SYSTEMATIC REVIEW

Acoustic Shadowing to Facilitate Ultrasound Guided Arterial Cannulation: A Systematic Review and Meta-analysis of Randomized Controlled Trials

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Abstract

Aim and background: Ultrasound-guided arterial catheterization is a frequently performed procedure. Additional techniques such as acoustic shadowing-assisted ultrasound may be useful in improving success rate. This systematic review aimed to assess the efficacy of acoustic shadowing assisted ultrasound for arterial catheterization.

Materials and methods: PubMed, Medline, EMBASE, Cochrane Library, EMCARE, and MedNar were searched in January 2024. Randomized controlled trials comparing the first attempt success rate of arterial catheterization using acoustic shadowing ultrasound vs unassisted ultrasound were included. Data were pooled for risk ratios (RRs) using the random-effects model. Subgroup analysis was conducted based on a single or double acoustic line. Sensitivity analysis was undertaken after excluding pediatric data. The certainty of evidence (COE) was assessed using the GRADE framework.

Results: Six randomized controlled trials ($n = 777$) were included. A meta-analysis found the first attempt success rate is significantly higher in the acoustic ultrasound group ($n = 6$, RR: 0.47, 95% CI: 0.34–0.66, $p \leq 0.00001$). Hematoma formation was significantly less in the acoustic ultrasound group ($n = 6$, RR: 0.52, 95% CI: 0.34–0.80, $p = 0.003$). First attempt success was significantly higher in the single acoustic line ultrasound (USG) group compared to the unassisted ultrasound group ($n = 3$, RR: 0.41, 95% CI: 0.28–0.59, $p \leq 0.00001$). Sensitivity analysis after excluding pediatric data was similar to the primary analysis ($n = 5$, RR: 0.50, 95% CI: 0.33–0.70, $p \leq 0.00001$). Certainty of evidence was "Moderate" for the first attempt cannulation.

Conclusions: Acoustic shadowing-assisted ultrasound improved first-attempt arterial catheterization success rate and was associated with reduced hematoma formation.

Keywords: Acoustic shadow, Arterial cannulation, Ultrasound.

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Highlights

Acoustic shadowing assisted USG during arterial cannulation may be associated with a significantly higher first-attempt success rate and less hematoma formation compared to unassisted USG.

Introduction

Arterial line (AL) placement is a common procedure in intensive care units (ICUs), Emergency Departments, and operating rooms.[1] Although AL placement is considered a safe technique, it is still associated with complications like bleeding, hematoma formation, arterial vasospasm, and injury of the adjacent nerve besides discomfort from skin puncture. Failed catheterization attempts may lead to vasospasm, intra, and extra-arterial hematoma, and further decrease the overall success rate. While uncommon, repeated attempts at cannulation can lead to severe complications such as permanent ischemic damage, sepsis, and the formation of pseudoaneurysms.[2] In the cardiac Cath-lab setting, physicians constantly seek to attain lower puncture injury rates for better diagnostic angiography, intervention, or monitoring.[3] The blind palpation technique is difficult in edematous, obese, and hypotensive patients which may lead to multiple failed-attempts. A recent Cochrane systematic review of 48 randomized controlled studies (RCTs) concluded that ultrasound (USG) guidance improves first attempt success rates, overall success rates, and time needed for a successful procedure.[4] Another systematic review concluded that USG improves radial arterial cannulation success rate by 14–37% on the first attempt compared to the palpation method.[5] Complications associated with USG-guided AL placement and aborted attempts are less frequent compared to palpation method.[4,6,7] However, USG guided AL line placement is not without problems. New trainees

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who are not USG trained and lack hand eye coordination might find USG assistance not so useful. The changing USG position on the skin and the beam angle during the procedure might reduce the success rates in inexperienced hands. A systematic review found that USG guidance correlated with a higher rate of success on the first attempt when administered by a proficient operator compared to an inexperienced one.[8] Investigators have used different USG modalities to improve the first attempt success rate. USG with developing line (acoustic shadow) by placing radiopaque objects on a USG probe is an easy technique to improve first attempt cannulation success rate. It can either be a single developing line (use of one radiopaque strip) or a double developing line (two radiopaque strips) and the artery on the USG screen is placed under (one strip) or in-between (two strips) the acoustic shadows so that arterial cannula can be introduced just below or in-between the radiopaque strips. While this technique utilizes USG guidance, it doesn't necessitate a highly skilled operator to pinpoint the puncture site. Consequently, it is theoretically suitable for both trainees and experienced clinicians. There are few recent publications available on this subject involving both inexperienced and experienced clinicians. Therefore, we undertook this systematic review to assess the effectiveness of acoustic shadow-assisted USG guidance in enhancing the success rate of first-attempt arterial cannulation.

Materials and Methods

This systematic review followed the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[9] Additionally, it was registered on the international prospective register of systematic reviews (PROSPERO: CRD42022372361).

