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Comparison of Ultrasound-Guided and Landmark-Guided Central Venous Catheterization Success Rate and Complications

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ABSTRACT

Background: Central venous catheterization (CVC) is widely used in perioperative and critical care practice but may be associated with multiple attempts and mechanical complications. Ultrasound guidance may improve procedural success and safety compared with the conventional anatomical landmark technique. **Objectives:** The purpose of this study was to compare ultrasound-guided (USG) and landmark-guided (LMG) internal jugular CVC in terms of first-attempt success, overall success, number of attempts, procedural time, and mechanical complications. **Materials and Methods:** Patients were allocated equally to an USG group (n = 70) and a LMG group (n = 70). The primary outcome was first-attempt catheterization success. Secondary outcomes included overall success within three attempts, number of puncture attempts, access time, total catheterization time, and procedure-related mechanical complications. Statistical significance was set at $P < 0.05$. Results: First-attempt success was significantly higher in the USG group than in the LMG group (91.4% vs. 71.4%; $P = 0.002$). Overall success within three attempts was 98.6% and 91.4%, respectively. Patients in the USG group required fewer puncture attempts (1.11 ± 0.40 vs. 1.43 ± 0.73; $P = 0.002$). **Conclusion:** USG internal jugular CVC provides higher first-attempt success, requires fewer attempts, shortens procedural time, and reduces overall mechanical complications compared with the anatomical landmark technique.

Keywords: Central venous catheterization, First-attempt success, Internal jugular vein, landmark technique, Mechanical complications, Ultrasound guidance

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Introduction

Central venous catheterization (CVC) is an essential invasive procedure frequently performed in operating rooms, intensive care units, emergency departments, and other acute-care settings. Central venous access is required for several diagnostic and therapeutic purposes, including administration of vasoactive medications, rapid delivery of fluids and blood products, parenteral nutrition, hemodynamic monitoring, hemodialysis, and reliable venous access in critically ill patients. The internal jugular, subclavian, and femoral veins are the most commonly used sites for central venous catheter placement. Despite being routinely performed, CVC is associated with potentially serious mechanical complications, including arterial puncture, hematoma, pneumothorax, hemothorax, catheter malposition, vascular injury, and, rarely, life-threatening complications.[1]

Traditionally, CVC has been performed using an anatomical landmark-guided (LMG) technique. This method relies on knowledge of surface anatomy and the expected relationship between the target vein and surrounding structures. However, the actual position and size of central veins can vary considerably between individuals, and the relationship between the internal jugular vein and carotid artery may differ from the expected anatomical configuration. Patient-related factors such as obesity, previous catheterization, thrombosis, anatomical abnormalities, skeletal deformity, hypovolemia, previous surgery, and inability to position the patient adequately can further reduce the reliability of surface landmarks.[2] Consequently, repeated needle passes may be required, increasing procedural duration and the possibility of mechanical complications. Early evidence demonstrated that ultrasound guidance substantially reduced catheter-placement failure, complications, and the requirement for multiple attempts compared with conventional landmark techniques.[3]

The introduction of ultrasonography has significantly changed the approach to central venous access. Ultrasound can be used either as a static technique, in which the target vessel is identified before needle insertion, or as real-time dynamic guidance, in which the needle is visualized while advancing toward and entering the target vein. Real-time ultrasound enables identification of the vein, neighboring artery, and other anatomical structures while also providing information regarding vessel size, depth, compressibility, anatomical variations, and possible venous thrombosis.[4] These advantages are particularly important when the anatomy is difficult or when repeated attempts using the landmark technique may expose the patient to unnecessary procedural risk.

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Evidence supporting ultrasound guidance has accumulated over several decades. Denys *et al.* demonstrated that ultrasound-assisted internal jugular vein cannulation improved the success rate, shortened access time, and reduced complications compared with external landmark guidance.[4] Subsequently, a meta-analysis by Hind *et al.* involving 18 trials and 1646 participants found that real-time two-dimensional ultrasound guidance significantly reduced overall failure during internal jugular venous cannulation compared with the landmark method.[5] These findings provided an important evidence base for the adoption of ultrasonography as a strategy to improve both procedural efficacy and patient safety.

