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# ULTRASOUND-GUIDED VS LANDMARK PERIPHERAL IV CANNULATION IN THE PEDIATRIC ED: A RANDOMIZED CONTROLLED TRIAL

*Sam Varghese[1], Thomas Ranjit[2]*

[1]*Professor, Department of Pediatrics, Sree Narayana Institute of Medical Science Chalakka, Kunnukara, Kerala, India*
[2]*Associate Professor, Department of Pediatrics, Sree Narayana Institute of Medical Science Chalakka, Kunnukara, Kerala, India*

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**Corresponding Author:**
**Dr. Thomas Ranjit,**
Associate Professor, Department of Pediatrics, Sree Narayana Institute of Medical Science Chalakka, Kunnukara, Kerala, India.
Email: thomas.ranjit@gmail.com

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ABSTRACT

**Background:** Peripheral intravenous (IV) cannulation is one of the most frequently performed procedures in pediatric emergency departments (EDs), yet it remains technically challenging due to smaller vessel size, poor vein visibility, and patient anxiety. Multiple failed attempts not only delay treatment but also increase distress and procedural complications. Ultrasound-guided (US) cannulation has been proposed as an alternative to the traditional landmark (LM) method, offering real-time vessel visualization and dynamic needle tracking to enhance success rates, especially in children with difficult intravenous access (DIVA). The aim is to compare the efficacy, efficiency, and safety of ultrasound-guided versus conventional landmark peripheral IV cannulation in pediatric patients presenting to a tertiary care emergency department.

**Materials and Methods:** This single-center, randomized controlled trial enrolled 90 pediatric patients (aged 1 month to 17 years) requiring IV access in the ED. Participants were randomly allocated in a 1:1 ratio to the ultrasound-guided group (n = 45) or the landmark group (n = 45). Primary outcome was first-attempt success. Secondary outcomes included overall success rate, number of attempts, procedure time, pain score, complications, and satisfaction (operator and caregiver). Data were analyzed using IBM SPSS Statistics version 26.0, applying Chi-square and t-tests as appropriate, with $p < 0.05$ considered statistically significant.

**Results:** Baseline characteristics were comparable between groups. Ultrasound guidance significantly improved first-attempt success (84.44% vs 55.56%, $p = 0.004$) and overall success (97.78% vs 82.22%, $p = 0.02$), while reducing the mean number of attempts ($1.22 \pm 0.52$ vs $1.84 \pm 0.87$; $p < 0.001$). The mean procedure time was shorter in the US group ($73.64 \pm 26.81$ s) compared to the LM group ($106.29 \pm 31.52$ s; $p < 0.001$). Pain scores were lower ($3.07 \pm 1.12$ vs $4.22 \pm 1.31$; $p = 0.001$), and both operator and caregiver satisfaction were higher ($p < 0.01$). Complications were fewer, and catheter patency at 2 hours was significantly higher with ultrasound (97.78% vs 84.44%, $p = 0.03$).

**Conclusion:** Ultrasound-guided peripheral IV cannulation significantly enhances first-attempt and overall success rates, reduces procedure time and patient discomfort, and improves satisfaction among operators and caregivers. The technique should be considered the preferred approach for pediatric IV access, particularly in children with difficult venous access in emergency settings.

**Keywords:** Ultrasound-guided cannulation, Pediatric emergency, Peripheral intravenous access, Difficult IV access, Randomized controlled trial.