Data Sources and Searches

Three reviewers autonomously conducted searches across electronic databases such as PubMed, EMBASE, EMCARE, MEDLINE, The Cochrane Library, and Google Scholar. The search encompassed records from their inception up to January 2024. Additionally, grey literature searches were performed on the "Opengrey" and "Mednar" databases. In March 2024, we conducted searches on ClinicalTrials.gov (www.ClinicalTrials.gov) and the World Health Organization (WHO) International Clinical Trials Registry Platform (ICTRP) Search Portal to identify ongoing or unpublished trials. PubMed was searched using the following broad keywords: ("acoust"[All Fields] OR "acoustical"[All Fields] OR "acoustically"[All Fields] OR "acoustics"[MeSH Terms] OR "acoustics"[All Fields] OR "acoustic"[All Fields]) AND ("shadow"[All Fields] OR "shadow s"[All Fields] OR "shadowed"[All Fields] OR "shadowing technique, histology"[MeSH Terms] OR ("shadowing"[All Fields] AND "technique"[All Fields] AND "histology"[All Fields]) OR "histology shadowing technique"[All Fields] OR "shadowing"[All Fields] OR "shadows"[All Fields])) OR (("develop"[All Fields] OR "develope" [All Fields] OR "developed"[All Fields] OR "developer"[All Fields] OR "developer s"[All Fields] OR "developers"[All Fields] OR "developing"[All Fields] OR "developments"[All Fields] OR "develops"[All Fields] OR "growth and development"[MeSH Subheading] OR ("growth"[All Fields] AND "development"[All Fields]) OR "growth and development"[All Fields] OR "development"[All Fields]) AND "line"[All Fields])) AND ("diagnostic imaging"[MeSH Subheading] OR ("diagnostic"[All Fields] AND "imaging"[All Fields]) OR "diagnostic imaging"[All Fields] OR "ultrasound"[All Fields] OR "ultrasonography"[MeSH Terms] OR "ultrasonography"[All Fields] OR "ultrasonics"[MeSH Terms] OR "ultrasonics"[All Fields] OR "ultrasounds"[All Fields] OR "ultrasound s"[All Fields]) AND (("arterialization"[All Fields] OR "arterializations"[All Fields] OR "arterialize"[All Fields] OR "arterialized"[All Fields] OR "arterializing"[All Fields] OR "arterially"[All Fields] OR "arterials"[All Fields] OR "arterie"[All Fields] OR "arteries"[MeSH Terms] OR "arteries"[All Fields] OR "arterial"[All Fields] OR "arteris"[All Fields] OR "artery"[All Fields] OR "arterious"[All Fields] OR "artery s"[All Fields] OR "arterys"[All Fields]) AND ("cannulate"[All Fields] OR "cannulated"[All Fields] OR "cannulating"[All Fields] OR "cannulator"[All Fields] OR "cannulators"[All Fields] OR "cannulisation"[All Fields] OR "cannulization"[All Fields] OR "cannulized"[All Fields] OR "catheterization"[MeSH Terms] OR "catheterization"[All Fields] OR "cannulation"[All Fields] OR "cannulations"[All Fields]). Consistent terminologies were utilized across all database searches. Furthermore, reference lists of relevant articles were manually screened. No language or period limitations were imposed.

Study Selection and Outcomes

Randomized controlled trials (RCTs) (both parallel and crossover) and quasi-randomized trials that met the following criteria were included: (1) Adults or children of either gender who required arterial line for diagnostic or therapeutic purposes (2) USG was used to cannulate any artery by any of the Seldinger techniques (3) Unassisted USG (without acoustic shadowing) and acoustic shadow assisted USG were compared. Cohort, case-control studies, and case series were excluded.

Primary outcome of interest: First-attempt success rate of arterial cannulation (Both single and double developing lines).

Secondary outcome of interest: (1) Hematoma formation (2) Second attempt success rate of arterial cannulation (3) Time, in minutes, needed for a successful procedure, (4) Any other adverse events.

Data Extraction and Quality Assessment

Two authors autonomously evaluated titles and abstracts to identify full-text articles suitable for inclusion in the review. Full-text articles of potentially eligible studies underwent meticulous examination by two reviewers to confirm eligibility. Data extraction was performed using a standardized form. The occurrence of various clinical outcomes of interest in both groups (ultrasound guidance unassisted vs. ultrasound guidance with acoustic shadow assistance) was documented. For binary outcomes, recorded risk ratios (RRs) with 95% confidence intervals (CIs) were noted if provided by the authors. The quality assessment of randomized controlled trials (RCTs) was conducted using the Cochrane risk-of-bias-2 tool by two independent reviewers.[10] The certainty of evidence (COE) was assessed using the GRADE methodology and categorized as high, moderate, low, or very low.[11] In case of discrepancies, reviewers engaged in discussions to achieve a consensus.