The advantages of ultrasound guidance have also been demonstrated in critically ill patients. Karakitsos *et al.* compared real-time ultrasound-guided (USG) and LMG internal jugular vein catheterization in 900 critically ill patients. Successful cannulation was achieved in 100% of patients in the USG group compared with 94.4% in the landmark group. Ultrasound guidance also significantly reduced access time and the number of attempts. In the landmark group, carotid artery puncture occurred in 10.6%, hematoma in 8.4%, hemothorax in 1.7%, and pneumothorax in 2.4%, with these complications being significantly more frequent than in the USG group.[6] Another clinical study by Palepu *et al.* demonstrated an overall internal jugular cannulation success rate of 97.6% with ultrasound guidance compared with 91.2% using the anatomical landmark technique, while first-attempt success was also significantly higher with ultrasound guidance.[7]

Although the evidence is particularly strong for internal jugular vein catheterization, ultrasound guidance has also been evaluated for subclavian and femoral venous access. Fragou *et al.*, in a prospective randomized study of subclavian vein cannulation, reported fewer complications, including arterial puncture, hematoma, hemothorax, and pneumothorax, with real-time ultrasound guidance compared with the landmark technique.[8] Systematic reviews have subsequently demonstrated that the magnitude of benefit may vary according to the venous access site. Brass *et al.* concluded that two-dimensional ultrasound guidance provides important improvements in safety and quality for internal jugular vein catheterization.[9] For subclavian and femoral catheterization, benefits have also been identified, although evidence regarding some outcomes is less consistent than for internal jugular access.[10]

A systematic review and meta-analysis by Lalu *et al.* further demonstrated that USG subclavian catheterization reduced overall procedural complications compared with LMG catheterization, with real-time ultrasound particularly reducing accidental arterial puncture, pneumothorax, and hematoma formation.[11] Collectively, these findings support the incorporation of ultrasound into routine vascular-access practice while recognizing that effectiveness is influenced by the target vessel, ultrasound approach, operator experience, equipment availability, and appropriate training.

International recommendations have increasingly supported USG vascular access. Evidence-based recommendations have advocated real-time ultrasound guidance, particularly for internal jugular catheterization, because of improved procedural success and reduced mechanical complications.[12] Nevertheless, LMG catheterization remains relevant in healthcare facilities where ultrasound equipment is unavailable, in emergency circumstances, and as an important anatomical skill for clinicians. Ultrasound guidance also requires appropriate training, hand-eye coordination, maintenance of sterile technique, and the ability to continuously identify the needle tip during advancement. Therefore, direct comparison of these two approaches remains clinically important, particularly in settings where both techniques continue to be used.

Considering the clinical importance of successful central venous access and the potentially serious consequences of unsuccessful or complicated catheter placement, further evaluation of procedural success and complications associated with different techniques is warranted. The present study therefore aimed to compare USG and anatomical LMG CVC with respect to overall and first-attempt success, number of attempts, procedural characteristics, and catheterization-related complications.

Materials and Methods

Study Design and Setting

This prospective, randomized, comparative study was conducted in the Department of Anaesthesiology and Critical Care at GIMS Kalaburagi. The study included adult patients requiring CVC for perioperative management, administration of vasoactive medications, fluid therapy, hemodynamic monitoring, or other clinically indicated purposes. The study was conducted over the period 2022–2024.

For methodological uniformity, internal jugular vein catheterization was selected as the central venous access route. Patients were randomly assigned in a 1:1 ratio to undergo either real-time USG CVC or conventional anatomical LMG catheterization.

Sample Size

A total of 140 patients were included in the study. The sample size was estimated considering an anticipated clinically meaningful difference in first-attempt catheterization success between USG and LMG techniques. Assuming first-attempt success rates of approximately 90% and 70%, respectively, a two-sided alpha error of 0.05 and statistical power of 80%, the minimum estimated sample size was approximately 62 patients per group. After allowing for approximately 10% attrition, failed enrollment, or incomplete observations, the required sample was rounded to 70 patients per group, giving a final sample size of 140 patients.

Patients were allocated into two groups:

- Group USG ($n = 70$): CVC using real-time ultrasound guidance.
- Group LM ($n = 70$): CVC using the conventional anatomical landmark technique.

Eligibility Criteria

Inclusion criteria

Patients were eligible for inclusion if they fulfilled all of the following criteria:

1. Age ≥18 years.
2. Requirement for internal jugular CVC for a clinically established indication.
3. Hemodynamically stable or sufficiently stabilized to undergo the procedure according to the study protocol.

4. Availability of an appropriate internal jugular venous access site.
5. Provision of written informed consent by the patient or legally authorized representative.