## INTRODUCTION

Peripheral intravenous (PIV) cannulation is among the most frequent—and often most stressful—procedures performed in pediatric emergency departments (EDs). Despite its ubiquity, first-attempt failure remains common because children have smaller, less visible veins, higher subcutaneous fat-to-vessel ratios, and low tolerance for prolonged restraint, all of which amplify procedural pain, anxiety, and downstream delays in care. In observational cohorts, between one in five and two in three children require more than one puncture, and a meaningful subset meets criteria for difficult intravenous access (DIVA), a phenotype associated with multiple failed attempts, escalation to intraosseous or central access, and early catheter failure. Introducing reliable strategies that raise first-pass success while limiting total attempts is therefore a patient-centred and system-level priority in pediatric emergency medicine.[1] Two broad approaches dominate the PIV cannulation landscape: conventional landmark (LM) techniques relying on inspection and palpation, and ultrasound-guided (US) techniques that visualize target vessels and needle tip in real time. Over the past decade, professional standards bodies have increasingly endorsed vascular visualization technologies—ultrasound foremost among them—to improve success and preserve peripheral vasculature in children. The Infusion Nurses Society's most recent Infusion Therapy Standards of Practice emphasizes vessel health and preservation, careful device selection, and adoption of adjuncts (including ultrasound) when an initial attempt is unlikely to succeed—principles directly salient to pediatric ED workflows.[2] Complementing this, the Association for Vascular Access (AVA) pediatric guidance promotes structured training and competency assessment for US-guided PIV insertion, with the aim of improving first-attempt success and reducing escalation to more invasive lines.[3] Ultrasound's theoretical advantages map well to pediatric needs: it allows operators to identify deeper or non-palpable veins, measure diameter and depth to match catheter gauge and length, and maintain dynamic tip tracking during advancement—capabilities that are crucial when surface clues are misleading or absent. Early pediatric trials and subsequent implementation studies suggest that US may improve first-attempt success, reduce the number of punctures, and shorten cannulation time, particularly in DIVA cohorts; however, questions have lingered about generalizability across operator disciplines (physicians vs nurses), the learning curve required for proficiency, and whether gains in success translate into fewer complications or better short-term catheter survival. A recent pediatric randomized clinical trial reported higher first-attempt success with US across risk strata, underscoring the possibility that benefits are not confined to the most difficult cases.[4] At the same time, the pediatric literature highlights heterogeneity in outcomes that likely reflects differences in training, device selection (standard short catheters vs longer "US-length" catheters), vein selection strategies (forearm vs antecubital), and rescue thresholds. For example, an earlier randomized study in hospitalized children comparing US to standard methods found higher overall success and fewer adverse events with US when operators adhered to a structured protocol—yet noted that performance varied with operator experience, reinforcing the need for targeted education and supervised practice before clinical deployment.[5] In the pediatric ED, where volumes are high and turnover rapid, a pragmatic curriculum that includes didactics, simulation, and competency sign-off may be essential to realize US's technical advantages at the bedside. Beyond technical success, pediatric PIV cannulation is fundamentally about minimizing pain and distress for children and families. Failed attempts are strongly linked to worse pain scores, higher child and parent anxiety, and lower satisfaction; conversely, strategies that increase first-pass success reduce procedural suffering and improve experience metrics. Innovative adjuncts from topical anesthetics and vapocoolants to child-life interventions and immersive distraction can mitigate the affective burden of cannulation. A randomized clinical trial of virtual reality distraction during pediatric PIV placement, for instance, demonstrated meaningful reductions in pain and anxiety relative to standard care, illustrating the broader ecosystem in which vascular access techniques operate.[6] Embedding US within a comprehensive, child-centred protocol that also prioritizes analgesia and distraction may therefore yield additive or even synergistic benefits. Identifying children likely to fail on palpation/visualization alone is equally important. DIVA prediction tools and ED clinical pathways encourage early recognition of high-risk patients and earlier deployment of rescue modalities such as US guidance, longer catheters, or, when appropriate, intraosseous access. Representative pathways specify practical scoring systems (e.g., visibility and palpability of veins, prior history of difficult access) and often use a threshold score to trigger escalation steps, standardizing care and reducing delay.[7]

## MATERIALS AND METHODS

This was a single-center, parallel-group, randomized controlled trial conducted in the pediatric emergency department (ED) of a tertiary care teaching hospital. Children requiring peripheral intravenous (IV) cannulation for clinical care were randomized 1:1 to ultrasound-guided (US-guided) cannulation or conventional landmark (LM) cannulation.

Consecutive patients aged 1 month to 17 years who required a peripheral IV line for diagnostics or therapy and for whom written informed consent (and assent when appropriate) was obtained were eligible.

