Ultrasound for Pediatric Peripheral Intravenous Catheter Insertion: A Systematic Review

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abstract

BACKGROUND AND OBJECTIVES: Establishing peripheral intravenous catheter (PIVC) access in infants and children is a common procedure but can be technically difficult. The primary objective was to determine the effect ultrasound had on first attempt PIVC insertion success rates in the pediatric population. Secondary objectives included overall success rates and subgroups analyses.

METHODS: A systematic review of articles using Medline, Embase, CENTRAL, World Health Organization International Clinical Trials Registry Platform, and ClinicalTrials.gov. Randomized trials evaluating ultrasound-guided PIVC insertion against the landmark approach in pediatric patients who reported at least 1 outcome of success rate (first attempt or overall) were included. Methodological quality of the literature was assessed using the Revised Cochrane risk-of-bias tool for randomized trials. A meta-analysis using a random-effects model was performed.

RESULTS: Nine studies with 1350 patients, from a total of 1033 studies, were included for analysis. Ultrasound showed a statistically significant improvement in PIVC insertion success on first attempt in 5 of 8 studies, with an overall success rate of 78% in the ultrasound group and 66% in the control group. The secondary outcome of overall success was improved by ultrasound in studies that allowed ≥3 attempts (pooled OR 3.57, 95% CI 2.05 to 6.21, $P < .001$, $I^2 = 0.0\%$).

CONCLUSIONS: This systematic review suggested that ultrasound improves pediatric PIVC first pass and overall success rates. Subgroup analysis showed improvement in PIVC success rates for patients with difficult intravenous access and a single operator, dynamic, short-axis ultrasound technique.

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Dr Mitchell conceptualized and designed the systematic review, extracted, and analyzed the data, performed the statistical analysis, drafted the initial manuscript, and reviewed and revised the manuscript; Dr Jones analyzed the data, performed the statistical analysis, and reviewed and revised the manuscript; Dr Snelling conceptualized and designed the systematic review, extracted, and analyzed the data, drafted the initial manuscript, and reviewed and revised the manuscript; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

This trial has been registered at PROSPERO database of systematic review protocols (identifier CRD42020213387).

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Peripheral intravenous catheter (PIVC) insertion in children is a common procedure that can be challenging. Vessel selection and catheterization has been traditionally performed with the aid of anatomic landmarks, including the inspection and palpation of veins. This can be technically difficult in a child due to their relatively smaller caliber vessels and increased subcutaneous tissue adiposity commonly encountered in infants and toddlers but also in older children, with increasing rates of childhood obesity worldwide.[1] The first attempt success rates in pediatric cohorts using traditional techniques have been recorded as low as 53%,[2] leading to prolonged discomfort and delays in management with ongoing attempts.[3,4] Therefore, techniques to increase PIVC insertion success in children is highly desirable for both the clinician and child.

Point-of-care ultrasound or bedside ultrasound, hereafter referred to as ultrasound, in pediatric medicine is increasingly used for procedural guidance, as a noninvasive tool that can safeguard the needle tip trajectory and increase success rates.[5,6] Ultrasound is a known effective adjunct in adult PIVC insertion,[7] particularly in patients deemed to have difficult intravenous access (DIVA),[8] but the association is less clear in children.[9–12] Given that children are often noncompliant for procedures and generally have smaller target vessels, the use of ultrasound conceptually adds another element of complexity.

With a significant growth in published data, a dedicated meta-analysis to clarify the clinical effectiveness of ultrasound for PIVC in pediatric patients is warranted. Additionally, with multiple ultrasound techniques, clinical settings, and patient demographics, a review of these subgroups within the literature would provide further guidance to its role. In this systematic review and meta-analysis, we aimed to assess the effect ultrasound has on PIVC insertion success rates in the pediatric population, compared with traditional landmark-based approaches. The primary outcome was first attempt success rate. Secondary outcomes included overall success rates, time to successful catheterization, and post hoc analysis of subgroup data available in ≥3 studies.

METHODS

This systematic review with meta-analysis was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. The study was prospectively registered in the PROSPERO database of systematic review protocols (CRD42020213387).

Search Strategy

Medline, Embase and CENTRAL databases were systematically searched on November 27th, 2020, based on predefined variables (Supplemental Information). This involved using controlled vocabularies where possible (MeSH and EMTREE headings) with wider free text and synonyms using nesting and use of "OR" Boolean operator. No limits were applied to the variables of "age" or "language," to not limit studies. Publications were searched from January 1, 2000 to November 27, 2020. Publication type was restricted to randomized controlled trials (RCTs) through The Cochrane Highly Sensitive Search Strategies for identifying randomized trials. This search was supplemented by reviewing the reference lists of all full text individual papers, including preprints, identified as eligible studies. ClinicalTrials.gov and World Health Organization International Clinical Trials Registry Platform were also concurrently searched for unpublished trials with preliminary data (search limited to pediatric studies with results available). To augment this, a SCOPUS (Elsevier B.V.) database search was performed on final included studies.

Study Selection

Search results were imported to EndNote (X9, Clarivate Analytics, PA). Two reviewers (E.M. and P.S.) independently identified potentially eligible studies for inclusion using a stepwise approach, including removal of duplicates, manual screening by title, and abstract removing papers that clearly did not meet the eligibility criteria (Table 1), and then full text review of the remaining studies. RCTs describing the success rate (first attempt or overall) of ultrasound-guided PIVC insertion in children (<18 years) were included. Studies were excluded if they did not have an adequate reference standard (landmark technique) or studied central venous (eg, peripherally inserted central catheter, or central venous line) or arterial access (Table 1).

Outcome Measures

The primary outcome measure was first attempt success of ultrasound-guided PIVC insertion, compared with the first attempt success of traditional landmark-based techniques. Secondary outcome measures included overall success of PIVC insertion and the time to catheterization success in the ultrasound-guided and landmark groups.

TABLE 1 Eligibility Criteria

Inclusion
Pediatric patients <18 y
Inclusion of case data from studies with a broader age range only if these studies reported separate data within the <18 eligibility age range.
Intravenous access
All patient groups and access attempts eg, known difficult intravenous access)
Ultrasound assisted techniques, any type (static or dynamic; single or dual operator; long or short-axis)
Traditional landmark approach reported as reference standard
Prospective, randomized study design
Reports success rate (first attempt or overall), catheterization attempt number, or time to successful catheterization
Exclusion
Adult patients ≥ 18y
Central venous access (eg, peripherally inserted central catheter, central venous line), arterial access
Retrospective study design, nonrandomized or not specified
Inadequate reference standard

Data Extraction

Initially, 2 reviewers (E.M. and P.S.) independently screened eligible studies gathered according to the above-described approach on title and abstract, and classified them as being relevant, potentially relevant, or not relevant. Next, the full text of the articles that were classified as being relevant were analyzed by both reviewers independently, deciding individually whether they were eligible, based on the inclusion and exclusion criteria (Table 1). Any discrepancy between reviewers was resolved with a final decision from a third independent investigator (P.J.). Eligibility of studies initially classified as potentially relevant was also decided by the third investigator, after which those studies with a positive final decision were included. Data tables were developed, modeled off Cochrane data extraction forms for RCTs.[13] Data were extracted under subgroups of study details, eligibility, demographics, specific patient cohort details, study design, catheterization details, ultrasound details, and outcomes, using an Excel spreadsheet (Microsoft Corp, Redmond, WA). These data were independently collected and verified by both reviewers (E.M. and P.S.).