Exclusion criteria

Patients were excluded in the presence of any of the following:

1. Refusal to participate.
2. Local infection, cellulitis, burn, or major trauma at the proposed catheterization site.
3. Known thrombosis or occlusion of the internal jugular vein.
4. Major anatomical abnormality or previous extensive surgery involving the neck.
5. Uncorrected severe coagulopathy or clinically significant thrombocytopenia where CVC was considered unsafe.
6. Requirement for immediate life-saving vascular access precluding study-group allocation.
7. Previous unsuccessful CVC at the same site immediately before enrollment.
8. Presence of a central venous catheter at the proposed access site.

Randomization and Allocation

Eligible participants were allocated to either the USG group or LM group in a 1:1 ratio using a computer-generated random allocation sequence. Allocation was concealed using sequentially numbered, opaque, sealed envelopes that were opened immediately before catheter insertion.

Because of the nature of the intervention, blinding of the operator was not possible. However, wherever feasible, procedural outcomes and complications were recorded by an investigator who was not directly involved in catheter insertion to minimize observer bias.

Preprocedural Preparation

Before catheterization, demographic and clinical information, including age, sex, body mass index, primary diagnosis, indication for CVC, hemodynamic parameters, and relevant comorbidities, was recorded.

Standard monitoring consisting of continuous electrocardiography, non-invasive blood pressure monitoring, and pulse oximetry was instituted before the procedure. Supplemental oxygen was administered when clinically indicated.

The patient was placed in the supine position with approximately 10–15° Trendelenburg tilt whenever clinically tolerated. The head was turned slightly to the contralateral side while avoiding excessive rotation. The right internal jugular vein was preferentially selected unless a clinical contraindication necessitated use of the left side.

Strict aseptic precautions were maintained throughout the procedure. Hand hygiene was performed, and the operator used sterile gloves, gown, mask, cap, and a large sterile drape. The skin was prepared with an appropriate antiseptic solution and allowed to dry before needle insertion. Local anesthesia was infiltrated at the puncture site in conscious patients.

All central venous catheters were inserted using the Seldinger technique with a standard central venous catheter set.

USG Catheterization Technique

In Group USG, real-time two-dimensional ultrasonography was used for internal jugular venous cannulation. A high-frequency linear-array transducer was covered with a sterile probe sheath, and sterile ultrasound gel was applied.

Before needle insertion, the internal jugular vein and carotid artery were identified. The vein was differentiated from the artery by its anatomical position, compressibility, respiratory variation, and ultrasonographic appearance. Vessel patency and the absence of visible thrombus were also assessed.

The internal jugular vein was visualized primarily in the transverse short-axis view. Under continuous real-time ultrasound guidance, the introducer needle was advanced toward the vein while maintaining visualization of the needle trajectory and target vessel. Entry into the vein was confirmed by aspiration of venous blood and ultrasonographic visualization where feasible.

A guidewire was subsequently advanced through the needle. After appropriate tract dilatation, the central venous catheter was inserted over the guidewire using the Seldinger technique. The guidewire was then removed, and free aspiration of venous blood from each catheter lumen was confirmed. Each lumen was flushed with sterile saline, and the catheter was secured appropriately.

Anatomical LMG Catheterization Technique

In Group LM, the internal jugular vein was cannulated using the conventional anatomical landmark technique without ultrasonographic assistance during needle insertion.

The sternal and clavicular heads of the sternocleidomastoid muscle and the carotid artery pulsation were identified by palpation. The puncture site was selected according to the standard central approach to internal jugular vein cannulation.

After infiltration of local anesthetic, the introducer needle attached to a syringe was advanced while continuous gentle negative pressure was applied. The needle was directed toward the ipsilateral nipple at an appropriate angle to the skin while avoiding the palpable carotid artery.

Successful venous puncture was identified by free aspiration of non-pulsatile dark venous blood. The guidewire was introduced through the needle, followed by dilatation and insertion of the central venous catheter according to the standard Seldinger technique. Free blood aspiration from all lumens was verified before flushing and securing the catheter.

Operator Standardization

To minimize operator-related variability, catheterizations in both groups were performed or directly supervised by anesthesiologists/clinicians with adequate experience in both USG and LMG central venous access.

The same procedural preparation, patient positioning, catheter type, aseptic precautions, and post-insertion assessment protocol were applied to both groups. Operators were instructed to follow the predefined procedural steps and outcome definitions throughout the study.