Exclusion criteria were hemodynamic instability requiring immediate vascular access (e.g., need for intraosseous access), anticipated central venous access, local infection or burn at potential insertion sites, known coagulopathy, upper-limb arteriovenous fistula, prior enrollment, or inability to obtain consent. Difficult IV access (DIVA) was prospectively characterized using a validated score; a DIVA score ≥4 was classified a priori as "difficult access."

**Methodology:** 90 Participants were randomized in permuted blocks of variable size using a computer-generated sequence prepared by an independent statistician. Allocation was concealed in consecutively numbered, opaque, sealed envelopes opened only after enrollment. Due to the nature of the procedures, operator and patient blinding were not feasible; however, outcome assessors recording times, attempts, and pain scores were blinded to group assignment.

In the US-guided arm, operators used a high-frequency linear transducer (5–13 MHz) with sterile probe cover and gel. Veins of the forearm or antecubital fossa were prioritized; in-plane or out-of-plane approaches were allowed per operator preference. In the LM arm, cannulation was performed by inspection and palpation without ultrasound. Across both arms, catheter size (22–24G for infants/young children; 18–22G for older children) was selected according to vein caliber and clinical need, and topical analgesia (e.g., eutectic lidocaine–prilocaine cream ≥45 minutes pre-procedure when feasible, or vapocoolant immediately before puncture) and comfort measures (distraction, swaddling, sucrose for infants) were applied per ED protocol.

Eligible operators were credentialed pediatric ED physicians or ED nurses with ≥6 months of IV cannulation experience. All underwent a standardized 2-hour training that included didactics and simulation on US-guided peripheral IV access (probe handling, needle visualization, dynamic tip tracking, and sterile technique) and a refresher on LM technique. Competency was confirmed on simulation before clinical participation. To limit performance bias, operators declared their primary technique experience and years of practice; procedures were supervised by faculty as required.

The primary outcome was first-attempt success (successful cannula placement with free saline flush and blood return on initial skin puncture). Key secondary outcomes were overall cannulation success within the assigned technique, number of skin punctures, time to successful cannulation (from skin antisepsis to confirmation of patency), pain during cannulation (FLACC for <7 years; Wong–Baker FACES for 7–12 years; 0–10 Numeric Rating Scale for ≥13 years), immediate complications (hematoma, arterial puncture, infiltration/extravasation, nerve irritation), need for rescue modality (crossover to the alternative technique or escalation to intraosseous/central access), catheter dwell at 2 hours post-placement (patent vs failed), and parent/caregiver and operator satisfaction (5-point Likert). Predefined subgroup analyses included patients with DIVA (score ≥4), age strata (infant/toddler 1–36 months, child 3–12 years, adolescent >12 years), and operator discipline (physician vs nurse).

Attempts were defined as each new skin puncture by a needle/catheter. A maximum of three attempts or 10 minutes per assigned technique was permitted before rescue; reasons for failure were recorded. Timekeeping was performed by a trained research assistant using synchronized digital timers. Pain scores were obtained within 2 minutes of the final attempt by a blinded observer using the age-appropriate validated scale. Complications were monitored continuously during the ED stay; insertion site was inspected at ~30 minutes and ~2 hours post-cannulation where clinically feasible. Data were captured on standardized case report forms and entered into a secure electronic database with double-entry verification.

**Statistical Analysis:** Analysis followed the intention-to-treat principle; a per-protocol sensitivity analysis excluded major crossovers before first attempt. Continuous variables were assessed for normality (Shapiro–Wilk) and compared using Student's t test or Mann–Whitney U test as appropriate; categorical variables were compared using $\chi^2$ or Fisher's exact test. Time to successful cannulation was analyzed as a continuous outcome and additionally summarized with cumulative success curves by technique; groups were compared with the log-rank test as a sensitivity description. Multivariable logistic regression estimated the adjusted odds ratio (aOR) for first-attempt success with covariates selected a priori (age, weight, DIVA category, site of cannulation, operator discipline, and years of experience). For count outcomes (number of attempts), Poisson or negative binomial regression was used based on dispersion. Interactions between technique and DIVA status or operator discipline were tested. Missing data were minimized through real-time checks; remaining missingness <5% was handled by complete case analysis, and if >5% for any key variable, multiple imputation with chained equations was planned. Statistical significance was set at $p<0.05$ (two-sided). Analyses were performed using IBM SPSS Statistics, Version 26.0 (IBM Corp., Armonk, NY).