Quality Assessment

Methodological quality of each study was assessed at the study inclusion level using the Revised Cochrane risk-of-bias tool for randomized trials (RoB 2).[14] This tool provides a standardized, table-based approach to assessment for selection, detection, attrition, and reporting bias.[15] Individual templates were independently completed by 2 reviewers (E.M. and P.S.) with overall risk of bias judgement reported before any disagreements resolved by discussion.

Statistical Analysis

Extracted data were analyzed using Stata (16.1, StataCorp LLC, TX) software. Pooled odds ratio (OR) and percentage success rate were derived for dichotomous variables (first attempt and overall success) and weighted mean difference (WMD) for continuous variables (time to catheterization) for the comparison of ultrasound to landmark approaches. DerSimonian-Laird random-effects model was used for all outcome measures. I^2 was calculated as a quantifying measure of heterogeneity, with $I^2 > 60\%$ defined as significant heterogeneity. Forest plots were used to present results for each outcome, with meta-analysis results included when significant heterogeneity was not present. Funnel plots were used to look for evidence of publication bias. A sensitivity analysis was performed by excluding studies with alternate study designs.

Post hoc analysis by subgroup was performed for identified important variables with data available from at least 3 studies (Supplemental Table 6). These categories included age ≤3 years, physician operator, clinical setting (“emergency department,” “operating room”), ultrasound technique (“dynamic,” “single operator,” “short axis”), site (“lower limb,” “other”), sedation, and “difficult intravenous access.”

RESULTS

Study Selection, Characteristics, and Quality

Initial search of CENTRAL, Embase, and Medline identified 1033 total articles, and after removal of duplicates, 759 remained (Fig 1). Title and abstract screening reduced this to 41 papers for full text evaluation. Of these, 12 studies were excluded without a pediatric cohort of patients, 3 without landmark catheterization as a control, 1 without an inclusion outcome, 2 containing the same data set of an included study, 1 was a comparative trial with nonrandom consecutive allocation of patients, and 13 listed trials without published works or results available. The remaining 9 studies underwent a SCOPUS database search, as well as manual review of their reference list, without any further eligible studies identified. Trials databases found 1 eligible study with published results

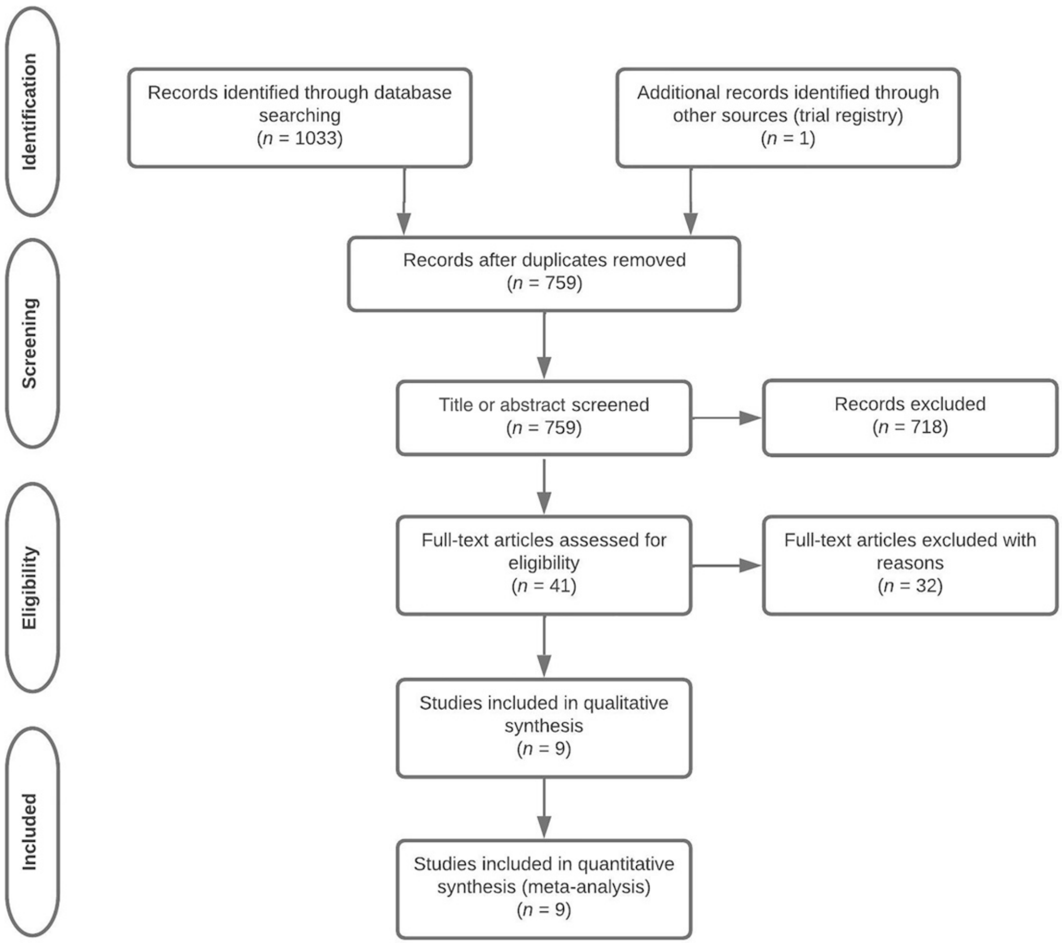

FIGURE 1
Study selection flowchart.

but it had already been included.[16] Manual review of related published systematic reviews failed to identify missing studies.[9–12]

A total of 1350 patients across the 9 eligible studies were included for analysis (Table 2).[16–24] One study only included patients less than 5 years of age,[20] while 4 studies were limited to patients ≤3 years of age.[16,19–21,23] The male proportion was 58.4%, with 1 study not reporting sex.[20] Distinct intervention and control groups were present throughout, other than Gopalasingam et al[23] being a crossover study. Bian