Definition of an Attempt

An attempt was defined as a separate percutaneous needle penetration of the skin with the intention of entering the internal

jugular vein. Needle redirection without complete withdrawal from the skin was recorded separately where applicable but was not considered a new skin-puncture attempt.

Definition of Successful Catheterization

Successful CVC was defined as successful entry into the target vein followed by guidewire passage, successful placement of the catheter, and satisfactory aspiration of venous blood through the catheter lumen(s).

First-attempt success was defined as successful catheter placement following the first skin puncture without requiring an additional needle insertion.

Overall success was defined as successful catheter placement within a maximum of three attempts using the initially allocated technique. Failure to achieve successful venous access after three attempts was considered procedural failure, after which further vascular-access management was undertaken according to the treating clinician's judgment and institutional safety protocol.

Assessment of Complications

Patients were evaluated for immediate mechanical complications during and following catheterization. The following complications were prospectively recorded:

- Accidental carotid artery puncture
- Local hematoma
- Significant bleeding at the insertion site
- Pneumothorax
- Hemothorax
- Catheter malposition
- Guidewire-related difficulty
- Failure of guidewire advancement
- Multiple punctures
- Local nerve injury
- Other procedure-related adverse events.

Arterial puncture was defined as inadvertent needle entry into the carotid artery, identified by pulsatile bright-red blood return and/or appropriate clinical or ultrasonographic confirmation.

Hematoma was defined as clinically apparent swelling or collection of blood around the catheterization site following needle puncture.

Patients were clinically assessed immediately after catheterization. Pneumothorax, hemothorax, and catheter-tip position were evaluated using bedside ultrasonography and/or chest radiography according to clinical indication and institutional protocol.

Outcome Measures

The primary outcome of the study was:

First-attempt success rate of CVC in the USG and LMG groups**.**

The secondary outcomes included:

1. Overall catheterization success rate.
2. Number of catheterization attempts.
3. Access time.
4. Total catheterization time.
5. Frequency of accidental arterial puncture.
6. Incidence of local hematoma.
7. Incidence of pneumothorax and hemothorax.
8. Catheter malposition.
9. Guidewire-related difficulties.
10. Overall incidence of procedure-related mechanical complications.

Data Collection

Data were recorded prospectively using a predefined structured case-record form. Baseline demographic characteristics, indication for catheterization, access side, number of attempts, first-attempt success, overall success, access time, total catheterization time, and procedural complications were documented for every participant.

Data completeness and consistency were checked before entry into the final database. Patient-identifying information was excluded from the analytical dataset.

Statistical Analysis

Statistical analysis was performed using IBM Statistical Package for the Social Sciences Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were assessed for distribution using the Shapiro–Wilk test and visual inspection of histograms. Normally distributed continuous variables were expressed as mean ± standard deviation, whereas non-normally distributed variables were presented as median with interquartile range.

Results

A total of 140 patients requiring internal jugular CVC were included in the study and randomized equally to the USG group (Group USG, $n = 70$) and anatomical LMG group (Group LM, $n = 70$). All enrolled patients were included in the final analysis.

Baseline demographic and clinical characteristics were comparable between the two groups, with no statistically significant differences in age, sex, body mass index, indication for catheterization, or side of catheter insertion. Therefore, the groups were considered comparable at baseline.

First-attempt successful catheterization was achieved in 64 of 70 patients (91.4%) in the USG group compared with 50 of 70 patients (71.4%) in the LMG group. The difference was statistically significant ($P = 0.002$).

The relative probability of achieving successful catheterization on the first attempt was approximately 28% higher with ultrasound guidance than with landmark guidance (relative risk [RR] = 1.28, 95% confidence interval [CI] = 1.09–1.51).

Overall successful catheterization within three attempts was achieved in 69 patients (98.6%) in Group USG and 64 patients (91.4%) in Group LM. Although overall success remained numerically higher with ultrasound guidance, the difference did not reach statistical significance ($P = 0.116$).

The absolute improvement in first-attempt success with ultrasound guidance was 20 percentage points, corresponding to approximately one additional first-attempt success for every five patients undergoing USG rather than LMG catheterization.

Patients undergoing USG catheterization required significantly fewer needle-puncture attempts than those undergoing LMG catheterization. The median number of attempts was 1 (IQR 1–1) in Group USG compared with 1 (IQR 1–2) in Group LM ($P = 0.002$).