Data Synthesis

Meta-analysis was conducted utilizing Review Manager V.5.4 (Cochrane Collaboration, Nordic Cochrane Center, Copenhagen, Denmark). Reported RRs from included studies were pooled using the inverse-variance method (Cochrane Handbook section 10.3.3). Subgroup analysis was performed based on studies that had reported the first attempt success rate for acoustic shadow-assisted USG with either a single developing line or double developing lines. A sensitivity analysis was conducted by excluding studies that had included pediatric populations. One study has provided data on

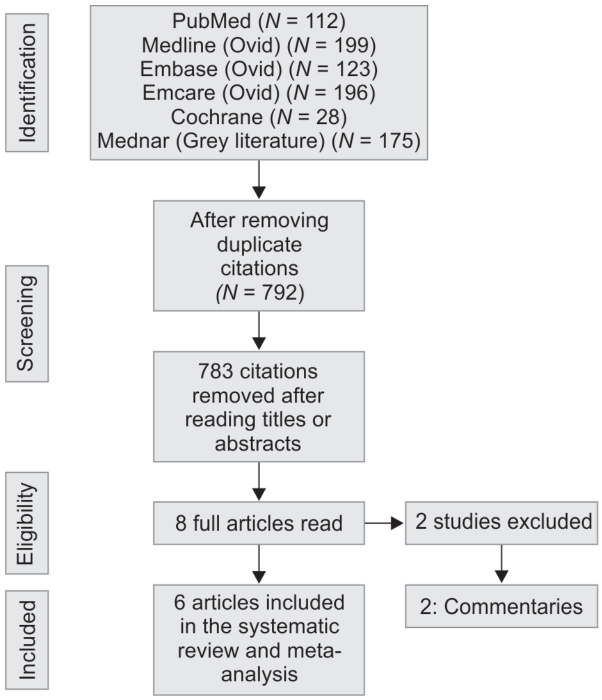

Fig. 1: Flowchart for study selection

both single and double acoustic lines, in that case double acoustic line data was used for the primary outcome analysis and single acoustic line data was used for subgroup analysis. Due to anticipated heterogeneity, a random-effects model (DerSimonian and Laird) was employed for meta-analysis. Raw numbers were utilized to calculate RRs if the included study manuscripts did not provide this information. Pooled effect size estimates for dichotomous outcomes were presented as pooled RRs with 95% CIs. We analyzed continuous data as mean differences (MD) with the same scale, and as standardized mean differences (SMDs) with different scales, with 95% CIs. For studies where meta-analysis was not feasible, a qualitative synthesis was conducted. Statistical heterogeneity was evaluated by visually inspecting forest plots and quantified using the I^2 statistic. The interpretation of I^2 results adhered to established guidelines: 0–40% indicated heterogeneity might not be significant; 30–60% suggested moderate heterogeneity; 50–90% indicated substantial heterogeneity; and 75–100% suggested considerable heterogeneity (Cochrane Handbook).[12] Given the inclusion of only a small number of studies, substantial uncertainty existed in the value of I^2; therefore, the *p*-value from the Chi-square test was also considered.

Results

Figure 1 presents a PRISMA flowchart depicting the screening and selection results. Initially, 792 articles were identified through the search, from which 6 studies met the selection criteria and were included.[13–18] All 6 studies were incorporated into the meta-analysis, with a total sample size of 777, ranging from 77 to 237 individuals per study. All 6 studies were parallel RCTs. Five out of the 6 studies were conducted on adults undergoing elective surgical procedures while one was conducted on pediatric population undergoing elective surgical procedure.[13–18] Patients underwent radial artery catheterization in all the 6 studies. Inexperienced physicians performed the procedure in 2 of the studies while experienced physicians inserted the cannulas in the other 4 studies.[13,14,16–18] Four out of the 6 trials used metal-containing strands from the X-ray detectable gauge to create acoustic shadow, while the other two trials used sutures.[13–18] Table 1 presents the characteristics of all the included studies. Among the included studies, five exhibited a low risk of bias, while one had some concerns. The risk of bias assessment graph and summary are depicted in Figure 2.

Pooling of RRs from 6 studies found first attempt arterial cannulation success rate to be significantly better with the use of acoustic shadow compared to unassisted USG (RR of failed first attempt: 0.47, 95% CI: 0.34–0.66, $p \leq 0.00001$) (Fig. 3). However, there was no significant difference in the second attempt success rate between acoustic shadow and unassisted USG when RRs of 3 studies were pooled (RR: 0.44, 95% CI: 0.19–1.03, $p = 0.06$) (Fig. 4). Pooling of RRs from 3 studies that have reported comparison of a single acoustic shadow line with unassisted USG also found a significantly better first attempt success rate with acoustic shadow USG (OR: 0.41, 95% CI: 0.28–0.59, $p \leq 0.00001$) (Fig. 5). Hematoma formation was significantly less common with the use of acoustic USG compared to unassisted USG when RRs from 6 studies were pooled (RR: 0.52, 95% CI: 0.34–0.80, $p = 0.003$) (Fig. 6). Result of the sensitivity analysis after excluding pediatrics data was similar to the primary analysis ($n = 5$, RR: 0.50, 95% CI: 0.36–0.70, $p \leq 0.00001$). Pooled SMD from 6 studies did not show a significantly less time to canulation with acoustic-assisted USG (Mean difference: –0.26, 95% CI: –0.72–0.20, $p = 0.27$) (Fig. 7).

