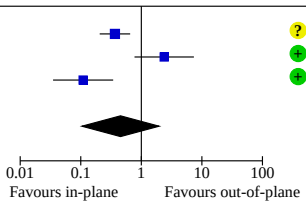


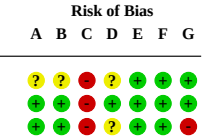
Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 7.15. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 15: Adverse events (posterior wall damage)

Study or Subgroup	In-plane B-mode US Events	In-plane B-mode US Total	Out-of-plane B-mode US Events	Out-of-plane B-mode US Total	Weight	Risk Ratio M-H, Random, 95% CI
Berk 2013	11	54	30	54	36.8%	0.37 [0.21 , 0.65]
Nam 2020	9	66	4	70	31.7%	2.39 [0.77 , 7.38]
Wang 2019	3	66	27	65	31.5%	0.11 [0.03 , 0.34]
Total (95% CI)		**186**		**189**	**100.0%**	**0.45 [0.10 , 1.97]**
Total events:	23		61			

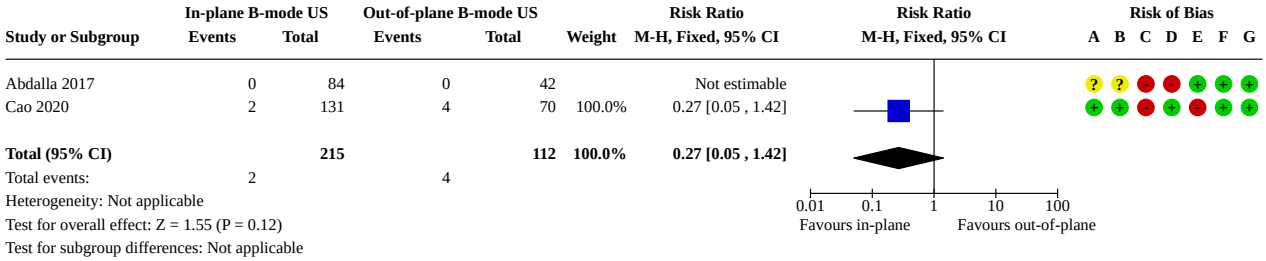
Heterogeneity: Tau² = 1.44; Chi² = 14.75, df = 2 (P = 0.0006); I² = 86%
Test for overall effect: Z = 1.06 (P = 0.29)
Test for subgroup differences: Not applicable





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 7.16. Comparison 7: [Radial] In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound, Outcome 16: Adverse events (ischaemia)



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

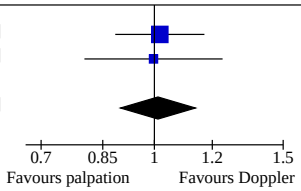
Comparison 8. [Radial] Doppler assistance versus palpation and landmarks

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
8.1 First-attempt success rate	2	666	Risk Ratio (M-H, Random, 95% CI)	1.01 [0.90, 1.14]
8.2 First-attempt success rate - trials at low risk of bias	1	166	Risk Ratio (M-H, Random, 95% CI)	1.02 [0.88, 1.17]
8.3 Overall success rate	2	666	Risk Ratio (M-H, Random, 95% CI)	0.99 [0.92, 1.07]
8.4 Overall success rate - trials at low risk of bias	1	166	Risk Ratio (M-H, Random, 95% CI)	1.00 [0.96, 1.03]
8.5 Time needed for a successful procedure	1	500	Mean Difference (IV, Fixed, 95% CI)	0.45 [0.20, 0.70]
8.6 Adverse events (haematoma or ischaemia)	1	500	Risk Ratio (M-H, Fixed, 95% CI)	0.80 [0.47, 1.35]

Analysis 8.1. Comparison 8: [Radial] Doppler assistance versus palpation and landmarks, Outcome 1: First-attempt success rate

Study or Subgroup	Doppler assistance Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Tada 2003	60	72	77	94	70.6%	1.02 [0.88 , 1.17]
Ueda 2015	96	244	101	256	29.4%	1.00 [0.80 , 1.24]
Total (95% CI)		**316**		**350**	**100.0%**	**1.01 [0.90 , 1.14]**
Total events:	156		178			

Heterogeneity: Tau² = 0.00; Chi² = 0.03, df = 1 (P = 0.86); I² = 0%
Test for overall effect: Z = 0.19 (P = 0.85)
Test for subgroup differences: Not applicable

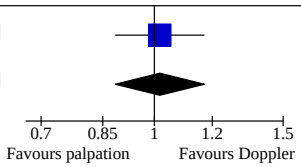


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 8.2. Comparison 8: [Radial] Doppler assistance versus palpation and landmarks, Outcome 2: First-attempt success rate - trials at low risk of bias

Study or Subgroup	Doppler assistance Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Tada 2003	60	72	77	94	100.0%	1.02 [0.88 , 1.17]
Total (95% CI)		**72**		**94**	**100.0%**	**1.02 [0.88 , 1.17]**
Total events:	60		77			