TABLE 2 Demographics and Design of Included Studies

Study	Year	Location	Sample Size, *n*	Age, y, median		Sex, male, %		Design
				Ultrasound	LM	Ultrasound	LM	
Avelar et al[18]	2015	Brazil	335	8.20	7.20	55.9	55.2	Prospective RCT
Bian et al[19]	2020	China	144	0.58	0.58	66.7	59.7	Prospective RCT
Bair et al[20]	2008	USA	44	1.17	0.58	NR		Prospective RCT
Benkhadra et al[21]	2012	France	40	1.25	1.15[a]	60.0	75.0	Prospective RCT
Curtis et al[17]	2015	Canada	418	7.00	5.95	54.0	57.9	Prospective RCT
Doniger et al[22]	2009	USA	50	2.90	1.80[a]	40.0	60.0	Prospective RCT
Gopalasingam et al[23]	2017	Denmark	50	1.25[b]		70[b]		Prospective, Crossover
Hanada et al[16]	2017	USA	102	0.67	1.00	68.6	52.9	Prospective RCT
Vinograd et al[24]	2019	USA	167	2.10	2.10	51.8	46.4	Prospective RCT

LM, Landmark control group; NR, not reported; RCT, randomized controlled trial.
[a] Age expressed as mean, not median.
[b] Total value, study subgroup statistics not reported.

et al[19] was the only paper not yet published in a peer reviewed journal at the time of initial search.

Six studies included only patients with DIVA, defined as either catheterization attempt(s) failure, age ≤3 years, history of DIVA or use of validated tool,[16,19–22,24] with Bian et al[19] also limited to infants or toddlers with congenital heart disease (Supplemental Table 7). Four studies provided sedation during catheterization attempt, all conducted in the operating room.[16,19,21,23] Two studies used solely the static (vein marked) ultrasound technique,[19,20] and the rest performed dynamic (real-time needle guidance) ultrasound[16,21–24] or a mixture of the 2 techniques.[17,18] Catheterization sites varied, with 3 studies predominantly[21] or only[16,19] using lower limbs.

There was significant methodological variability between studies for total number of catheterization attempts, ranging from 2 to 4 total attempts, and with and without total time limits.[16,19,21–24] This subsequently affected overall success and number of attempt rates. Vinograd et al[24] measured time to catheterization from randomization while all other studies reporting time from procedure commencement (ultrasound placement versus tourniquet placement) to PIVC flush without evidence of extravasation.

None of the included studies were assessed to be at high risk of bias, allocated either low risk or as having some concerns regards bias (Table 3). Of concern there was an alternative patient allocation strategy in Gopalasingam et al,[23] with a crossover study design. Given its structured allocation and general inability to blind intervention, it was included in the analysis. The funnel plots showed no obvious asymmetry to indicate publication bias (Supplemental Figures 6–8).

Primary Outcome: First Attempt Success

First attempt success was reported in 8 studies, with a total of 623 patients in the ultrasound group and 637 in the control group (Table 4). Statistically significant improvement in first attempt success with ultrasound was detected in 5 of 8 studies (Fig 2). Overall, first attempt success rate was 78% in the ultrasound group compared with 66% in the control group (Table 4). Meta-analysis suggested improvement in likelihood of catheterization success on the first attempt with ultrasound compared with the landmark technique, with pooled OR 2.61 (95% CI 1.18 to 5.76, $P = .018$). However, this analysis was limited by significant heterogeneity, with $I^2 = 86.4\%$. Sensitivity analysis with Gopalasingam et al[23] excluded showed similar results, including excessive heterogeneity (pooled OR 2.52, 95% CI 1.04 to 6.09, $P = .041$, $I^2 = 87.9\%$). A funnel plot of individual effect estimates showed significant heterogeneity but no asymmetry to suggest reporting bias (Supplemental Fig 6).

Secondary Outcome: Overall Success

Six studies reported overall success rates, with a total of 300 patients in the ultrasound group and 301 patients in the control group (Table 4). Of those 6 studies, 4 showed statistically significant improvement in overall success with ultrasound, with a combined success rate of 93% in the ultrasound group and 78% in the control group. Meta-analysis showed that ultrasound improved overall success rates compared with the landmark technique, with pooled OR 3.57 (95% CI 2.05 to 6.21, $P < .001$) (Fig 3). Heterogeneity of this secondary outcome measure was low, with $I^2 = 0.0\%$. Sensitivity analysis with removal of Gopalasingam et al[23] showed similar results (pooled OR 3.33, 95% CI 1.89 to 5.87, $P < .001$, $I^2 = 0.0\%$).

TABLE 3 Risk of Bias Assessment Using the Revised Cochrane Risk-of-Bias Tool for Randomized Trials (RoB 2)

Study	Randomization Process	Assignment to Intervention	Adhering to Intervention	Missing Outcome Data	Measurement of the Outcome	Selection of the Reported Result	Overall Risk of Bias
Avelar et al[18]	↓	↔	↔	↓	↔	↓	↔
Bian et al[19]	↓	↓	↔	↓	↓	↓	↓
Bair et al[20]	↔	↔	↔	↓	↓	↓	↔
Benkhadra et al[21]	↓	↓	↓	↓	↓	↓	↓
Curtis et al[17]	↓	↓	↓	↓	↓	↓	↓
Doniger et al[22]	↓	↔	↓	↓	↔	↓	↓
Gopalasingam et al[23]	↔	↔	↓	↓	↓	↔	↔
Hanada et al[16]	↓	↓	↓	↓	↓	↓	↓
Vinograd et al[24]	↓	↓	↓	↓	↓	↓	↓

↓, low bias. ↔, some concerns. ↑, high bias.

TABLE 4 First Attempt Success, Overall Success, and Time to Catheterization of Included Studies