Heterogeneity (I^2) was 33% for first attempt success rate ($p = 0.19$), 0% for single acoustic shadow ($p = 0.74$), 15% for hematoma formation ($p = 0.32$), and 3% for second attempt success ($p = 0.36$). Time to arterial cannulation was highly heterogeneous ($I^2 = 89\%$, $p \leq 0.00001$).

Assessment of publication bias was not feasible due to the limited number of studies (<10) included in the meta-analysis. The certainty of evidence was "Moderate" for the outcomes of first attempt success for all studies, the first attempt success including only single line acoustic shadow USG, and hematoma formation. The certainty of evidence for the second attempt success was "Low" and for time to cannulation was "Very low" (Table 2).

Discussion

This systematic review, encompassing 6 randomized controlled trials ($n = 777$), concluded that acoustic shadowing-assisted USG guidance during arterial cannulation is linked to a significantly higher first-attempt success rate and reduced incidence of hematoma formation compared to unassisted ultrasound guidance.

Multiple punctures and use of multiple arterial catheters involve cost.[19,20] The use of USG to cannulate arteries has certainly improved the first attempt success with a reported rate of around 76 and 70% in experienced and inexperienced hands respectively.[4] Different methods like dynamic needle tip positioning, long axis view in-plane approach, bevel orientation, and Nitroglycerin have been used to improve first attempt success rate and to reduce complications.[21] The use of acoustic shadow to improve success rate is an easy technique and may be useful in the hands of both experts and novices.

Successful arterial cannulation comprises two crucial steps: accurately identifying the puncture point and assessing the depth of the puncture. Acoustic shadow-assisted USG guidance aids in pinpointing the puncture point accurately, while 2D USG guidance

Table 1: Study characteristics

Study ID; Design; Sample size	*Inclusion criteria*	*Proceduralist, artery*	*Acoustic shadowing procedure*	*Results*	*Procedure related adverse effects*	*Conclusion*
Siddaramaiah 2023_India; RCT;120 (c 60, DDL 60)	>18 years, undergoing major surgeries where an arterial line was required	Experienced clinicians, RA	Metal containing strands from surgical gauze were positioned parallel to one another on the USG probe. The probe was positioned so that the RA was located between these shadows in short axis view.	The success rate at the first attempt in the control (DNTP) and DDL groups was 66.7 and 71.7% respectively. The median cannulation attempt was 1 both the groups. The overall success rate among the C and DDL group was 98.3%, and 96.7%, respectively. ($p = 0.789$). The median time for RA cannulation in the C and DDL group was 71.0 (50.0–170) s and 108.0 (58.0–181.0) respectively.	Hematoma 0/60 in C and 0/60 in DDL group. Spasm 1/60 in C group and 1/60 in DDL group. Hematoma and spasm 0/60 in C group compared to 1/60 in DDL group.	RA cannulation by DNTP, as well as acoustic shadowing techniques performed by experienced clinician's in hemodynamically stable adult patients are equally advantageous.
Zou 2022_ China; RCT; 237 (C 80, SDL 78, DDL 79)	Patient undergoing bariatric surgery, Age: 18–70 years, BMI > 30	Trained anesthesia residents, RA	The metal-containing strand taken from X-ray-detectable gauze was bound to the middle of the USG probe and positioned perpendicularly to the long axis. In the SDL group, one strand was set, whereas 2 parallel strands (2 mm interval) were placed in the DDL group	First attempt success rate: SDL: 90%, DDL: 91% and C: 71%. ($p = 0.003$ and 0.001 when compared with SDL and DDL) Time to a successful first attempt: 54, 40 and 63 seconds for SDL, DDL and C respectively ($p = 0.004$ and < 0.001 when compared with SDL and DDL) Two attempt success rates: 96, 97 and 86% for SLD, DDL and C respectively ($p = 0.003$ and 0.001 when compared with SDL and DDL). No difference between SDL and DDL group in terms of success or time.	Overall complications (Vasospasm and hematoma): 10%, 9% and 29% for SDL, DDL and C respectively ($p < 0.003$ and 0.001when compared with SDL and DDL). Each of these complications were significantly lower in the SDL and DDL group compared to C. Hematoma 21, 7 and 5% for C, DDL and SDL respectively.	SDL and DDL improve first attempt success rate and reduce complication rates in obese patients.
Dong 2022_ China; RC; 101 (DDL 51, C 50)	Patients undergoing an elective surgical procedure	Post graduate students who had not performed artery puncture or received relevant training previously, RA	The metal-containing strand of the X-ray detectable surgical gauze is separated and placed on the USG probe to make it perpendicular to the long axis of the USG probe. The USG coupler and sterile 3 M membrane were applied over the USG probe to secure the USG probe and the metal-containing strand	First attempt success rate: DDL: 74.51% and C: 52%. ($p = 0.019$). Time to a successful first attempt: 10.43 ± 2.38 and 14.78 ± 8.02 seconds for DDL and C respectively ($p = 0.012$)	Hematoma: 15.7% and 24% in DDL and C respectively ($p = 0.295$)	Using acoustic shadowing-facilitated USG guided arterial catheterization. Standardized teaching of residents can help students master the skills more quickly and increase the first-attempt success rate.