Heterogeneity: Not applicable
Test for overall effect: Z = 0.24 (P = 0.81)
Test for subgroup differences: Not applicable

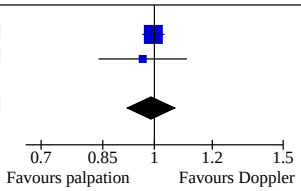


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 8.3. Comparison 8: [Radial] Doppler assistance versus palpation and landmarks, Outcome 3: Overall success rate

Study or Subgroup	Doppler assistance Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Tada 2003	71	72	93	94	78.0%	1.00 [0.96 , 1.03]	? ? - ? + + -
Ueda 2015	147	244	160	256	22.0%	0.96 [0.84 , 1.11]	+ + - + - - -
Total (95% CI)		**316**		**350**	**100.0%**	**0.99 [0.92 , 1.07]**	
Total events:	218		253				

Heterogeneity: Tau² = 0.00; Chi² = 1.58, df = 1 (P = 0.21); I² = 37%
Test for overall effect: Z = 0.28 (P = 0.78)
Test for subgroup differences: Not applicable

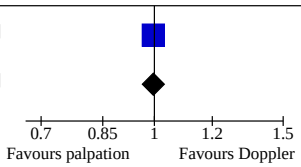


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 8.4. Comparison 8: [Radial] Doppler assistance versus palpation and landmarks, Outcome 4: Overall success rate - trials at low risk of bias

Study or Subgroup	Doppler assistance Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Tada 2003	71	72	93	94	100.0%	1.00 [0.96 , 1.03]	? ? - ? + + -
Total (95% CI)		**72**		**94**	**100.0%**	**1.00 [0.96 , 1.03]**	
Total events:	71		93				

Heterogeneity: Not applicable
Test for overall effect: Z = 0.19 (P = 0.85)
Test for subgroup differences: Not applicable

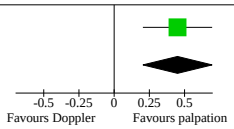


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 8.5. Comparison 8: [Radial] Doppler assistance versus palpation and landmarks, Outcome 5: Time needed for a successful procedure

Study or Subgroup	Doppler assistance Mean [minutes]	SD [minutes]	Total	Palpation Mean [minutes]	SD [minutes]	Total	Weight	Mean Difference IV, Fixed, 95% CI [minutes]	Risk of Bias A B C D E F G
Ueda 2015	2.138	1.603	244	1.688	1.155	256	100.0%	0.45 [0.20 , 0.70]	+ + - + - - -
Total (95% CI)			**244**			**256**	**100.0%**	**0.45 [0.20 , 0.70]**	

Heterogeneity: Not applicable
Test for overall effect: Z = 3.59 (P = 0.0003)
Test for subgroup differences: Not applicable

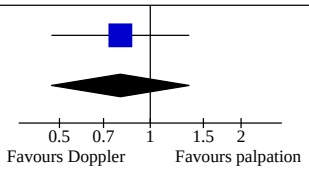


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 8.6. Comparison 8: [Radial] Doppler assistance versus palpation and landmarks, Outcome 6: Adverse events (haematoma or ischaemia)

Study or Subgroup	Doppler assistance Events	Total	Palpation Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI	Risk of Bias A B C D E F G
Ueda 2015	22	244	29	256	100.0%	0.80 [0.47 , 1.35]	+ + - + - - -
Total (95% CI)		**244**		**256**	**100.0%**	**0.80 [0.47 , 1.35]**	
Total events:	22		29				

Heterogeneity: Not applicable
Test for overall effect: Z = 0.85 (P = 0.39)
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

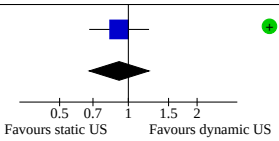
Comparison 9. [Radial] Dynamic out-of-plane B-mode ultrasound versus static out-of-plane B-mode ultrasound

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
9.1 First-attempt success rate	1	131	Risk Ratio (M-H, Random, 95% CI)	0.91 [0.67, 1.23]
9.2 Overall success rate	1	131	Risk Ratio (M-H, Random, 95% CI)	1.07 [0.92, 1.25]
9.3 Time needed for a successful procedure	1	131	Mean Difference (IV, Random, 95% CI)	0.37 [0.07, 0.66]
9.4 Adverse events (posterior wall puncture)	1	131	Risk Ratio (M-H, Random, 95% CI)	0.52 [0.34, 0.81]

Analysis 9.1. Comparison 9: [Radial] Dynamic out-of-plane B-mode ultrasound versus static out-of-plane B-mode ultrasound, Outcome 1: First-attempt success rate