Study	First Pass Success: Ultrasound, % (*n*/*N*)	First Pass Success: Control, % (*n*/*N*)	First Pass Success: OR (95% CI)	Overall Success: Ultrasound, % (*n*/*N*)	Overall Success: Control, % (*n*/*N*)	Overall Success: OR (95% CI)	Time to Catheterization[a]: Ultrasound	Time to Catheterization[a]: Control	Time to Catheterization[a]: Difference (95% CI)
Avelar et al[18]	85.6 (161/188)	91.8 (178/194)	0.5 (0.28 to 1.03)	—	—	—	—	—	—
Bian et al[19]	63 (45/72)	38 (27/72)	2.8 (1.4 to 5.5)	90 (65/72)	78 (56/72)	2.6 (1.01 to 6.9)	60 (72)	108 (72)	−47 (−70 to −25)
Bair et al[20]	35 (8/23)	29 (6/21)	1.3 (0.37 to 4.79)	—	—	—	—	—	—
Benkhadra et al[21]	85 (17/20)	35 (7/20)	10.5 (2.3 to 48.8)	90 (18/20)	85 (17/20)	1.6 (0.24 to 10.7)	88 (20)	463 (20)	−375 (−580 to −169)
Curtis et al[17]	70.8 (97/137)	74.7 (109/146)	0.82 (0.49 to 1.39)	—	—	—	498 (146)	390 (146)	108 (−81 to 297)
Doniger et al[22]	—	—	—	80 (20/25)	64 (16/25)	2.3 (0.63 to 8.06)	378 (25)	864 (25)	−486 (749 to 223)
Gopalasingam et al[23]	84 (42/50)	60 (30/50)	3.5 (1.4 to 9.0)	100 (50/50)	84 (42/50)	20.2 (1.1 to 360.3)	235 (50)	155 (50)	80 (10 to 149)
Hanada et al[16]	90 (46/51)	51 (26/51)	8.8 (3.0 to 25.9)	92 (47/51)	63 (32/51)	7.0 (2.2 to 22.4)	238 (51)	171 (102.2)	67 (30 to 105)
Vinograd et al[24],[b]	85 (70/82)	46 (38/83)	6.9 (3.3 to 14.6)	98 (80/82)	89 (74/83)	4.9 (1.01 to 23.3)	903 (82)	1722 (83)	−819 (−1087 to −551)
Total	78.0 (486/623)	66.1 (421/637)	2.61 (1.18 to 5.76) (P = .018)	93.3 (280/300)	78.7 (237/301)	3.57 (2.05 to 6.21) (P < .001)	—	—	−131.0 (−240.2 to −21.8)
Heterogeneity	I^2 = 86.4%	I^2 = 0.0%				I^2 = 93.6%			

Continuity correction of 0.5 applied for categorical results with count 0. CI, confidence Interval; OR, odds ratio; —, not applicable.
[a] Time to catheterization reported as mean time in seconds (number of patients).
[b] Vinograd et al[24] used alternate measure of time to other studies (from randomization).

Secondary Outcome: Time to Catheterization Success

Time to success was reported in 7 studies. Statistically significant improvement in time to success was seen in 4 out of 7 studies (Table 4). The weighted mean difference was 131 seconds (95% CI 22 seconds to 240 seconds, P = .019) improvement in time to catheterization in the ultrasound group (Fig 4). However, this analysis was limited by marked heterogeneity (I^2 = 93.6%). Vinograd et al[24] was identified as a statistical outlier with markedly different time to catheterization outcome data, related to an alternate measure of time compared with other studies (from randomization). Sensitivity analysis after removal of Vinograd et al[24] and Gopalasingam et al[23] showed no difference in time to catheterization, with heterogeneity remaining very high (WMD = 87 seconds, 95% CI −24 to 199 seconds, P = .125, I^2 = 92.2%)

Subgroup Analysis

Meta-analyses of data by subgroup showed statistically significant improvements in likelihood of first attempt success rates with ultrasound-guided PIVC insertion compared with the landmark technique for the subgroups of: physician operator, operating room setting, dynamic ultrasound technique, single operator ultrasound technique, lower limb site, sedation, and DIVA (Table 5, Fig 5). All of these subgroups also had acceptable heterogeneity, with $I^2 < 60\%$. Four studies (Bian et al,[19] Benkhadra et al,[21] Gopalasingam et al,[23] and Hanada et al[16]) were conducted in the operating room with patients receiving sedation, with improvement in first attempt success seen in this subgroup (n = 386, pooled OR 4.58, 95% CI 2.45 to 8.56, P < .001, I^2 = 37.6%). Ultrasound also improved first

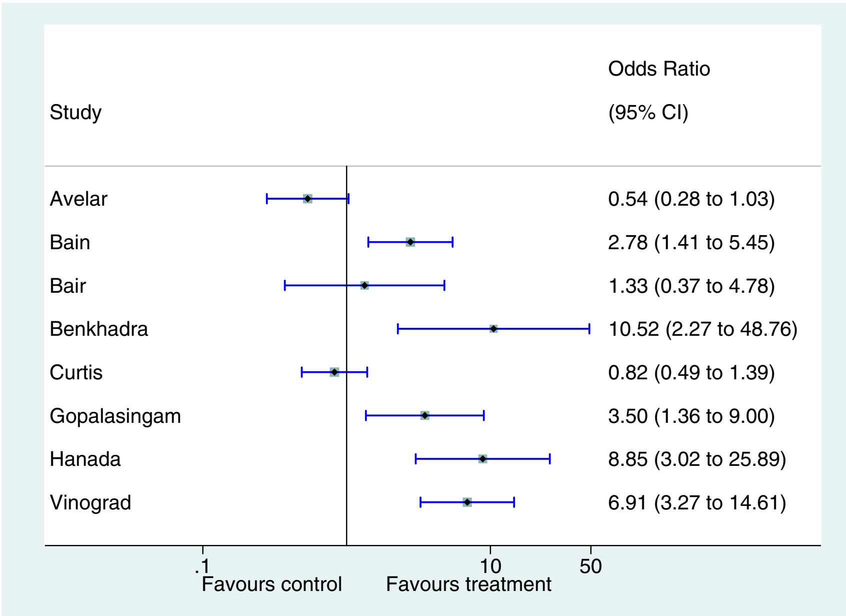

FIGURE 2
First attempt success forest plot. CI, confidence interval.

attempt success in patients with difficult IV access (n = 495, pooled OR 4.60, 95% CI 2.34 to 9.07, $P < .001$, $I^2 = 57.4\%$). Improvement was not demonstrated in the emergency department (ED) subgroup, which was also limited by high heterogeneity (n = 492, OR 1.98, 95% CI 0.45 to 8.69, $P = .368$, $I^2 = 90.4\%$). The combination of single operator, dynamic, and short-axis technique was used in Gopalasingam et al,[23] Hanada et al,[16] and Vinograd et al,[24] and was associated with marked improvement in first attempt success (n = 367, pooled OR 5.97, 95% CI 3.57 to 10.0, $P < .001$, $I^2 = 0.0\%$). The subgroup analysis of overall success showed similar results, with improved success with ultrasound seen for the subgroups of age 3 or less, physician operator, operating room setting, dynamic, single operator and short-axis ultrasound technique, both lower limb and other catheterization sites, sedation, and DIVA (Table 5, Fig 5).