A single puncture was sufficient in 91.4% of patients in Group USG compared with 71.4% in Group LM. Conversely, three punctures were required in only 2.9% of patients in the ultrasound group compared with 14.3% in the landmark group.

Both access time and total catheterization time were significantly shorter with ultrasound guidance. Mean access time was 37.8 ± 17.2 s in Group USG compared with 58.6 ± 27.4 s in Group LM ($P < 0.001$). Similarly, total catheterization time was 151.6 ± 42.8 s versus 211.3 ± 68.5 s, respectively ($P < 0.001$).

Mechanical complications occurred less frequently in patients undergoing USG catheterization. At least one procedure-related mechanical complication was identified in 3 patients (4.3%) in Group USG compared with 14 patients (20.0%) in Group LM, representing a statistically significant reduction ($P = 0.004$).

Accidental carotid artery puncture occurred in 1 patient (1.4%) in Group USG and 7 patients (10.0%) in Group LM. Although the absolute difference was clinically notable, statistical significance was not achieved using Fisher's exact test ($P = 0.063$).

Local hematoma occurred in 1.4% and 8.6% of patients, respectively. Pneumothorax occurred in three patients in the LMG group but was not observed in the USG group. One case of hemothorax was observed in Group LM, whereas none occurred in Group USG.

Guidewire advancement was generally easier in the USG group, with guidewire-related difficulty occurring in only one patient compared with five patients in the LMG group. Catheter malposition was also less frequent in the ultrasound group.

A rescue or alternative catheterization strategy following protocol-defined failure was required in one patient in Group USG compared with six patients in Group LM.

The magnitude of treatment effect was further assessed using RRs and absolute risk differences. Ultrasound guidance increased first-attempt success by 20.0% and reduced the risk of requiring repeated punctures by 70% relative to the landmark technique.

The absolute risk of experiencing any mechanical complication was reduced from 20.0% with landmark guidance to 4.3% with ultrasound guidance, corresponding to an absolute risk reduction of 15.7%. The RR of a mechanical complication with ultrasound guidance was 0.21 (95% CI = 0.06–0.71).

Overall, USG internal jugular CVC was associated with a significantly higher first-attempt success rate, fewer needle-puncture attempts, shorter procedural duration, and a lower overall incidence of mechanical complications than the conventional anatomical LMG technique. Although overall catheterization success and several individual rare complications did not differ significantly, the direction of effect consistently favored ultrasound guidance.

Figure 1 shows a significantly higher first-attempt success rate in the USG group compared with the LMG group (91.4% vs. 71.4%; $P = 0.002$). Overall catheterization success within three attempts was also higher with ultrasound guidance (98.6%) than with the landmark technique (91.4%), although this difference was not statistically significant.

Figure 2 demonstrates significantly shorter mean access time in the USG group compared with the LMG group (37.8 ± 17.2 vs. 58.6 ± 27.4 s; $P < 0.001$). Total catheterization time was also significantly lower with ultrasound guidance (151.6 ± 42.8 vs. 211.3 ± 68.5 s; $P < 0.001$), indicating greater procedural efficiency with USG catheterization.

Discussion

The present study compared real-time USG and anatomical LMG internal jugular CVC in 140 patients and demonstrated a clear procedural advantage associated with ultrasound guidance.

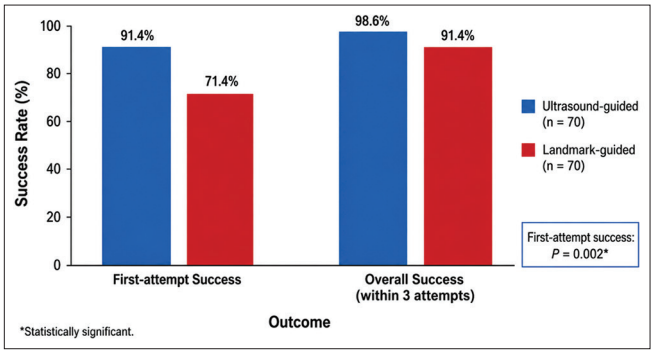

Figure 1: First-attempt and overall success rates of ultrasound-guided and landmark-guided central venous catheterization. *Statistically significant

