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Original Research Article

ULTRASOUND-GUIDED VERSUS LANDMARK TECHNIQUE FOR CENTRAL VENOUS CANNULATION: A COMPARATIVE CROSS-SECTIONAL STUDY OF SUCCESS RATE AND COMPLICATIONS

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ABSTRACT

Background: Central venous cannulation is a frequently performed invasive procedure in critical care and perioperative settings. The landmark technique, traditionally used for venous access, is associated with variable success rates and mechanical complications. Ultrasound guidance has been proposed to improve safety and procedural efficacy. **Aim:** To compare the success rate and complication profile of ultrasound-guided versus landmark technique for central venous cannulation.

Materials and Methods: This hospital-based comparative cross-sectional study included 120 adult patients requiring central venous cannulation, divided equally into ultrasound-guided (n=60) and landmark (n=60) groups. Internal jugular vein cannulation was performed using the Seldinger technique. Primary outcomes included overall and first-attempt success rates, number of attempts, procedure time, and mechanical complications. Statistical analysis was performed using Chi-square test and independent t-test, with $p < 0.05$ considered statistically significant.

Results: The overall successful cannulation rate was significantly higher in the ultrasound group (95.0%) compared to the landmark group (81.7%) ($p = 0.019$). First-attempt success was also significantly greater with ultrasound guidance (86.7% vs 63.3%, $p = 0.003$). The mean number of attempts (1.18 ± 0.46 vs 1.94 ± 0.88, $p < 0.001$) and mean procedure time (4.82 ± 1.36 vs 7.41 ± 2.18 minutes, $p < 0.001$) were significantly lower in the ultrasound group. Total mechanical complications were significantly reduced in the ultrasound group (10.0% vs 30.0%, $p = 0.005$), with a notable reduction in arterial puncture rates.

Conclusion: Ultrasound-guided central venous cannulation significantly improves procedural success while reducing complications and procedure time compared to the landmark technique. Routine implementation of ultrasound guidance is recommended to enhance patient safety and procedural efficiency.

Keywords: Ultrasound-guided cannulation. Central venous catheterization. Landmark technique.

INTRODUCTION

Central venous cannulation (CVC) is a commonly performed invasive procedure in critical care, emergency medicine, anesthesia, and perioperative settings. It provides reliable venous access for hemodynamic monitoring, administration of vasoactive drugs, total parenteral nutrition, chemotherapy, and hemodialysis. Despite its routine use, central venous catheterization is associated with significant mechanical, infectious, and thrombotic complications. Traditional cannulation has been performed using the landmark technique, which

relies on anatomical surface landmarks to identify vascular structures. However, variations in anatomy, obesity, edema, hypovolemia, and prior catheterizations may alter normal anatomical relationships and increase the risk of complications such as arterial puncture, hematoma, pneumothorax, and failed attempts.[1]

Over the past two decades, ultrasound-guided (USG) cannulation has emerged as a superior alternative to the landmark technique. Real-time ultrasound visualization allows direct identification of the vein, adjacent artery, pleura, and other structures, thereby improving first-attempt success rates and reducing complications.[2] Several randomized controlled trials and meta-analyses have demonstrated that ultrasound guidance significantly decreases failed catheter placements, number of attempts, and mechanical complications compared to the landmark approach.[3]

The internal jugular vein (IJV) is the most commonly accessed site for central venous cannulation due to its predictable anatomy and lower complication rate compared to subclavian access. However, even IJV cannulation using landmarks carries a risk of carotid artery puncture and hematoma formation. Ultrasound guidance enables differentiation between artery and vein based on compressibility and Doppler flow characteristics, thereby enhancing procedural safety.[4]

International guidelines strongly recommend the routine use of ultrasound guidance for central venous catheter placement, particularly for internal jugular vein cannulation. The National Institute for Health and Care Excellence (NICE) and other professional bodies have advocated ultrasound as the standard of care whenever equipment and trained personnel are available.[5]

Aim

To compare the success rate and complication profile of ultrasound-guided versus landmark technique for central venous cannulation.

Objectives

1. To compare the first-attempt and overall success rates between ultrasound-guided and landmark techniques.
2. To assess and compare the number of attempts and time required for cannulation in both techniques.
3. To evaluate and compare procedure-related complications such as arterial puncture, hematoma, pneumothorax, and catheter malposition.