Study or Subgroup	Dynamic out-of-plane B-mode US Events	Total	Static out-of-plane B-mode US Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Bai 2020	35	65	39	66	100.0%	0.91 [0.67 , 1.23]	+ + - + + + +
Total (95% CI)		**65**		**66**	**100.0%**	**0.91 [0.67 , 1.23]**	
Total events:	35		39				

Heterogeneity: Not applicable
Test for overall effect: Z = 0.60 (P = 0.55)
Test for subgroup differences: Not applicable

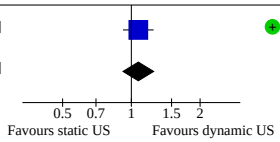


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 9.2. Comparison 9: [Radial] Dynamic out-of-plane B-mode ultrasound versus static out-of-plane B-mode ultrasound, Outcome 2: Overall success rate

Study or Subgroup	Dynamic out-of-plane B-mode US Events	Total	Static out-of-plane B-mode US Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Bai 2020	56	65	53	66	100.0%	1.07 [0.92 , 1.25]	+ + - + + + +
Total (95% CI)		**65**		**66**	**100.0%**	**1.07 [0.92 , 1.25]**	
Total events:	56		53				

Heterogeneity: Not applicable
Test for overall effect: Z = 0.89 (P = 0.37)
Test for subgroup differences: Not applicable

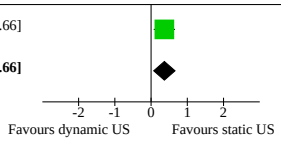


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 9.3. Comparison 9: [Radial] Dynamic out-of-plane B-mode ultrasound versus static out-of-plane B-mode ultrasound, Outcome 3: Time needed for a successful procedure

Study or Subgroup	Dynamic out-of-plane B-mode US Mean	SD	Total	static out-of-plane B-mode US Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Risk of Bias A B C D E F G
Bai 2020	1.348	0.694	65	0.981	0.997	66	100.0%	0.37 [0.07 , 0.66]	+ + - + + + +
Total (95% CI)			**65**			**66**	**100.0%**	**0.37 [0.07 , 0.66]**	

Heterogeneity: Not applicable
Test for overall effect: Z = 2.45 (P = 0.01)
Test for subgroup differences: Not applicable

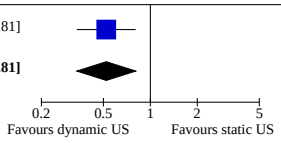


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 9.4. Comparison 9: [Radial] Dynamic out-of-plane B-mode ultrasound versus static out-of-plane B-mode ultrasound, Outcome 4: Adverse events (posterior wall puncture)

Study or Subgroup	Dynamic out-of-plane B-mode US Events	Total	Static out-of-plane B-mode US Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Bai 2020	19	65	37	66	100.0%	0.52 [0.34 , 0.81]	+ + - + + + +
Total (95% CI)		**65**		**66**	**100.0%**	**0.52 [0.34 , 0.81]**	
Total events:	19		37				

Heterogeneity: Not applicable
Test for overall effect: Z = 2.94 (P = 0.003)
Test for subgroup differences: Not applicable