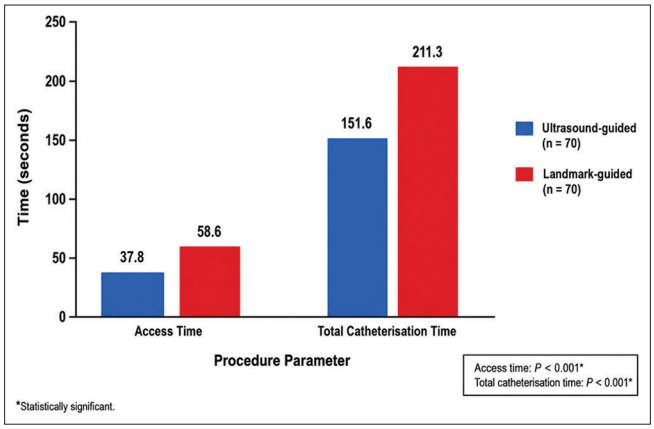

Figure 2: Comparison of access time and total catheterization time between ultrasound-guided and landmark-guided groups. *Statistically significant

The principal findings were a significantly higher first-attempt success rate, fewer repeated punctures, shorter access and total catheterization times, and a significantly lower overall incidence of mechanical complications in the USG group. Although overall catheterization success and several individual complications did not reach statistical significance, the direction of effect consistently favored ultrasound guidance. Collectively, these findings support the use of real-time ultrasonography as the preferred approach for internal jugular central venous access.

The first-attempt success rate was significantly higher in the USG group than in the LMG group (91.4% vs. 71.4%, $P = 0.002$). This absolute difference of 20 percentage points is clinically important because successful catheterization at the first puncture reduces tissue trauma and the cumulative risk associated with repeated needle manipulation. Earlier evidence has demonstrated similar benefits. Slama *et al.* reported successful internal jugular vein cannulation in all patients undergoing USG placement compared with 76% of those undergoing LMG placement, supporting the ability of ultrasound to improve procedural success, particularly in the intensive care setting.[13]

The findings are also consistent with those of Leung *et al.*, who conducted a prospective randomized study in an emergency department and reported an overall cannulation success rate of 93.9% with real-time ultrasound compared with 78.5% using anatomical landmarks. First-attempt cannulation was also

Table 1: Baseline demographic and clinical characteristics of the study participants

Characteristic	Group USG (*n*=70)	Group LM (*n*=70)	*P* value
Age, years, mean±SD	48.9±14.1	49.7±13.8	0.735
Male, *n* (%)	42 (60.0)	39 (55.7)	0.608
Female, *n* (%)	28 (40.0)	31 (44.3)	
BMI, kg/m^2, mean±SD	25.1±3.6	25.6±3.9	0.432
Right internal jugular access, *n* (%)	65 (92.9)	64 (91.4)	1.000
Left internal jugular access, *n* (%)	5 (7.1)	6 (8.6)	
Vasoactive drug administration, *n* (%)	24 (34.3)	25 (35.7)	0.995
Hemodynamic monitoring, *n* (%)	18 (25.7)	17 (24.3)	
Difficult peripheral venous access, *n* (%)	11 (15.7)	10 (14.3)	
Major surgery/perioperative indication, *n* (%)	10 (14.3)	11 (15.7)	
Other indications, *n* (%)	7 (10.0)	7 (10.0)	

SD: Standard deviation, USG: Ultrasound-guided, LM: Landmark

Table 2: Comparison of catheterization success between the two groups

Outcome	Group USG (*n*=70) (%)	Group LM (*n*=70) (%)	Relative risk (95% CI)	*P* value
First-attempt success	64 (91.4)	50 (71.4)	1.28 (1.09-1.51)	**0.002**
Second-attempt success	4 (5.7)	10 (14.3)	-	-
Third-attempt success	1 (1.4)	4 (5.7)	-	-
Overall success within 3 attempts	69 (98.6)	64 (91.4)	1.08 (1.00-1.16)	0.116
Procedural failure	1 (1.4)	6 (8.6)	0.17 (0.02-1.35)	0.116
Required>1 attempt	6 (8.6)	20 (28.6)	0.30 (0.13-0.70)	**0.002**

USG: Ultrasound-guided, LM: Landmark, CI: Confidence interval. P value means null hypothesis