MATERIALS AND METHODS

Source of Data

The data were obtained from patients requiring central venous cannulation admitted to the Intensive Care Unit (ICU), emergency department, and operation theatre of the tertiary care hospital. All eligible patients who met the inclusion criteria during the study period were enrolled.

Study Design

The study was conducted as a hospital-based comparative cross-sectional study.

Study Location

The study was carried out in the Department of Anesthesiology and Critical Care at a tertiary care teaching hospital.

Study Duration

The study was conducted over a period of 12 months following approval from the Institutional Ethics Committee.

Sample Size

A total of 120 patients were included in the study. Patients were divided equally into two groups:

- Group A: Ultrasound-guided technique (n = 60)
- Group B: Landmark technique (n = 60)

Inclusion Criteria

- Patients aged ≥18 years
- Patients requiring central venous cannulation for clinical indications
- Patients who provided informed written consent

Exclusion Criteria

- Patients with known coagulopathy (INR >1.5 or platelet count <50,000/mm³)
- Local infection at insertion site
- Anatomical deformity or neck trauma
- Previous central venous catheterization at same site within 7 days
- Refusal to participate

Procedure and Methodology

After obtaining informed consent, patients were allocated into either ultrasound-guided or landmark group. Standard monitoring (ECG, pulse oximetry, NIBP) was applied. The internal jugular vein was chosen as the preferred site.

In the ultrasound group, a high-frequency linear probe covered with sterile sheath was used. Real-time visualization of the vein and artery was performed. The vein was identified based on compressibility and absence of pulsatility. Cannulation was performed under direct visualization using Seldinger's technique.

In the landmark group, the central vein was identified using anatomical landmarks (triangle formed by the sternal and clavicular heads of sternocleidomastoid muscle). Needle insertion was performed without imaging guidance.

Number of attempts, time taken for successful cannulation, and immediate complications (arterial puncture, hematoma, pneumothorax) were recorded. Post-procedure chest X-ray was performed to confirm catheter position and rule out pneumothorax.

Sample Processing

All procedural data including number of attempts, time duration (measured in minutes), and complications were recorded in structured proforma. Radiological confirmation reports were

documented. Data were verified for completeness before statistical entry.

Statistical Methods

Data were entered in Microsoft Excel and analyzed using SPSS version 25. Quantitative variables were expressed as mean ± standard deviation (SD). Qualitative variables were expressed as frequency and percentage. Independent t-test was used for comparison of continuous variables, while Chi-square test was applied for categorical variables. A p-value <0.05 was considered statistically significant.

Data Collection

Data were collected prospectively using a pre-designed case record form. Demographic details (age, gender), indication for cannulation, technique used, number of attempts, success rate, procedure time, and complications were recorded. Confidentiality of patient information was strictly maintained throughout the study.

RESULTS

Table 1: Comparison of Overall Success Rate and Overall Complication Profile

Parameter	Ultrasound (n=60)	Landmark (n=60)	Test of Significance	95% CI	p-value
Overall Successful Cannulation	57 (95.0%)	49 (81.7%)	$\chi^2 = 5.42$	2.1% to 24.3%	0.019*
Any Complication	6 (10.0%)	18 (30.0%)	$\chi^2 = 7.87$	-33.4% to -6.5%	0.005*
Mean Procedure Time (minutes)	4.82 ± 1.36	7.41 ± 2.18	t = 7.48	-3.28 to -1.90	<0.001*

Table 1 demonstrates a statistically significant superiority of ultrasound-guided central venous cannulation over the landmark technique in terms of overall success and safety. The overall successful cannulation rate was significantly higher in the ultrasound group (95.0%) compared to the landmark group (81.7%) ($\chi^2 = 5.42$, p = 0.019), with a 95% confidence interval (CI) for the difference ranging from 2.1% to 24.3%, indicating a clinically meaningful improvement. The incidence of any complication was significantly lower in the ultrasound group (10.0%) compared to the landmark group (30.0%) ($\chi^2 = 7.87$, p = 0.005), with the 95% CI (-33.4% to -6.5%) confirming a significant reduction in complication rates. Furthermore, the mean procedure time was markedly shorter in the ultrasound group (4.82 ± 1.36 minutes) than in the landmark group (7.41 ± 2.18 minutes), and this difference was highly statistically significant (t = 7.48, p < 0.001), with a 95% CI of -3.28 to -1.90 minutes.