DISCUSSION

This systematic review suggested that the use of ultrasound increased

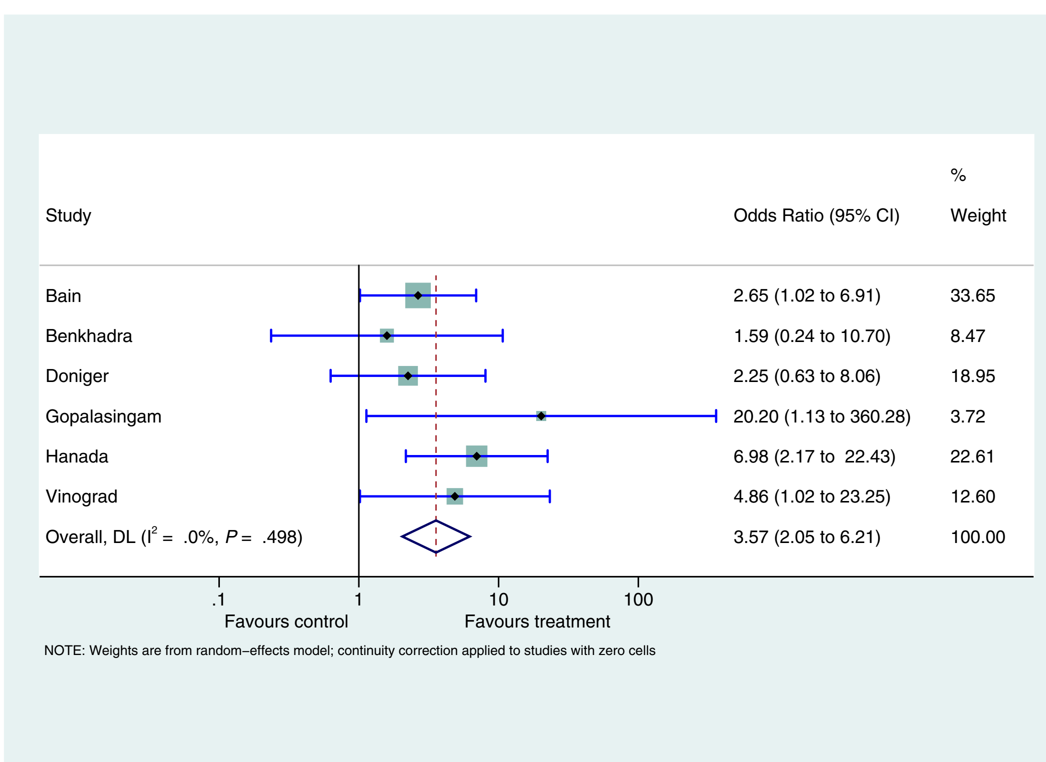

FIGURE 3
Overall success meta-analysis results and forest plot. CI, confidence interval.

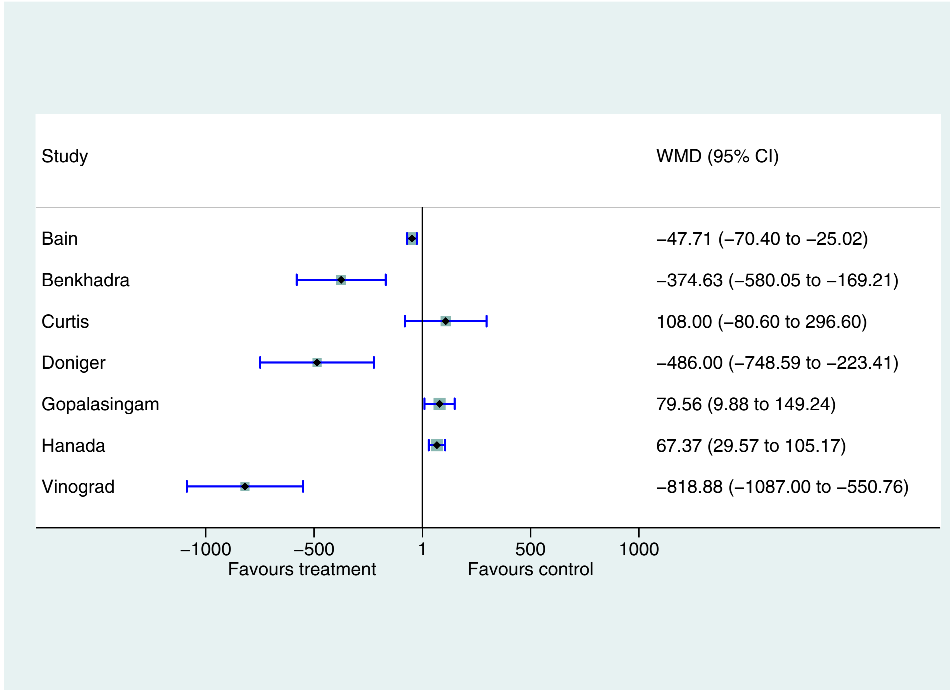

FIGURE 4
Time to catheterization forest plot. CI, confidence interval; WMD, weighted mean difference.

first attempt and overall success PIVC insertion rates in pediatric patients compared with a standard (landmark) approach. Previous systematic reviews on the topic of ultrasound for pediatric PIVC insertion were limited by a paucity of studies to enable a dedicated meta-analysis.[9–12,25] A systematic review on pediatric catheterization strategies has been published with only 3 clinical papers identified and did not support the use of ultrasound, necessitating the need for further RCTs.[25] The uptake of ultrasound-guided PIVC insertion has since burgeoned over the past decade, along with numerous studies supporting its benefit in the pediatric population.[16,19,21,23,24] This systematic review showed statistically significant improvement in first attempt and overall success with ultrasound in the majority of included studies. Meta-analysis demonstrated improved rates of overall success with ultrasound. However, meta-analysis of the primary outcome of first attempt success was limited by high heterogeneity.

The predominant application for ultrasound-guided PIVC insertion is in patients considered to have DIVA.[8] The definition for this in children is broad and includes factors such as having no visible and/or palpable veins, younger age, previous history of DIVA, history of prematurity, increased adiposity or obesity, dehydration, frequent phlebotomy or PIVC insertion or comorbidities.[26–28] The use of ultrasound in patients with DIVA was associated with an overall benefit in first attempt and overall success rates, which is inherently the main utility of ultrasound-guided insertion. This was further supported by subgroup analysis of overall success in patients at or under 3 years of age, who are also considered to have DIVA. However, the use of ultrasound was reported to be beneficial for PIVC insertion in children with obesity in the study by Hanada et al,[16] but had no demonstrable difference in the study by Curtis et al.[17]

Although several studies support the use of ultrasound for pediatric PIVC insertion in the ED,[20,22,24] the subgroup analysis of this setting overall was not statistically significant and had high heterogeneity. This could partly be attributed to the confounding issue of children not being still enough for appropriate use of ultrasound in some studies,[17] and no children were sedated. It could also reflect the often-chaotic environment or a higher proportion of unwell children compared with other settings, although many studies excluded children from their trial if they were critically unwell.[17,22,24] The ultrasound technique and lack of adequate training on actual patients may have also been contributing factors. More studies are required in this setting for conclusive evidence.