(Contd...)

Table 1: *(Contd...)*

Study ID; Design; Sample size	*Inclusion criteria*	*Proceduralist, artery*	*Acoustic shadowing procedure*	*Results*	*Procedure related adverse effects*	*Conclusion*
Quan 2014_ China; RCT; 163 (SDL 81, C 82)	Patients undergoing liver surgery or splenic resection under GA.	Experienced anesthesiologists, who had previously cannulated 450 arteries and used the USG-guided technique for approximately 200 procedures, RA	A suture was tied on the midpoint of the ultrasound probe (a developing line) and perpendicular to the long axis as a guide. (Compared with long axis plane technique)	First attempt success rate: SDL: 88.9% and C: 73.2%. ($p = 0.015$). Two attempt success rates: 96.3 and 95.1% for SLD and C respectively ($p = 1.0$) Time to a successful cannulation (mean (SD): 29.7 (17.20) and 26.2 (9.8) seconds for SDL and C respectively.	No thrombosis, edema, or vasospasm in either group. Hematoma: 14.8% and 18.3% in SDL and C respectively ($p =$ 0.674)	The modified short axis out of plane technique may improve the success rate of cannula insertion into the radial artery on the first attempt
Quan 2019 (A)_ China; RCT; 79 (DDL 39, C 40)	Children age range, 4–24 months; weight range, 4–10 kg undergoing elective surgical procedure	Attendants who had performed more than 50 USG guided punctures, radial artery	The metal-containing strand taken from X-ray–detectable surgical gauze was bound parallelly (interval: 2 mm) to the USG probe and positioned perpendicular to the long axis of the probe. An ultrasonic couplant and sterile 3M membrane were applied over the USG probe to fix the DDL.	First attempt success rate: DDL: 90% and C: 60%. ($p = 0.002$). Time to a successful cannulation (median (IQR): 24 (15, 41) and 40 (23, 56) seconds for DDL and C respectively) ($p = 0.012$)	Bleeding at the puncture site: 10 vs 30% in the DDL and C group respectively ($p = 0.029$) Hematoma: 8 and 18% in DDL and C respectively ($p = 0.19$)	Acoustic shadowing via the use of DDL significantly improved the success rate of radial artery puncture in young children, compared with that achieved with the use of traditional USG guidance.
Quan 2019 (B)_ China; RCT; 77 (SDL 39, C 38)	Adults 18–60 years schedule to undergo elective hepatectomy or splenectomy with GA	USG trained interns, RA	A suture was tied on the midpoint of the ultrasound probe (a developing line) and perpendicular to the long axis as a guide.	First attempt success rate: SDL: 71.79%, C: 34.21% (proportion difference: –0.3408 (95% CI, –0.5483 to –0.1334), $p = 0.0025$) Cannula insertion failure rates were SDL: 5.13% and C: 18.42% (proportion difference: 0.1329 (95% CI, –0.0084 to 0.2743), $p = 0.0866$) Time to successful cannulation: No significant between-group difference (mean difference: –4.90 s (95% CI, –11.85–2.04 s), $p = 0.1637$)	Vasospasm: No significant between-group difference was observed (proportion difference: –0.0963 (95% CI, –0.3316 to 0.1391), $p = 0.4361$] Hematoma: No difference (proportion difference: –0.0963% (95% CI, –0.1391–0.3316), $p = 0.4361$) No instances of thrombosis, occlusion, or aneurysm occurred in this study	Use of USG with developing line significantly improved the success rate of radial artery puncture performed by interns.