Table 2: Comparison of First-Attempt and Overall Success Rates

Parameter	Ultrasound (n=60)	Landmark (n=60)	Test of Significance	95% CI	p-value
First-Attempt Success	52 (86.7%)	38 (63.3%)	$\chi^2 = 8.54$	8.4% to 36.2%	0.003*
Overall Success	57 (95.0%)	49 (81.7%)	$\chi^2 = 5.42$	2.1% to 24.3%	0.019*
Failed Cannulation	3 (5.0%)	11 (18.3%)	$\chi^2 = 5.19$	-24.1% to -1.5%	0.023*

Table 2 highlights the enhanced procedural efficacy associated with ultrasound guidance. The first-attempt success rate was significantly higher in the ultrasound group (86.7%) compared to the landmark group (63.3%) ($\chi^2 = 8.54$, p = 0.003), with a 95% CI of 8.4% to 36.2%, suggesting a substantial improvement in immediate cannulation success. Similarly, overall success was significantly greater with ultrasound guidance (95.0%) versus the landmark method (81.7%) ($\chi^2 = 5.42$, p = 0.019). Correspondingly, failed cannulation was significantly less frequent in the ultrasound group (5.0%) compared to the landmark group (18.3%) ($\chi^2 = 5.19$, p = 0.023), with the 95% CI (-24.1% to -1.5%) confirming a significant reduction in failure rates.

Table 3: Comparison of Number of Attempts and Time Required for Cannulation

Parameter	Ultrasound (n=60)	Landmark (n=60)	Test of Significance	95% CI	p-value
Number of Attempts (Mean ± SD)	1.18 ± 0.46	1.94 ± 0.88	t = 5.94	-1.01 to -0.49	<0.001*
Time to Cannulation (minutes)	4.82 ± 1.36	7.41 ± 2.18	t = 7.48	-3.28 to -1.90	<0.001*
>2 Attempts Required	4 (6.7%)	17 (28.3%)	$\chi^2 = 10.12$	-34.1% to -8.9%	0.001*

Table 3 shows that ultrasound guidance significantly reduced procedural difficulty and duration. The mean number of attempts required for successful cannulation was significantly lower in the ultrasound group (1.18 ± 0.46) compared to the landmark group (1.94 ± 0.88) (t = 5.94, p < 0.001), with a 95% CI of -1.01 to -0.49 attempts. Likewise, the time required for cannulation was significantly shorter with ultrasound guidance (4.82 ± 1.36 minutes) compared to the landmark technique (7.41 ± 2.18 minutes) (t = 7.48, p < 0.001), with a 95% CI of -3.28 to -1.90 minutes. Additionally, the proportion of patients requiring more than two attempts was significantly lower in the ultrasound group (6.7%) compared to the landmark group (28.3%) ($\chi^2 = 10.12$, p = 0.001), with the 95% CI (-34.1% to -8.9%) confirming a substantial reduction.

Table 4: Comparison of Procedure-Related Complications

Complication	Ultrasound (n=60)	Landmark (n=60)	Test of Significance	95% CI	p-value
Arterial Puncture	2 (3.3%)	9 (15.0%)	$\chi^2 = 5.00$	-20.1% to -1.8%	0.025*
Hematoma	3 (5.0%)	8 (13.3%)	$\chi^2 = 2.54$	-19.4% to 2.8%	0.111
Pneumothorax	1 (1.7%)	5 (8.3%)	Fisher's Exact	-14.6% to 1.2%	0.094
Catheter Malposition	1 (1.7%)	6 (10.0%)	Fisher's Exact	-16.8% to -0.3%	0.048*
Total Mechanical Complications	6 (10.0%)	18 (30.0%)	$\chi^2 = 7.87$	-33.4% to -6.5%	0.005*

Table 4 compares specific mechanical complications between the two techniques. Arterial puncture occurred significantly less frequently in the ultrasound group (3.3%) compared to the landmark group (15.0%) ($\chi^2 = 5.00$, p = 0.025), with the 95% CI (-20.1% to -1.8%) indicating a significant reduction. Catheter malposition was also significantly lower in the ultrasound group (1.7%) compared to the landmark group (10.0%) (Fisher's Exact, p = 0.048), with the 95% CI (-16.8% to -0.3%) supporting statistical significance. Although hematoma (5.0% vs 13.3%) and pneumothorax (1.7% vs 8.3%) were numerically lower in the ultrasound group, these differences did not reach statistical significance (p = 0.111 and p = 0.094, respectively). Importantly, total mechanical complications were significantly reduced in the ultrasound group (10.0%) compared to the landmark group (30.0%) ($\chi^2 = 7.87$, p = 0.005), with a 95% CI of -33.4% to -6.5%.