Unsurprisingly, the use of ultrasound for pediatric PIVC

TABLE 5 First Attempt and Overall Success by Subgroup

	First Attempt Success						Overall Success					
Subgroup	Studies	Patients	Pooled OR	95% CI	*P*	I^2 (%)	Studies	Patients	Pooled OR	95% CI	*P*	I^2 (%)
Age 3 or less	6	577	—	—	—	90.7	5	485	3.73	2.00 to 6.95	<.001	0.0
Physician operator	4	390	3.34	1.75 to 6.37	<.001	44.8	4	396	3.78	1.89 to 7.59	<.001	14.6
Setting												
ED	3	492	—	—	—	90.4	2	215	—	—	—	—
Operating room	4	386	4.58	2.45 to 8.56	<.001	37.6	4	386	3.92	1.79 to 8.62	.001	18.4
Ultrasound technique												
Dynamic	4	407	6.33	3.89 to 10.3	<.001	0.0	5	457	4.14	2.10 to 8.19	<.001	0.0
Single operator	7	878	—	—	—	93.3	5	551	3.97	2.14 to 7.36	<.001	0.0
Short-axis	6	838	—	—	—	83.8	5	561	3.84	2.15 to 6.87	<.001	0.0
Dynamic, single operator and short-axis	3	367	5.97	3.57 to 10.0	<.001	0.0	3	367	6.87	2.82 to 16.7	<.001	0.0
Site												
Lower limb	3	286	5.47	2.18 to 13.8	<.001	57.0	3	286	3.47	1.62 to 7.44	.001	13.8
Other	5	974	—	—	—	88.0	3	315	3.76	1.46 to 9.68	.006	1.7
Sedation												
No	3	591	—	—	—	92.1	1	165	—	—	—	—
Yes	4	386	4.58	2.45 to 8.56	<.001	37.6	4	386	3.92	1.79 to 8.62	.001	18.4
DIVA												
No	3	765	—	—	—	80.9	1	100	—	—	—	—
Yes	5	495	4.60	2.34 to 9.07	<.001	57.4	5	501	3.34	1.89 – 5.87	<.001	0.0

Meta-analysis not performed for subgroups with <3 studies. Studies with <3 studies for all outcome measures included: age over 3, nurse operator and ultrasound technique (static, dual operator, or long axis). Meta-analysis findings not reported for subgroups with excessive heterogeneity (I^2 > 60%). CI, confidence interval; DIVA, difficult intravenous access; ED, emergency department; OR, odds ratio; —, not applicable.

insertion in the operating room setting was highly effective. Highly skilled operators (anesthesiologists) combined with patients who were anesthetized and still, provided conditions highly conducive to successful ultrasound-guided PIVC insertions.[16,19,21,23] Furthermore, many of the sedative agents used, such as Sevofluorane, are known to be potent vasodilators.[29] Additionally, the majority of patients were undergoing elective procedures or imaging.[16,21,23] All studies involved children ≤3 years and, apart from 1 study,[23] all primarily used the saphenous vein,[16,19,21] which may otherwise have been challenging in an awake infant or young child.

The technique for ultrasound-guided PIVC insertion varied considerably between studies. The dynamic ultrasound method, which involved visualizing the needle tip in real-time, in either the long or short axis, was associated with a higher insertion success rate than the use of a static ultrasound method, which involved marking-up the vein, before "blind" insertion. The single-operator technique and short-axis technique subgroups had improved overall success over the landmark technique but had excessive heterogeneity for meta-analysis of first attempt success. The single-operator technique has the additional advantage of being less resource intensive. The short-axis was the most used axis and has been demonstrated to be the most effective axis for PIVC insertion in a dedicated systematic review, although this only included RCTs on adult patients or phantom models.[30] However, the long-axis was demonstrated to be useful for large, straight veins (eg, saphenous) in a sedated child[21] or can be used to confirm placement after short-axis insertion.[22,31]

Combining all these elements, the standard technique for ultrasound-guided PIVC insertion in children is arguably a dynamic, single-operator, short-axis approach using a high-frequency linear probe.[31,32] This combination was used by ultrasound operators in 3 studies, 2 in the operating room[16,23] and the other in the ED,[24] and was associated with high first attempt and overall success rates. Routine tourniquet use with this technique may also assist with avoiding vein compression from the ultrasound probe.[16,23] Moreover, topical anesthetic medication may mitigate pain and thereby increase cooperation in an awake child.[33] Appropriate training and experience of the operators is crucial to the successful implementation of ultrasound, with 1 study reporting higher PIVC success rates after at least 15 ultrasound-guided insertions in adult patients,[34] which may imply more training is required in children, given the finer psychomotor skills required.

Besides improving PIVC insertion success rates, ultrasound has numerous other potential advantages over a landmark technique insertion. Use of ultrasound has been associated with