BMI, body mass index; C, control; DDL, double developing line; DNTP, dynamic needle tip positioning; GA, general anesthesia; IQR, inter quartile range; RA, radial artery; RCT, randomized controlled trial; SDL, single developing line; SD, standard deviation; USG, ultrasonography

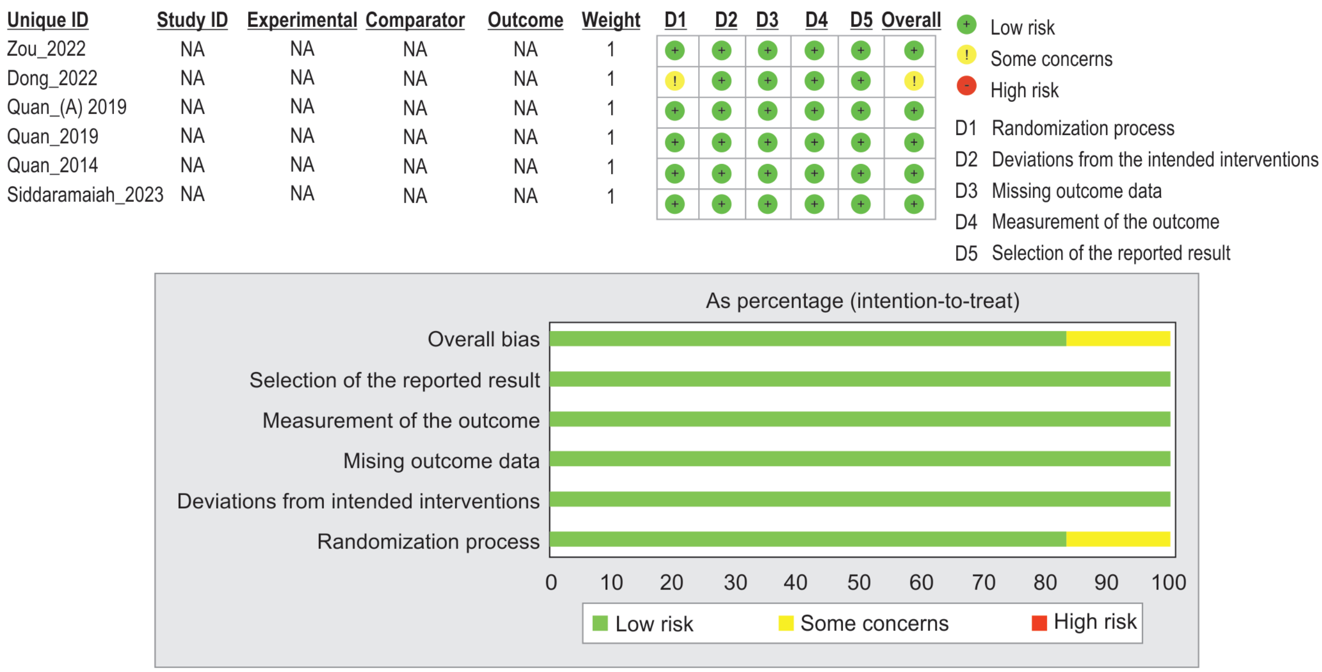

Fig. 2: Risk of bias and applicability concerns summary

Study or subgroup	Acoustic shadowing USG Events	Total	Unassisted USG Events	Total	Weight	Risk ratio IV, Random, 95% CI
Dong_2022	13	51	24	50	20.9%	0.53 [0.31, 0.92]
Quan_2014	9	81	22	82	15.0%	0.41 [0.20, 0.84]
Quan_2019	11	39	25	38	20.9%	0.43 [0.25, 0.74]
Quan_2019 (A)	4	39	16	40	8.8%	0.26 [0.09, 0.70]
Siddaramaiah_2023	17	60	20	60	21.5%	0.85 [0.50, 1.46]
Zou_2022	7	79	23	80	12.9%	0.31 [0.14, 0.68]
Total (95% CI)		**349**		**350**	**100.0%**	**0.47 [0.34, 0.66]**
Total events	61		130			

Heterogeneity: Tau² = 0.05; Chi² = 7.48, df = 5 (*p* = 0.19); I² = 33%
Test for overall effect: *Z* = 4.48 (*p* < 0.00001)

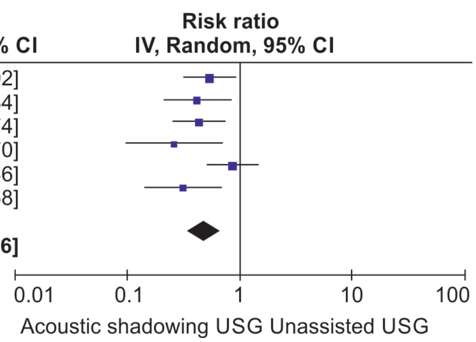

Fig. 3: Forest plot showing first attempt arterial cannulation success rate to be significantly better with the use of acoustic shadow compared to unassisted USG
CI, confidence interval; IV, inverse variance; USG, ultrasound

Study or subgroup	Acoustic shadowing USG Events	Total	Unassisted USG Events	Total	Weight	Risk ratio IV, Random, 95% CI
Quan_2014	3	81	4	82	32.2%	0.76 [0.18, 3.29]
Siddaramaiah_2023	3	60	5	60	35.9%	0.60 [0.15, 2.40]
Zou_2022	2	79	11	80	31.9%	0.18 [0.04, 0.80]
Total (95% CI)		**220**		**222**	**100.0%**	**0.44 [0.19, 1.03]**
Total events	8		20			