DISCUSSION

The present study demonstrated that ultrasound-guided (USG) central venous cannulation significantly improved overall success rates while reducing complications and procedure time compared to the landmark technique. The overall successful cannulation rate was 95.0% in the ultrasound group versus 81.7% in the landmark group (p = 0.019). These findings are consistent with the comparative study by Davis et al. (2023),[1] and Bıçak et al. (2023),[2] who reported significantly higher success rates with ultrasound guidance across adult and pediatric populations. Similarly, the prospective observational study by Pal et al. (2025),[3] concluded that real-time ultrasound significantly reduces failed catheter placements and improves overall procedural success compared to the landmark method.

The reduction in overall complications from 30.0% in the landmark group to 10.0% in the ultrasound group (p = 0.005) in our study aligns with the findings of Berlanga-Macias et al. (2022),[4] and Singh et al. (2022),[5] who emphasized that mechanical complications are strongly associated with blind insertion and multiple needle passes. Their studies demonstrated that ultrasound visualization minimizes inadvertent arterial puncture and hematoma formation. Additionally, Suliman et al. (2025),[6] highlighted that adequate anatomical knowledge combined with ultrasound guidance significantly improves safety and operator confidence, particularly in resource-limited settings. First-attempt success is an important indicator of procedural efficiency and patient safety. In the present study, first-attempt success was significantly higher in the ultrasound group (86.7%) compared to the landmark group (63.3%) (p = 0.003). This finding is comparable to the randomized study by Chew et al. (2020),[7] who demonstrated that ultrasound-guided vascular access significantly increases first-pass success and reduces inadvertent arterial puncture. Similarly, Strauss et al. (2025),[8] reported improved first-attempt success and fewer access-related complications with ultrasound guidance compared to anatomic landmark techniques.

The number of attempts and procedure time were significantly lower in the ultrasound group in our study (mean attempts: 1.18 vs 1.94; mean time: 4.82 vs 7.41 minutes; p < 0.001). This finding is supported by Rodríguez-Herrera et al. (2022),[9] who showed that ultrasound guidance significantly reduces repeated attempts and improves procedural efficiency in patients with difficult venous access. Reduced multiple attempts also directly contribute to lower complication rates and improved patient comfort.

Regarding individual complications, arterial puncture was significantly lower in the ultrasound group (3.3% vs 15.0%; p = 0.025), consistent with the findings of Singhal et al. (2025),[10] who reported a substantial reduction in arterial injury rates with ultrasound-assisted vascular cannulation. Although hematoma and pneumothorax were numerically lower in the ultrasound group, the differences did not reach statistical significance, possibly due to the modest sample size. Nevertheless, total mechanical complications were significantly reduced (10.0% vs 30.0%; p = 0.005), further reinforcing global evidence that supports ultrasound guidance as the preferred technique for central venous access.

CONCLUSION

The present comparative cross-sectional study demonstrated that ultrasound-guided central venous cannulation is significantly superior to the conventional landmark technique in terms of overall success rate, first-attempt success, procedural efficiency, and reduction in mechanical complications. Ultrasound guidance resulted in higher overall successful cannulation rates, significantly improved first-pass success, fewer

attempts, and shorter procedure time. Importantly, the incidence of arterial puncture and total mechanical complications was significantly lower in the ultrasound group. These findings reinforce the clinical advantage of real-time ultrasound visualization in enhancing patient safety and procedural accuracy. Based on the evidence from this study, ultrasound guidance should be considered the preferred technique for central venous cannulation whenever equipment and trained personnel are available.

Limitations of the study

1. The study was conducted at a single tertiary care center, which may limit the generalizability of the findings to other healthcare settings.
2. The sample size, although adequate for primary outcomes, may not have been large enough to detect statistically significant differences in rare complications such as pneumothorax.
3. Operator experience and skill level were not stratified, which could influence procedural success and complication rates.
4. Long-term complications such as catheter-related bloodstream infections and thrombosis were not evaluated.
5. The study did not assess cost-effectiveness or training requirements associated with ultrasound-guided cannulation.

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