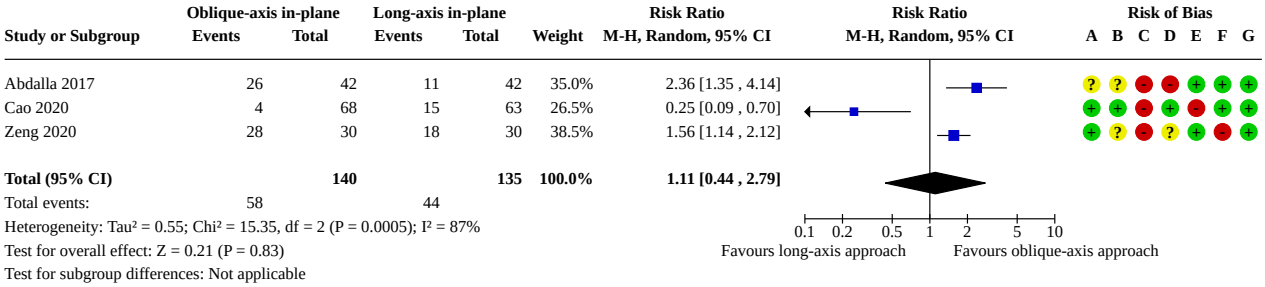


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Comparison 10. [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
10.1 First-attempt success rate	3	275	Risk Ratio (M-H, Random, 95% CI)	1.11 [0.44, 2.79]
10.2 First-attempt success rate - trials at low risk of bias	1	84	Risk Ratio (M-H, Random, 95% CI)	2.36 [1.35, 4.14]
10.3 Overall success rate	2	215	Risk Ratio (M-H, Random, 95% CI)	1.27 [1.05, 1.53]
10.4 Overall success rate - trials at low risk of bias	1	84	Risk Ratio (M-H, Random, 95% CI)	1.28 [1.01, 1.61]
10.5 Time needed for a successful procedure	3	275	Mean Difference (IV, Random, 95% CI)	-0.35 [-0.95, 0.25]
10.6 Time needed for a successful procedure - trials at low risk of bias	1	84	Mean Difference (IV, Random, 95% CI)	-0.83 [-0.88, -0.79]
10.7 Major haematoma	2	215	Risk Ratio (M-H, Random, 95% CI)	0.68 [0.32, 1.47]
10.8 Major haematoma - trials at low risk of bias	1	84	Risk Ratio (M-H, Random, 95% CI)	0.55 [0.22, 1.34]
10.9 Adverse events (vasospasm or haematoma)	1	60	Risk Ratio (M-H, Random, 95% CI)	0.09 [0.01, 1.57]
10.10 Adverse events (ischaemia)	2	215	Risk Ratio (M-H, Random, 95% CI)	4.64 [0.23, 94.77]

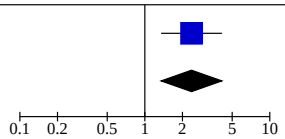
Analysis 10.1. Comparison 10: [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound, Outcome 1: First-attempt success rate



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 10.2. Comparison 10: [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound, Outcome 2: First-attempt success rate - trials at low risk of bias

Study or Subgroup	Oblique-axis in-plane Events	Total	Long-axis in-plane Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Abdalla 2017	26	42	11	42	100.0%	2.36 [1.35 , 4.14]		? ? - - + + +
Total (95% CI)		**42**		**42**	**100.0%**	**2.36 [1.35 , 4.14]**		
Total events:	26		11					

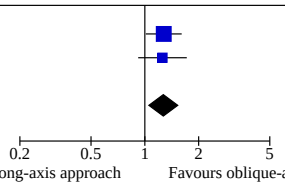


Heterogeneity: Not applicable
Test for overall effect: Z = 3.01 (P = 0.003)
Test for subgroup differences: Not applicable

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 10.3. Comparison 10: [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound, Outcome 3: Overall success rate

Study or Subgroup	Oblique-axis in-plane Events	Total	Long-axis in-plane Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Abdalla 2017	37	42	29	42	64.7%	1.28 [1.01 , 1.61]		? ? - - + + +
Cao 2020	42	68	31	63	35.3%	1.26 [0.92 , 1.72]		+ + - + - + +
Total (95% CI)		**110**		**105**	**100.0%**	**1.27 [1.05 , 1.53]**		
Total events:	79		60					

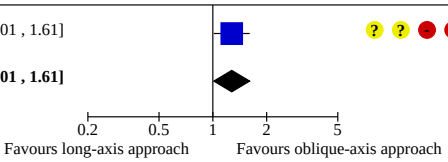


Heterogeneity: Tau² = 0.00; Chi² = 0.01, df = 1 (P = 0.93); I² = 0%
Test for overall effect: Z = 2.51 (P = 0.01)
Test for subgroup differences: Not applicable

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 10.4. Comparison 10: [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound, Outcome 4: Overall success rate - trials at low risk of bias

Study or Subgroup	Oblique-axis in-plane Events	Total	Long-axis in-plane Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Abdalla 2017	37	42	29	42	100.0%	1.28 [1.01 , 1.61]		? ? - - + + +
Total (95% CI)		**42**		**42**	**100.0%**	**1.28 [1.01 , 1.61]**		
Total events:	37		29					

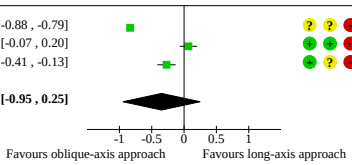


Heterogeneity: Not applicable
Test for overall effect: Z = 2.07 (P = 0.04)
Test for subgroup differences: Not applicable

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 10.5. Comparison 10: [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound, Outcome 5: Time needed for a successful procedure

Study or Subgroup	Oblique-axis in-plane Mean [minutes]	SD [minutes]	Total	Long-axis in-plane Mean [minutes]	SD [minutes]	Total	Weight	Mean Difference IV, Random, 95% CI [minutes]	Mean Difference IV, Random, 95% CI [minutes]	Risk of Bias A B C D E F G
Abdalla 2017	0.266	0.116	42	1.1	0.083	42	33.7%	-0.83 [-0.88 , -0.79]		? ? - - + + +
Cao 2020	0.233	0.516	68	0.166	0.216	63	33.2%	0.07 [-0.07 , 0.20]		+ + - + - + +
Zeng 2020	0.365	0.141	30	0.636	0.368	30	33.1%	-0.27 [-0.41 , -0.13]		+ ? - ? + - +
Total (95% CI)			**140**			**135**	**100.0%**	**-0.35 [-0.95 , 0.25]**		