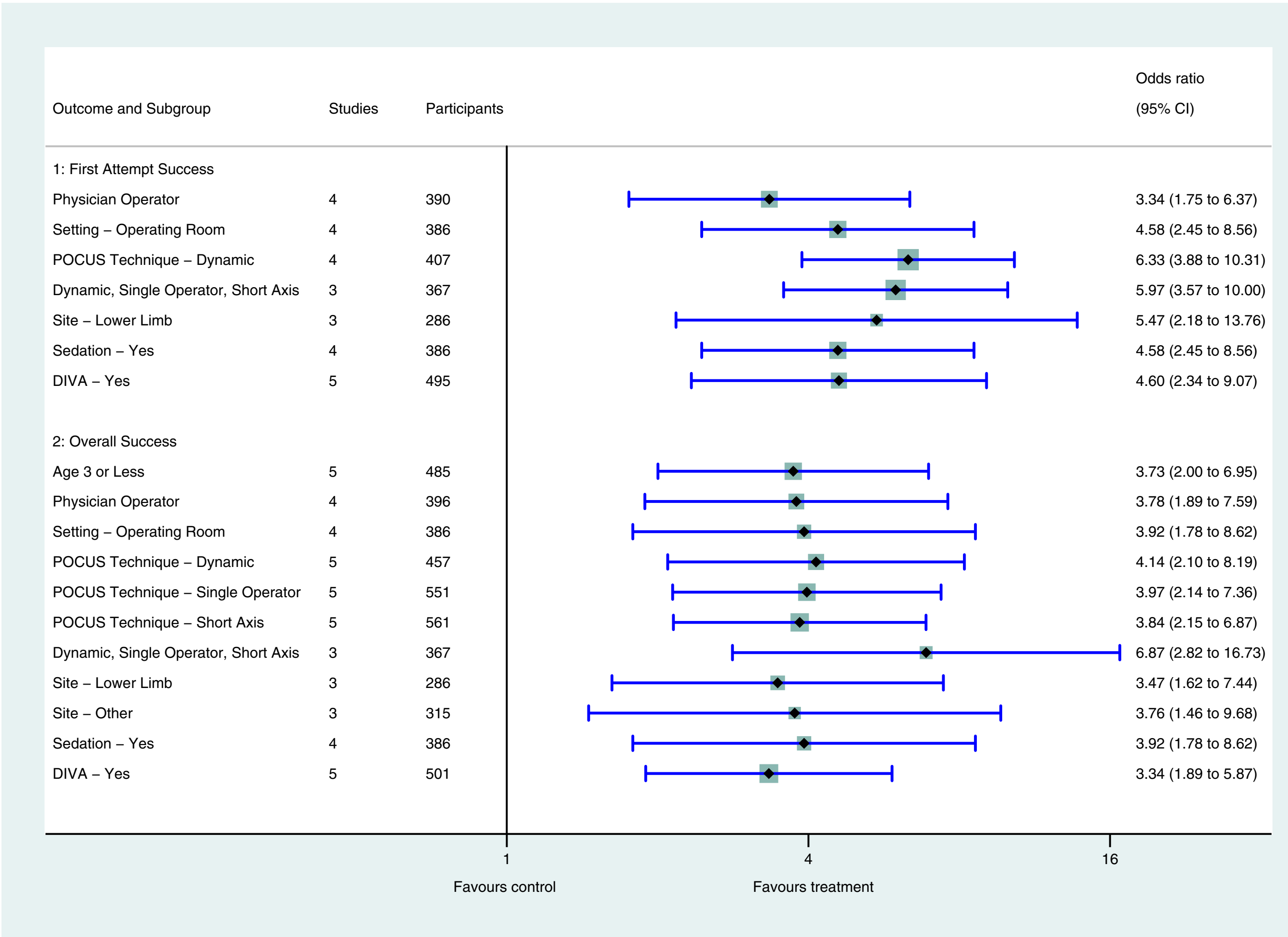

FIGURE 5
First attempt and overall success according to subgroup. CI, confidence interval; DIVA, difficult intravenous; access; ED, emergency department.

fewer attempts (skin punctures)[16,19–22,24] and redirections (partial withdrawal with advancement in new direction),[19,20,22,23] which are important factors for long-term vessel health preservation.[35] It also provides the ability to grade the size and quality of veins before selection for insertion,[16,19,23,24] it enables insertion away from flexural regions for joint mobility and comfort compared with the landmark technique,[23] and can allow for placement of longer or larger peripheral devices for increased longevity.[24] Furthermore, ultrasound has been associated with a higher level of parental satisfaction.[24] Most studies reported no significant increase in complications compared with the landmark technique, apart from an inconsequential arterial puncture in 1 study.[22]

Ultrasound use was associated with a reduction in time to catheterization in 4 of 7 studies. This was confounded by significant heterogeneity of studies, with Vinograd et al[24] attempting to address the total procedure time for ultrasound (locating the machine, cleaning, and operating it) by defining it from time of randomization. This high heterogeneity precluded meta-analysis and subgroup analysis.

Limitations

The main limitation from this systematic review and meta-analysis was the significant heterogeneity of studies. A random-effects model, using skewed weighting of individual data sets, was used to help compensate for this. Where heterogeneity was significant ($I^2 > 60\%$), meta-analysis was treated as hypothesis-generating only for main outcome measures and not performed for subgroups. The control method varied with 3 studies allowing adjunct methods, such as transillumination,[22,24] infrared,[17] or heat packs,[24] although, this may have only overstated the outcomes in the landmark technique group. Due to the open-label nature of the intervention, operators were unable to be double-blinded. Gopalasingam et al[23] performed a cross-over trial with subsequent concern for a degree of carry-over effect.

In terms of strengths, several features support the validity of this systematic review. Publication bias was minimized by searching the literature as broadly as possibly, including an unpublished study (preprint) in the final analysis. A strict, stepwise search and data extraction was performed by independent reviewers following a prospectively published protocol. Of the included studies, none were identified as highly biased. A sensitivity analysis was performed throughout, excluding the Gopalasingam et al[23] study with an alternate design.

Future RCTs should be consistent with clear reporting on the ultrasound technique, standardization of training, and outcome measures. They could also potentially incorporate the neonatal age group (<3 months), which is currently lacking in the literature. Furthermore, in environments outside of the operating room, methods of restraint, presence of parent or guardian, distraction tools (eg, virtual reality), topical anesthesia, and methods of appropriate sedation should be explored, as this could improve the effectiveness of ultrasound for patients with DIVA by facilitating a still target vessel.

CONCLUSIONS

This systematic review suggested that ultrasound improved the first attempt success rate of pediatric PIVC insertion, although meta-analysis of this outcome measure was limited by high study heterogeneity. ultrasound-guided PIVC insertion improved overall success rates as well as both first attempt and overall success rates in patients with DIVA. The standard ultrasound technique should be a single-operator, dynamic, short-axis approach. This study provides a robust evidence base to support the routine use of ultrasound for PIVC insertions in children with DIVA and should be implemented as standard of care across clinical settings.

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ABBREVIATIONS

CI: confidence interval
DIVA: difficult intravenous access

LM: landmark
NR: not reported
OpR: operating room
OR: odds ratio
PIVC: peripheral intravenous catheter
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analyses
RCT: randomized controlled trial
RoB 2: revised Cochrane risk-of-bias tool for randomized trials (RoB 2)
WMD: weighted mean difference