Heterogeneity: Tau² = 0.02; Chi² = 2.07; df = 2 (*p* = 0.36); I² = 3%
Test for overall effect: *Z* = 1.88 (*p* = 0.06)

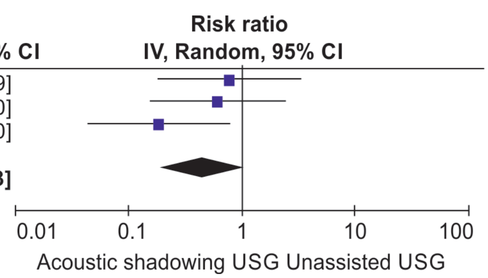

Fig. 4: Forest plot showing no significant difference in second attempt success rate between acoustic shadow and unassisted USG
CI, confidence interval; IV, inverse variance; USG, ultrasound

	Acoustic shadowing USG		Unassisted USG			Risk ratio
Study or subgroup	Events	Total	Events	Total	Weight	IV, Random, 95% CI
Quan_2014	9	81	22	82	27.8%	0.41 [0.20, 0.84]
Quan_2019	11	39	25	38	46.5%	0.43 [0.25, 0.74]
Zou_2022	8	78	23	80	25.7%	0.36 [0.17, 0.75]
Total (95% CI)		**198**		**200**	**100.0%**	**0.41 [0.28, 0.59]**
Total events	28		70			

Heterogeneity: Tau² = 0.00; Chi² = 0.16; df = 2 (p = 0.92); I² = 0%
Test for overall effect: Z = 4.72 (p = 0.00001)

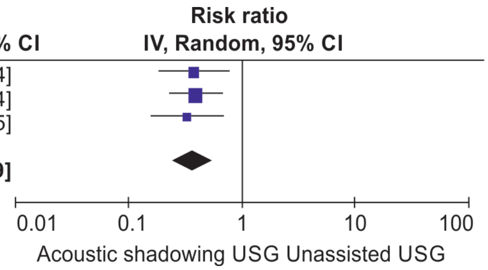

Fig. 5: Forest plot showing first attempt arterial cannulation success rate to be significantly better with the use of single acoustic shadow compared to unassisted USG
CI, confidence interval; IV, inverse variance; USG, ultrasound

	Acoustic shadowing USG		Unassisted USG			Risk ratio
Study or subgroup	Events	Total	Events	Total	Weight	IV, Random, 95% CI
Dong_2022	8	51	12	50	23.5%	0.65 [0.29, 1.46]
Quan_2014	12	81	15	82	29.8%	0.81 [0.40, 1.62]
Quan_2019	5	39	11	38	17.5%	0.44 [0.17, 1.15]
Quan_2019 (A)	3	39	7	40	10.4%	0.44 [0.12, 1.58]
Siddaramaiah_2023	0	60	0	60		Not estimable
Zou_2022	5	79	21	80	18.6%	0.24 [0.10, 0.61]
Total (95% CI)		**349**		**350**	**100.0%**	**0.52 [0.34, 0.80]**
Total events	33		66			

Heterogeneity: Tau² = 0.04; Chi² = 4.70; df = 4 (p = 0.32); I² = 15%
Test for overall effect: Z = 2.99 (p = 0.003)

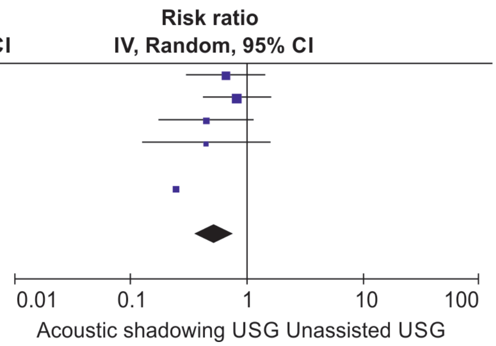

Fig. 6: Forest plot showing significantly less hematoma formation in the acoustic USG group compared to unassisted USG
CI, confidence interval; IV, inverse variance; USG, ultrasound

	Acoustic shadowing USG			Unassisted USG				Std. Mean difference
Study or subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Dong_2022	10.43	2.38	51	14.78	8.02	50	16.5%	–0.73 [–1.14, –0.33]
Quan_2014	29.7	17.2	81	26.2	9.8	82	17.4%	0.25 [–0.06, 0.56]
Quan_2019	31.1	17.9	39	27.6	12.6	38	16.0%	0.22 [–0.22, 0.67]
Quan_2019 (A)	26.66	20.01	39	39.66	25.37	40	16.0%	–0.56 [–1.01, –0.11]
Siddaramaiah_2023	115.66	93.43	60	97	91.15	60	16.9%	0.20 [–0.16, 0.56]
Zou_2022	46.33	27.94	79	90.66	59.64	80	17.2%	–0.95 [–1.27, –0.62]
Total (95% CI)			**349**			**350**	**100.0%**	**–0.26 [–0.72, 0.20]**