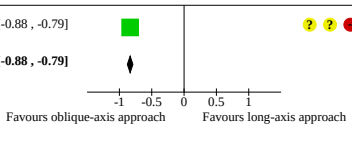


Heterogeneity: Tau² = 0.28; Chi² = 198.63, df = 2 (P < 0.00001); I² = 99%
Test for overall effect: Z = 1.14 (P = 0.25)
Test for subgroup differences: Not applicable

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 10.6. Comparison 10: [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound, Outcome 6: Time needed for a successful procedure - trials at low risk of bias

Study or Subgroup	Oblique-axis in-plane Mean [minutes]	SD [minutes]	Total	Long-axis in-plane Mean [minutes]	SD [minutes]	Total	Weight	Mean Difference IV, Random, 95% CI [minutes]	Mean Difference IV, Random, 95% CI [minutes]	Risk of Bias A B C D E F G
Abdalla 2017	0.266	0.116	42	1.1	0.083	42	100.0%	-0.83 [-0.88 , -0.79]		? ? - - + + +
Total (95% CI)			**42**			**42**	**100.0%**	**-0.83 [-0.88 , -0.79]**		

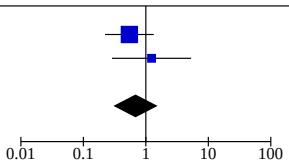


Heterogeneity: Not applicable
Test for overall effect: Z = 37.89 (P < 0.00001)
Test for subgroup differences: Not applicable

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 10.7. Comparison 10: [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound, Outcome 7: Major haematoma

Study or Subgroup	Oblique-axis in-plane Events	Total	Long-axis in-plane Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Abdalla 2017	6	42	11	42	72.5%	0.55 [0.22 , 1.34]		? ? - - + + +
Cao 2020	4	68	3	63	27.5%	1.24 [0.29 , 5.30]		+ + - + - + +
Total (95% CI)		**110**		**105**	**100.0%**	**0.68 [0.32 , 1.47]**		
Total events:	10		14					

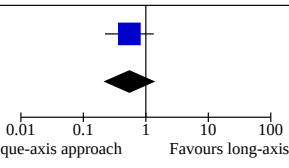


Heterogeneity: Tau² = 0.00; Chi² = 0.88, df = 1 (P = 0.35); I² = 0%
Test for overall effect: Z = 0.98 (P = 0.33)
Test for subgroup differences: Not applicable

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 10.8. Comparison 10: [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound, Outcome 8: Major haematoma - trials at low risk of bias

Study or Subgroup	Oblique-axis in-plane Events	Total	Long-axis in-plane Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F G
Abdalla 2017	6	42	11	42	100.0%	0.55 [0.22 , 1.34]		? ? - - + + +
Total (95% CI)		**42**		**42**	**100.0%**	**0.55 [0.22 , 1.34]**		
Total events:	6		11					



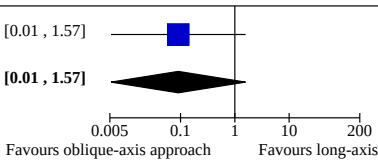
Heterogeneity: Not applicable
Test for overall effect: Z = 1.32 (P = 0.19)
Test for subgroup differences: Not applicable

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 10.9. Comparison 10: [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound, Outcome 9: Adverse events (vasospasm or haematoma)

Study or Subgroup	Oblique-axis in-plane Events	Total	Long-axis in-plane Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Zeng 2020	0	30	5	30	100.0%	0.09 [0.01 , 1.57]
Total (95% CI)		**30**		**30**	**100.0%**	**0.09 [0.01 , 1.57]**
Total events:	0		5			

Heterogeneity: Not applicable
Test for overall effect: Z = 1.65 (P = 0.10)
Test for subgroup differences: Not applicable

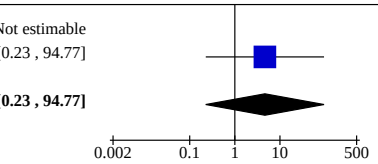


Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting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

Analysis 10.10. Comparison 10: [Radial] Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound, Outcome 10: Adverse events (ischaemia)

Study or Subgroup	Oblique-axis in-plane Events	Total	Long-axis in-plane Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Abdalla 2017	0	42	0	42		Not estimable
Cao 2020	2	68	0	63	100.0%	4.64 [0.23 , 94.77]
Total (95% CI)		**110**		**105**	**100.0%**	**4.64 [0.23 , 94.77]**
Total events:	2		0			

Heterogeneity: Not applicable
Test for overall effect: Z = 1.00 (P = 0.32)
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

ADDITIONAL TABLES

Table 1. Classification of adults according to BMI

Classification	BMI values[a,b]
Underweight	< 18.5
Normal range	18.5 to 24.99
Overweight:	
Pre-obese	25.00 to 29.99
Obese class I	30.00 to 34.99

Table 1. Classification of adults according to BMI *(Continued)*

Obese class II	35.00 to 39.99
Obese class Ill	≥ 40

BMI: body mass index.
[a]These BMI values are age-independent and are the same for both sexes.
[b]Body mass divided by the square of body height, universally expressed in units of kg/m^2.