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REFERENCES

1. Weihrauch-Blüher S, Wiegand S. Risk factors and implications of childhood obesity. *Curr Obes Rep.* 2018;7(4):254–259
2. Lininger RA. Pediatric peripheral i.v. insertion success rates. *Pediatr Nurs.* 2003;29(5):351–354
3. Gerçeker GO, Ayar D, Özdemir EZ, Bektaş M. The impact of the difficult vascular access, fear, and anxiety level in children on the success of first-time phlebotomy. *J Vasc Access.* 2018;19(6): 620–625
4. Shokoohi H, Loesche MA, Duggan NM, et al. Difficult intravenous access as an independent predictor of delayed care and prolonged length of stay in the emergency department. *J Am Coll Emerg Physicians Open.* 2020;1(6):1660–1668
5. Snelling PJ, Tessaro M. Paediatric emergency medicine point-of-care ultrasound: Fundamental or fad? *Emerg Med Australas.* 2017;29(5):486–489
6. Tibbles CD, Porcaro W. Procedural applications of ultrasound. *Emerg Med Clin North Am.* 2004;22(3):797–815
7. Tran QK, Fairchild M, Yardi I, Mirda D, Markin K, Pourmand A. Efficacy of ultrasound-guided peripheral intravenous cannulation versus standard of care: a systematic review and meta-analysis. *Ultrasound Med Biol.* 2021;47(11): 3068–3078
8. van Loon FHJ, Buise MP, Claassen JJF, Dierick-van Daele ATM, Bouwman ARA. Comparison of ultrasound guidance with palpation and direct visualisation for peripheral vein cannulation in adult patients: a systematic review and meta-analysis. *Br J Anaesth.* 2018;121(2): 358–366
9. Heinrichs J, Fritze Z, Vandermeer B, Klassen T, Curtis S. Ultrasonographically guided peripheral intravenous cannulation of children and adults: a systematic review and meta-analysis. *Ann Emerg Med.* 2013;61(4):444–454.e1
10. Liu YT, Alsaawi A, Bjornsson HM. Ultrasound-guided peripheral venous access: a systematic review of randomized-controlled trials. *Eur J Emerg Med.* 2014;21(1):18–23
11. Egan G, Healy D, O'Neill H, Clarke-Moloney M, Grace PA, Walsh SR. Ultrasound guidance for difficult peripheral venous access: systematic review and meta-analysis. *Emerg Med J.* 2013;30(7): 521–526
12. Kuo CC, Wu CY, Feng IJ, Lee WJ. [Efficacy of ultrasound-guided peripheral intravenous access: a systematic review and meta-analysis]. *Hu Li Za Zhi.* 2016;63(6): 89–101
13. Cochrane. Data extraction forms. Available at: https://dplp.cochrane.org/data-extraction-forms. Accessed January 15th, 2021
14. Cochrane. RoB 2: a revised Cochrane risk-of-bias tool for randomized trials. Available at: https://methods.cochrane.org/bias/resources/rob-2-revised-cochrane-risk-bias-tool-randomized-trials. Accessed January 15, 2021
15. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ.* 2019;366:l4898
16. Hanada S, Van Winkle MT, Subramani S, Ueda K. Dynamic ultrasound-guided short-axis needle tip navigation technique vs. landmark technique for difficult saphenous vein access in children: a randomised study. *Anaesthesia.* 2017;72(12):1508–1515
17. Curtis SJ, Craig WR, Logue E, Vandermeer B, Hanson A, Klassen T. Ultrasound or near-infrared vascular imaging to guide peripheral intravenous catheterization in children: a pragmatic randomized controlled trial. *CMAJ.* 2015;187(8):563–570
18. Avelar AF, Peterlini MA, da Luz Gonçalves Pedreira M. Ultrasonography-guided peripheral intravenous access in children: a randomized controlled trial. *J Infus Nurs.* 2015;38(5):320–327
19. Bian Y, Huang Y, Bai J, Zheng J, Huang Y. A randomized controlled trial of ultrasound-assisted technique versus conventional puncture method for saphenous venous cannulations in children with congenital heart disease. *BMC Anesthesiol.* 2021;21(1):131
20. Bair AE, Rose JS, Vance CW, Andrada-Brown E, Kuppermann N. Ultrasound-assisted peripheral venous access in young children: a randomized controlled trial and pilot feasibility study. *West J Emerg Med.* 2008;9(4):219–224
21. Benkhadra M, Collignon M, Fournel I, et al. Ultrasound guidance allows faster

peripheral IV cannulation in children under 3 years of age with difficult venous access: a prospective randomized study. *Paediatr Anaesth.* 2012;22(5):449–454

22. Doniger SJ, Ishimine P, Fox JC, Kanegaye JT. Randomized controlled trial of ultrasound-guided peripheral intravenous catheter placement versus traditional techniques in difficult-access pediatric patients. *Pediatr Emerg Care.* 2009;25(3):154–159
23. Gopalasingam N, Obad DS, Kristensen BS, et al. Ultrasound-guidance outperforms the palpation technique for peripheral venous catheterisation in anaesthetised toddlers: a randomised study. *Acta Anaesthesiol Scand.* 2017;61(6):601–608
24. Vinograd AM, Chen AE, Woodford AL, et al. Ultrasonographic guidance to improve first-attempt success in children with predicted difficult intravenous access in the emergency department: a randomized controlled trial. *Ann Emerg Med.* 2019;74(1):19–27
25. Parker SIA, Benzies KM, Hayden KA. A systematic review: effectiveness of pediatric peripheral intravenous catheterization strategies. *J Adv Nurs.* 2017;
73(7):1570–1582
26. Girotto C, Arpone M, Frigo AC, et al. External validation of the DIVA and DIVA3 clinical predictive rules to identify difficult intravenous access in paediatric patients. *Emerg Med J.* 2020;37(12):762–767
27. Yen K, Riegert A, Gorelick MH. Derivation of the DIVA score: a clinical prediction rule for the identification of children with difficult intravenous access. *Pediatr Emerg Care.* 2008;24(3):143–147
28. Riker MW, Kennedy C, Winfrey BS, Yen K, Dowd MD. Validation and refinement of the difficult intravenous access score: a clinical prediction rule for identifying children with difficult intravenous access. *Acad Emerg Med.* 2011;18(11):1129–1134
29. Izumi K, Akata T, Takahashi S. The action of sevoflurane on vascular smooth muscle of isolated mesenteric resistance arteries (part 1): role of endothelium. *Anesthesiology.* 2000;92(5):1426–1440
30. Gottlieb M, Holladay D, Peksa GD. Comparison of short- vs long-axis technique for ultrasound-guided peripheral line placement: a systematic review and meta-analysis. *Cureus.* 2018;10(5):e2718
31. Snelling PJ. Getting started in paediatric emergency medicine point-of-care ultrasound: five fundamental applications. *Australas J Ultrasound Med.* 2020;23(1):5–9
32. Joing S, Strote S, Caroon L, et al. Videos in clinical medicine. ultrasound-guided peripheral i.v. placement. *N Engl J Med.* 2012;366(25):e38
33. Lander JA, Weltman BJ, So SS. EMLA and amethocaine for reduction of children's pain associated with needle insertion. *Cochrane Database Syst Rev.* 2006;(3):CD004236
34. Stolz LA, Cappa AR, Minckler MR, et al. Prospective evaluation of the learning curve for ultrasound-guided peripheral intravenous catheter placement. *J Vasc Access.* 2016;17(4):366–370
35. Moureau NL, Trick N, Nifong T, et al. Vessel health and preservation (Part 1): a new evidence-based approach to vascular access selection and management. *J Vasc Access.* 2012;13(3):351–356