## RESULTS

**[Table 1] Baseline Characteristics:** Both study groups were comparable in all baseline characteristics, confirming adequate randomization and group homogeneity. The mean age of children in the ultrasound-guided (US) group was 6.18 ± 3.74 years, while in the landmark (LM) group it was 6.43 ± 3.61 years ($p = 0.74$). Similarly, the mean body weight did not differ significantly between groups

(US 18.72 ± 7.83 kg vs LM 19.31 ± 8.11 kg; p = 0.73). Male predominance was comparable (US 60.00% vs LM 55.56%; p = 0.68). The proportion of children classified as difficult IV access (DIVA ≥ 4) was nearly identical in both groups (US 33.33% vs LM 35.56%; p = 0.83). The primary cannulation site (forearm) and the proportion of procedures performed by physicians rather than nurses were also balanced across groups (p > 0.05 for all variables).

**[Table 2] Cannulation Success and Attempts**

Ultrasound guidance markedly improved success metrics compared with the landmark technique. First-attempt success was significantly higher in the US group (84.44%) compared to the LM group (55.56%, p = 0.004), indicating that ultrasound substantially enhanced the likelihood of achieving IV access on the initial attempt. Overall success within the assigned technique also favored the US approach (97.78% vs 82.22%, p = 0.02). The mean number of attempts required per patient was considerably lower in the US group (1.22 ± 0.52) than in the LM group (1.84 ± 0.87; p < 0.001), reflecting greater procedural efficiency and less patient discomfort. Furthermore, the need for rescue modalities—defined as crossover to an alternative technique or escalation to intraosseous/central access—was substantially reduced in the ultrasound group (2.22% vs 17.78%, p = 0.03).

**[Table 3] Procedural Time and Pain Assessment**

Procedure efficiency and patient comfort were both superior with ultrasound guidance.

The mean time to successful cannulation was significantly shorter with ultrasound (73.64 ± 26.81 seconds) than with the landmark method (106.29 ± 31.52 seconds; p < 0.001), highlighting the procedural speed benefit once the technique is mastered. Pain scores, measured using age-appropriate validated scales, were also significantly lower in the US group (mean 3.07 ± 1.12) compared to the LM group (4.22 ± 1.31; p = 0.001), suggesting that ultrasound not only improves efficiency but also reduces procedural distress.

Additionally, both parent/caregiver satisfaction and operator satisfaction were higher in the ultrasound arm (4.58 ± 0.56 and 4.71 ± 0.48, respectively) than in the landmark arm (3.93 ± 0.64 and 3.87 ± 0.59; all p ≤ 0.002).

**[Table 4] Complications and Catheter Outcomes**

Although complication rates were generally low in both groups, minor adverse events were less frequent in the ultrasound group. Hematoma formation occurred in 4.44% of ultrasound cases compared to 13.33% of landmark cases (p = 0.14), while infiltration/extravasation occurred in 2.22% versus 11.11%, respectively (p = 0.09). Although these differences did not reach statistical significance—likely due to limited sample size—they indicate a clinically meaningful trend favoring ultrasound guidance. No cases of arterial puncture or nerve irritation were reported in the ultrasound group, whereas one arterial puncture (2.22%) occurred in the landmark group. Importantly, catheter patency at two hours was significantly higher in the ultrasound group (97.78%) than in the landmark group (84.44%; p = 0.03).

**[Table 5] Subgroup Analysis: Difficult IV Access (DIVA ≥ 4):** In children with difficult IV access, ultrasound guidance showed particularly pronounced benefits. Among this subgroup, the first-attempt success rate was 73.33% in the US group versus only 31.25% in the LM group (p = 0.02), representing more than a twofold improvement. Similarly, overall cannulation success reached 100% with ultrasound compared to 81.25% with the landmark technique (p = 0.04). The mean number of attempts was also significantly lower for ultrasound (1.33 ± 0.62) compared to landmark (2.06 ± 0.85; p = 0.01).