APPENDICES

Appendix 1. Glossary of terms

Term	Definition
Ambulation	The act of walking
Angiography	A medical imaging technique used to visualise the inside, or lumen, of blood vessels and the heart chambers. This is traditionally performed by injecting a radio-opaque contrast agent into the peripheral vein and imaging the body part using X-ray-based techniques such as fluoroscopy
Anticoagulants	Drugs that suppress, delay, or prevent blood clots
Antiplatelet agents	Drugs that prevent blood clots by inhibiting platelet function
Arterial	Relative to the artery
Atherosclerosis	A disease characterised by a buildup of abnormal fat, cholesterol, and platelet deposits on the inner wall of the arteries
B-mode ultrasound	Brightness mode ultrasound is a 2-dimensional image of a structure by ultrasound technology
Body mass index (BMI)	Body mass divided by the square of the body height, universally expressed in units of kg/m^2
Brachial access	To access inside the blood vessels through the brachial artery, commonly using vascular devices
Catheterisation	A minimally invasive procedure to access inside of the blood vessels using a catheter
Coronary arteries	The arteries that carry blood to the cardiac muscle
Direct ultrasound guidance	Ultrasound scanning to verify the presence and position of a suitable target vessel at the time of needle insertion (i.e. real-time ultrasound needle guidance)
Doppler auditory ultrasound assistance	Ultrasound scanning to verify the presence and position of a suitable target vessel. It commonly uses the Doppler effect transformed in auditory sound
Duplex ultrasound	Non-invasive evaluation of blood flow through the arteries and veins by ultrasound devices
Dyslipidemia	Abnormal concentration of fats (lipids or lipoproteins) in the blood
Gasometry	A laboratory examination that evaluates gas dosages in a blood sample
Heparin	A drug that is used to prevent blood clotting (anticoagulant, blood thinner)

(Continued)

Indirect ultrasound guidance	Ultrasound scanning to verify the presence and position of a suitable target vessel by using B-mode ultrasound before needle insertion without real-time ultrasound needle guidance
Low-molecular-weight heparin	A drug that is used to prevent blood clotting (anticoagulant)
Obesity	Amount of body fat is beyond healthy conditions (BMI > 30 kg/m^2)
Oedema	The excess watery fluid that collects in tissues of the body, causing swelling when fluid leaks out of the body's vessels
Overweight	Amount of body fat is over that of the average population but is less than in unhealthy conditions (BMI between 25 and 30 kg/m^2)
Percutaneous	A procedure performed by a puncture in the skin without skin cutting and direct visualisation of the vessel or the interested structure
Peripheral artery disease (PAD)	An abnormal narrowing of arteries other than those that directly supply the heart or brain
Placebo	Substance or treatment with no active effect, like a sugar pill
Radioulnar arch	An artery structure that connects the ulnar and radial arteries in the hand
Randomised clinical trial (RCT)	A study in which participants are divided randomly into separate groups to compare different treatments
Sham	A placebo procedure that omits the step thought to be therapeutically necessary
Thrombosis	Local coagulation of blood (clot) in a part of the circulatory system
Ultrasound	Sound waves at a frequency higher than can be heard by a human being
Unfractionated heparin (UFH)	A mixture of heparins obtained from animals that is used to prevent blood coagulation. Used to avoid and treat clotting disorders
Vascular	Related to blood vessels (arteries and veins)
Virchow's triad	Three factors that contribute to thrombosis: (1) changes in the vessel wall; (2) changes in the pattern of blood flow; (3) changes in blood constituents (hypercoagulability)

Appendix 2. Search strategies

CENTRAL

#1 MeSH descriptor: [Ultrasonography, Interventional] this term only

#2 MeSH descriptor: [Ultrasonography] this term only

#3 ultrasound*

#4 2D mode

#5 (two-dimensional near/3 ultraso*)

#6 (in-plane near/3 ultraso*)

#7 (out-of-plane near/3 ultraso*)

#8 #1 or #2 or #3 or #4 or #5 or #6 or #7

#9 MeSH descriptor: [Catheterization] explode all trees

#10 MeSH descriptor: [Arteries] explode all trees

#11 ((artery or arteri*) near/3 puncture*)

#12 ((artery or arteri*) near/3 catheter*)

#13 (intra-arterial near/3 catheter*)

#14 ((artery or arteri*) near/3 cannula*)

#15 arterial line*

#16 a-line*

#17 art line*

#18 artery access

#19 vascular access

#20 #9 or #10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19

#21 #8 and #20

MEDLINE Ovid

1 Ultrasonography, Interventional/ or Ultrasonography/

2 ultrasound*.tw.

3 2D mode.tw.

4 (two-dimensional adj3 ultraso*).tw.

5 (in-plane adj3 ultraso*).tw.