Heterogeneity: Tau² = 0.29; Chi² = 45.03; df = 5 (p < 0.00001); I² = 89%
Test for overall effect: Z = 1.11 (p = 0.27)

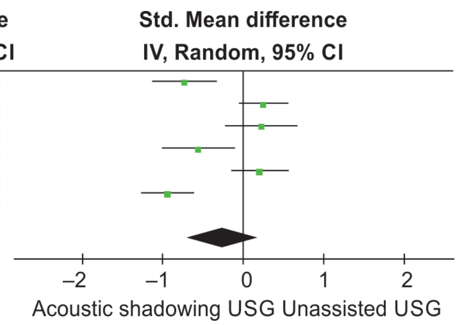

Fig. 7: Forest plot did not show a significantly less time to canulation with acoustic assisted USG compared to unassisted USG
CI, confidence interval; IV, inverse variance; USG, ultrasound

assists in determining the depth, thus complementing each other in the process. It is important to have a guiding line or two guiding lines to ascertain the puncture point, which can be done by either using acoustic shadow or in some USG machines using M mode.[22] However, the M mode can only draw a single line corresponding to the center of the USG probe and not 2 lines. Is the use of 2 lines more accurate than 1 line in determining the point of puncture? The answer is still unclear. One of the included studies has compared first-attempt success rates between single and double-developing lines and did not find any significant difference.[16] In addition, pooling RRs from studies that have reported first-attempt success rates using single or double acoustic lines were no different. However, this needs to be tested in a setting where inexperienced physicians are undertaking this procedure.

Preparation of the USG probe to produce an acoustic line is cumbersome, takes time, and might compromise asepsis integrity. Future USG probes can be designed to have either one or two central M mode line along with probe markings to facilitate cannula insertion.

Our systematic review possesses several strengths, particularly its robust methodology incorporating risk of bias assessment and sensitivity analyses. To the best of our knowledge, this represents the inaugural systematic review with meta-analysis on this subject. Nonetheless, our review also presents several limitations. The pool of studies and participants was constrained. A publication bias assessment couldn't be conducted due to the scant number of studies. The studies included in our review encompassed diverse patient cohorts, and the USG operators exhibited varying levels of experience, potentially introducing notable heterogeneity. Additionally, achieving blinding of clinicians to the study intervention was unattainable in all included trials, possibly leading to performance bias.

Table 2: Grade analysis

	Certainty assessment							No. of patients		Effect	
Outcomes	*No. of studies*	*Study design*	*Risk of bias*	*Inconsistency*	*Indirectness*	*Imprecision*	*Other considerations*	*Acoustic shadow ultrasound*	*Unassisted ultrasound*	*Relative (95% CI)*	*Certainty*
First attempt success	6	Randomised trials	Not serious[a]	Not serious	Not serious	Not serious	Publication bias strongly suspected[b]	61/349 (17.5%)	130/350 (37.1%)	RR 0.47 (0.34–0.66)	⊕⊕⊕◯ Moderate
Second attempt success	3	Randomised trials	Not serious[a]	Not serious	Not serious	Seriousc	Publication bias strongly suspected[b]	8/220 (3.6%)	20/222 (9.0%)	RR 0.44 (0.19–1.03)	⊕⊕◯◯ Low
Single developing line first attempt success	3	Randomised trials	Not serious[a]	Not serious	Not serious	Not serious	Publication bias strongly suspected[b]	28/198 (14.1%)	70/200 (35.0%)	RR 0.41 (0.28–0.59)	⊕⊕⊕◯ Moderate
Haematoma formation	6	Randomised trials	Not serious[a]	Not serious	Not serious	Not serious	Publication bias strongly suspected[b]	33/349 (9.5%)	66/350 (18.9%)	RR 0.52 (0.34–0.80)	⊕⊕⊕◯ Moderate
Time to cannulation	6	Randomised trials	Not serious	Very serious[d]	Not serious	Very serious[c]	Publication bias strongly suspected[b]			not estimable	⊕◯◯◯ Very low

CI, confidence interval; RR, risk ratio. [a]Selection and performance bias; [b]Publication bias could not be assessed since there are less than 10 studies; [c]Wide confidence intervals; [d]High statistical heterogeneity

Conclusions

Acoustic shadowing assisted USG during arterial cannulation is associated with a significantly higher first-attempt success rate and less hematoma formation compared to unassisted USG. Future RCTs should be conducted in various clinical settings like ICUs and emergency departments on patients with compromised hemodynamics. Studies should also endeavor to report success rates by experienced and inexperienced clinicians using single or double acoustic shadow.

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