**Table 1: Baseline characteristics of study participants**

| Variable | US-guided (n = 45) | LM (n = 45) | p-value |
|---|---|---|---|
| Mean age (years ± SD) | 6.18 ± 3.74 | 6.43 ± 3.61 | 0.74 |
| Male sex, n (%) | 27 (60.00%) | 25 (55.56%) | 0.68 |
| Mean weight (kg ± SD) | 18.72 ± 7.83 | 19.31 ± 8.11 | 0.73 |
| DIVA score ≥ 4, n (%) | 15 (33.33%) | 16 (35.56%) | 0.83 |
| Primary site: forearm, n (%) | 28 (62.22%) | 26 (57.78%) | 0.67 |
| Operator: physician, n (%) | 32 (71.11%) | 30 (66.67%) | 0.65 |

**Table 2: Cannulation success and attempts**

| Outcome | US-guided (n = 45) | LM (n = 45) | p-value |
|---|---|---|---|
| First-attempt success, n (%) | 38 (84.44%) | 25 (55.56%) | 0.004 |
| Overall success within technique, n (%) | 44 (97.78%) | 37 (82.22%) | 0.02 |
| Mean number of attempts ± SD | 1.22 ± 0.52 | 1.84 ± 0.87 | <0.001 |
| Need for rescue modality, n (%) | 1 (2.22%) | 8 (17.78%) | 0.03 |

**Table 3: Procedural time and pain assessment**

| Outcome | US-guided (n = 45) | LM (n = 45) | p-value |
|---|---|---|---|
| Time to successful cannulation (sec ± SD) | 73.64 ± 26.81 | 106.29 ± 31.52 | <0.001 |
| Pain score (mean ± SD) | 3.07 ± 1.12 | 4.22 ± 1.31 | 0.001 |
| Parent/caregiver satisfaction (1–5) | 4.58 ± 0.56 | 3.93 ± 0.64 | 0.002 |
| Operator satisfaction (1–5) | 4.71 ± 0.48 | 3.87 ± 0.59 | <0.001 |

**Table 4: Complications and catheter outcomes**

| Complication | US-guided (n = 45) | LM (n = 45) | p-value |
|---|---|---|---|
| Hematoma, n (%) | 2 (4.44%) | 6 (13.33%) | 0.14 |
| Infiltration/extravasation, n (%) | 1 (2.22%) | 5 (11.11%) | 0.09 |
| Arterial puncture, n (%) | 0 (0.00%) | 1 (2.22%) | 0.32 |
| Nerve irritation, n (%) | 0 (0.00%) | 0 (0.00%) | — |
| Catheter patent at 2 h, n (%) | 44 (97.78%) | 38 (84.44%) | 0.03 |

**Table 5: Subgroup analysis: first-attempt success in difficult IV access (DIVA ≥ 4)**

| Subgroup | US-guided (n = 15) | LM (n = 16) | p-value |
|---|---|---|---|
| First-attempt success, n (%) | 11 (73.33%) | 5 (31.25%) | 0.02 |
| Overall success, n (%) | 15 (100.00%) | 13 (81.25%) | 0.04 |
| Mean number of attempts ± SD | 1.33 ± 0.62 | 2.06 ± 0.85 | 0.01 |

## DISCUSSION

Our randomized trial in a tertiary pediatric ED found substantially higher first-attempt success with ultrasound guidance (US) compared with landmark (LM) cannulation (84.44% vs 55.56%; p = 0.004). This aligns with the pediatric RCT by Doniger et al. (2009), conducted in difficult-access children, which demonstrated superior success rates and fewer attempts with real-time US compared with traditional techniques; taken together, our first-attempt success of 84.44% is consonant with their RCT showing clinically important gains after ≥2 failed LM attempts, reinforcing US utility once DIVA is anticipated.[8]

Our overall success within the assigned technique (97.78% US vs 82.22% LM; p = 0.02) also mirrors results from the pediatric Annals of Emergency Medicine RCT by Vinograd et al. (2019) in children with predicted DIVA, where US significantly improved first-attempt success and reduced multiple needle sticks; popular summaries of that trial report >85% first-attempt success with US versus <50% with standard care, which is directionally consistent with our effect size.[9]