6 (out-of-plane adj3 ultraso*).tw.

7 1 or 2 or 3 or 4 or 5 or 6

8 exp Catheterization/ and exp Arteries/

9 ((artery or arteri*) adj3 puncture*).tw.

10 ((artery or arteri*) adj3 catheter*).tw.

11 (intra-arterial adj3 catheter*).tw.

12 ((artery or arteri*) adj3 cannula*).tw.

13 arterial line*.tw.

14 a-line*.tw.

15 art line*.tw.

16 artery access.tw.

17 vascular access.tw.

18 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17

19 7 and 18

20 randomized controlled trial.pt.

21 controlled clinical trial.pt.

22 randomized.ab.

23 placebo.ab.

24 drug therapy.fs.

25 randomly.ab.

26 trial.ab.

27 groups.ab.

28 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27

29 exp animals/ not humans.sh.

30 28 not 29

31 19 and 30

Embase Ovid

1 interventional ultrasonography/ or echography/

2 ultrasound*.tw.

3 2D mode.tw.

4 (two-dimensional adj3 ultraso*).tw.

5 (in-plane adj3 ultraso*).tw.

6 (out-of-plane adj3 ultraso*).tw.

7 1 or 2 or 3 or 4 or 5 or 6

8 exp catheterization/ or exp artery/

9 ((artery or arteri*) adj3 puncture*).tw.

10 ((artery or arteri*) adj3 catheter*).tw.

11 (intra-arterial adj3 catheter*).tw.

12 ((artery or arteri*) adj3 cannula*).tw.

13 arterial line*.tw.

14 a-line*.tw.

15 art line*.tw.

16 artery access.tw.

17 vascular access.tw.

18 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17

19 7 and 18

20 random$.tw.

21 factorial$.tw.

22 crossover$.tw.

23 cross over$.tw.

24 cross-over$.tw.

25 placebo$.tw.

26 (doubl$ adj blind$).tw.

27 (singl$ adj blind$).tw.

28 assign$.tw.

29 allocat$.tw.

30 volunteer$.tw.

31 crossover procedure/

32 double blind procedure/

33 randomized controlled trial/

34 single blind procedure/

35 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34

36 (animal/ or nonhuman/) not human/

37 35 not 36

38 19 and 37

39 limit 38 to embase

CINAHL

S44 S20 AND S43

S43 S42 NOT S41

S42 S21 OR S22 OR S23 OR S24 OR S25 OR S26 OR S27 OR S28 OR S29 OR S30 OR S31 OR S32 OR S33 OR S34 OR S35

S41 S39 NOT S40

S40 MH (human)

S39 S36 OR S37 OR S38

S38 TI (animal model*)

S37 MH (animal studies)

S36 MH animals+

S35 AB (cluster W3 RCT)

S34 MH (crossover design) OR MH (comparative studies)

S33 AB (control W5 group)

S32 PT (randomized controlled trial)

S31 MH (placebos)

S30 MH (sample size) AND AB (assigned OR allocated OR control)

S29 TI (trial)

S28 AB (random*)

S27 TI (randomised OR randomized)

S26 MH cluster sample

S25 MH pretest-posttest design

S24 MH random assignment

S23 MH single-blind studies

S22 MH double-blind studies

S21 MH randomized controlled trials

S20 S7 AND S19

S19 S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18

S18 TX vascular access

S17 TX artery access

S16 TX art line*

S15 TX a-line*

S14 TX arterial line*

S13 TX ((artery or arteri*) n3 cannula*)

S12 TX (intra-arterial n3 catheter*)

S11 TX ((artery or arteri*) n3 catheter*)

S10 TX ((artery or arteri*) n3 puncture*)

S9 (MH "Arteries+")

S8 (MH "Catheterization+")

S7 S1 OR S2 OR S3 OR S4 OR S5 OR S6

S6 TX (out-of-plane n3 ultraso*)

S5 TX (in-plane n3 ultraso*)

S4 TX (two-dimensional n3 ultraso*)

S3 TX 2D mode

S2 TX ultrasound*

S1 (MH "Ultrasonography")

LILACS

Ultrasound$ or “2D mode” [Words] and Artery or arteri$ or intra-arterial or a-line$ or art line$ or “vascular access” [Words] and Puncture $ or catheter$ or cannula$ or access or line$ [Words]

IBECS

(mh: Ultrasonography or Ultrasonografía or Ultrassonografia or (Computer Echotomography) or (Diagnos* Ultrasonic) or (Diagnostic Ultrasound*) or Echography or Echotomography or (Echotomography Computer) or (Imaging Ultrasonic) or (Imaging* Ultrasonographic) or (Imaging* Ultrasound) or (Medical Sonography) or (Tomography Ultrasonic) or (Ultrasonographic Imaging*) or (Diagnóstico por Ultrasonido) or Ecografía or (Ecografía Médica) or Ecotomografía or (Ecotomografía por Computador) or (Imagen Ultrasonográfica) or (Imagen Ultrasónica) or (Imagen de Ultrasonido) or (Imagen por Ultrasonido) or (Sonografía Médica) or (Tomografía Ultrasonica) or (Diagnóstico por Ultrassom) or Ecografia or (Ecografia Médica) or Ecotomografia or (Ecotomografia por Computador) or (Imageamento Ultrassonográfico) or (Imagem Ultrassonográfica) or (Imagem Ultrassônica) or (Imagem de Ultrassom) or (Imagem por Ultrassom) or (Sonografia Médica) or (Tomografia Ultrassônica) or (2D mode ultraso*) or (two-dimensional ultraso*) or (in-plane ultraso*) or (out-of-plane ultraso*)) and (mh: Catheterization or Cateterismo or Cateterismo or Cannulation* or Catheterizations or E02.148 or E05.157 or Canulación or Cateterización or Canulação or Cateterização or mh: Arteries or Arterias or Artérias or Artery or ((artery or arteri*) puncture*) or ((artery

or arteri*) catheter*) or (intra-arterial catheter*) or ((artery or arteri*) cannula*) or (arterial line*) or a-line* or (art line*) or (artery access) or (vascular access))

ClinicalTrials.gov

condition and other terms

#1

catheterization and ultrasonography

#2

artery access and ultrasonography

#1 or #2

WHO ICTRP

condition and intervention

#1

catheterization and ultrasonography

#2

artery access and ultrasonography

#1 or #2

HISTORY

Protocol first published: Issue 4, 2020

CONTRIBUTIONS OF AUTHORS

RLGF: acquired trial reports; selected trials; extracted, analysed and, interpreted data; performed risk of bias assessments and GRADE assessments; drafted the review; and acted as a guarantor of the review.

VFMT: analysed and interpreted data; and drafted the review.

RDL: analysed and interpreted data; and drafted the review.

JCCBS: analysed and interpreted data; and drafted the review.

CDQF: selected trials; extracted, analysed, and interpreted data; performed risk of bias assessments and GRADE assessments; and drafted the review.

LCUN: arbitrated any disagreement in trial selection, risk of bias, and GRADE judgements; analysed and interpreted data; and drafted the review.

DECLARATIONS OF INTEREST

RLGF: none known.

VFMT: none known.

RDL: declares grants from Bristol-Myers Squibb, GlaxoSmithKline, Medtronic, Pfizer, and Sanofi via institution and consulting fees from Bayer, Boehringer Ingleheim, Bristol-Myers Squibb, Daiichi Sankyo, GlaxoSmithKline, Medtronic, Merck, Pfizer, Portola, and Sanofi.

JCCBS: none known.

CDQF: none known.

LCUN: none known.

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Internal sources

- Division of Vascular and Endovascular Surgery, Universidade Federal de Sao Paulo, Brazil

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DIFFERENCES BETWEEN PROTOCOL AND REVIEW

In our protocol (Flumignan 2020), we planned to describe skewed data reported as medians and interquartile ranges, but in our review, we estimated the MD using the method reported by Wan 2014 to convert median and IQR into MD and CI. When it was not possible, we narratively described skewed data reported as medians and interquartile ranges.

In our protocol (Flumignan 2020), we planned to create funnel plots only for primary outcomes, but we created funnel plots for all outcomes where we were able to pool more than 10 trials, to explore possible small-study biases.

Although we did not specify this in our protocol, in our review, we performed subgroup analysis only if we identified at least 10 studies for that outcome, to follow a Cochrane Heart recommendation.

Although we established "two-dimensional ultrasound guidance as our intervention of interest", and we planned to include trials comparing any type of ultrasound guidance "versus any other techniques for arterial puncture", we did not list all possible comparisons in our protocol. Therefore, we amended the 'Types of interventions' section to include the following comparisons.

- B-mode ultrasound versus near-infrared laser guidance.
- B-mode ultrasound versus modified B-mode ultrasound.
- In-plane B-mode ultrasound versus out-of-plane B-mode ultrasound.
- Doppler auditory ultrasound assistance versus palpation and landmarks.
- Dynamic out-of-plane B-mode ultrasound versus static out-of-plane B-mode ultrasound.
- Oblique-axis in-plane B-mode ultrasound versus long-axis in-plane B-mode ultrasound.

We planned to assess publication bias in our protocol, but we detailed in the review the additional statistical tests used to analyse these data.

Because 'in-plane or out-of-plane ultrasound image' and 'vessel accessed in a longitudinal or transverse way' were considered in different comparisons, we deleted them from the subgroup analysis. We detailed better how we would deal with no sufficient information for subgroup analysis (e.g. Goswami 2020 for the experience of operators).

INDEX TERMS

Medical Subject Headings (MeSH)

*Arteries; *Catheterization; Ultrasonography

MeSH check words

Adult; Humans