The reduction in number of attempts we observed (1.22 ± 0.52 vs 1.84 ± 0.87; p < 0.001) and the lower need for rescue (2.22% vs 17.78%; p = 0.03) accord with the pediatric systematic review and meta-analysis in Pediatrics by Waddington et al. (2022), which concluded that US improves first-pass and overall success in children and particularly benefits DIVA cohorts; pooled estimates showed markedly higher odds of overall success with US (e.g., pooled OR ~3.57 in studies allowing ≥3 attempts).[10]

Regarding procedure time, our US group was faster (73.64 ± 26.81 s vs 106.29 ± 31.52 s; p < 0.001). Pediatric evidence on time has been mixed: the EMJ systematic review by Van Loon et al. (2013) across DIVA populations reported clear success gains with US but heterogeneous effects on time and puncture counts. Our data add pediatric RCT evidence that, when teams are trained, US can shorten time to cannulation in the ED environment.[11]

Our significantly lower pain scores with US (3.07 ± 1.12 vs 4.22 ± 1.31; p = 0.001) and higher parent and operator satisfaction echo findings from the pediatric RCT in predicted DIVA by Vinograd et al. (2019), which captured improvements in parental experience alongside technical outcomes—supporting the patient-centred advantages of US when first-attempt success improves and attempts are minimized.[9]

Although individual complications (hematoma and infiltration) were numerically lower but not statistically different in our trial, our significantly better 2-hour catheter patency (97.78% vs 84.44%; p = 0.03) is consistent with emerging pediatric ED experience that US-placed PIVs can perform at least as well—and sometimes better with respect to early longevity. An Annals editorial by Chen et al. (2019) contextualized trial data showing favorable line survival with US in children, countering the assumption that US PIVs fail sooner.[12]

Our DIVA subgroup (score ≥4) showed pronounced gains with US (first-attempt success 73.33% vs 31.25%; overall success 100.00% vs 81.25%). This dovetails with the DIVA clinical prediction literature: the Riker et al. (2011) external validation refined a 4-variable pediatric DIVA score that reliably stratifies risk; applying such scores prospectively, as we did, targets US to the children most likely to benefit.[13]

Broader pediatric syntheses corroborate our pattern across endpoints. The Frontiers in Pediatrics meta-analysis by Mumtaz et al. (2021) pooled pediatric RCTs and found US improved first-pass success, overall success, fewer attempts, and shorter time, with trends toward fewer complications—closely matching our absolute differences (e.g., +28.88 percentage-point first-attempt success and 0.62 fewer attempts).[14]

Earlier emergency-medicine syntheses by Gregori et al. already suggested that US guidance improves cannulation success in difficult access populations; our pediatric ED trial extends those conclusions by demonstrating large, clinically meaningful effects in a randomized pediatric cohort with standardized training and blinded outcome assessment.[15]

Finally, pragmatic implementation data from pediatric centers indicate that structured US-PIV training programs for ED nurses can raise first-attempt success and standardize technique—paralleling our finding that, with a short curriculum and competency check-off, US performance was robust across operator types (physicians 71.11%; nurses 28.89%). The Journal of Emergency Nursing program evaluation by Beck et al. (2023) reported improved success after roll-out, reinforcing the

importance of credentialing and simulation emphasized in our methods.[16]

## CONCLUSION

In this randomized controlled trial of 90 pediatric patients, ultrasound-guided peripheral IV cannulation demonstrated significantly higher first-attempt (84.44%) and overall success rates (97.78%) compared with the landmark technique (55.56% and 82.22%, respectively). Ultrasound guidance also reduced the mean number of attempts, shortened procedure time, lowered pain scores, and improved both parent and operator satisfaction. Although complication rates were similar, catheter patency was superior with ultrasound. These findings support the routine adoption of ultrasound-guided cannulation in pediatric emergency departments, particularly for children with difficult intravenous access, to enhance procedural success and patient experience.

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