Table 3: Number of attempts and procedural duration

Procedural parameter	Group USG (*n*=70)	Group LM (*n*=70)	*P* value
Successful/terminated after first attempt, *n* (%)	64 (91.4)	50 (71.4)	**0.002**
Required second attempt, *n* (%)	4 (5.7)	10 (14.3)	
Required≥3 attempts, *n* (%)	2 (2.9)	10 (14.3)	
Number of puncture attempts, median (IQR)	1 (1-1)	1 (1-2)	**0.002**
Mean number of attempts	1.11±0.40	1.43±0.73	**0.002**
Access time, s, mean±SD	37.8±17.2	58.6±27.4	**<0.001**
Total catheterization time, seconds, mean±SD	151.6±42.8	211.3±68.5	**<0.001**

SD: Standard deviation, USG: Ultrasound-guided, LM: Landmark, IQR: Interquartile range. P value means null hypothesis

Table 4: Comparison of mechanical complications between the groups

Complication	Group USG (*n*=70) (%)	Group LM (*n*=70) (%)	*P* value
Carotid artery puncture	1 (1.4)	7 (10.0)	0.063
Local hematoma	1 (1.4)	6 (8.6)	0.116
Pneumothorax	0 (0.0)	3 (4.3)	0.245
Hemothorax	0 (0.0)	1 (1.4)	1.000
Significant insertion-site bleeding	0 (0.0)	2 (2.9)	0.496
Catheter malposition	1 (1.4)	4 (5.7)	0.366
Guidewire-related difficulty	1 (1.4)	5 (7.1)	0.209
At least one mechanical complication	**3 (4.3)**	**14 (20.0)**	**0.004**

USG: Ultrasound-guided, LM: Landmark

Table 5: Technical and post-insertion catheterization outcomes

Outcome	Group USG (*n*=70) (%)	Group LM (*n*=70) (%)	*P* value
More than one skin puncture required	6 (8.6)	20 (28.6)	**0.002**
Guidewire-related difficulty	1 (1.4)	5 (7.1)	0.209
Catheter malposition	1 (1.4)	4 (5.7)	0.366
Catheter repositioning required	1 (1.4)	4 (5.7)	0.366
Rescue/alternative technique after failure	1 (1.4)	6 (8.6)	0.116
Satisfactory catheter placement without mechanical complication	67 (95.7)	56 (80.0)	**0.004**

USG: Ultrasound-guided, LM: Landmark

more frequent with ultrasound guidance.[14] The slightly higher first-attempt success observed in our ultrasound group may be related to standardization of the internal jugular approach, operator experience, patient selection, and continuous real-time visualization of the target vein.

The reduction in repeated punctures represents another important finding. Only 8.6% of patients in the ultrasound group required more than one attempt compared with 28.6% in the landmark group (P = 0.002). Similarly, the mean number of attempts was significantly lower with ultrasound guidance. Turker *et al.*, in a randomized study involving 380 patients, demonstrated that the landmark technique required significantly more attempts and was associated with longer vascular access time than real-time USG internal jugular cannulation.[15] Real-time ultrasound allows direct visualization of the vein, its depth and diameter, and its relationship with the carotid artery. Consequently, the operator

Table 6: Effect estimates for major clinical outcomes associated with ultrasound guidance

Outcome	USG rate (%)	LM rate (%)	Relative risk (95% CI)	Absolute difference (%)	*P* value
First-attempt success	91.4	71.4	1.28 (1.09-1.51)	+20.0	**0.002**
Overall success	98.6	91.4	1.08 (1.00-1.16)	+7.2	0.116
Requirement for>1 attempt	8.6	28.6	0.30 (0.13-0.70)	−20.0	**0.002**
Any mechanical complication	4.3	20.0	0.21 (0.06-0.71)	−15.7	**0.004**
Carotid artery puncture	1.4	10.0	0.14 (0.02-1.13)	−8.6	0.063
Local hematoma	1.4	8.6	0.17 (0.02-1.35)	−7.2	0.116

USG: Ultrasound-guided, LM: Landmark, CI: Confidence interval

does not have to rely exclusively on the assumption that the patient's vascular anatomy corresponds to conventional surface landmarks.

The clinical relevance of limiting needle passes should not be underestimated. Each additional puncture may increase the possibility of arterial injury, hematoma formation, patient discomfort, and procedural failure. Furthermore, difficult or repeated attempts may become particularly hazardous in patients with obesity, hypovolemia, distorted anatomical landmarks, or limited ability to tolerate optimal positioning. Airapetian *et al.* found that USG cannulation performed by inexperienced operators was associated with greater procedural success and fewer complications than landmark-based techniques, highlighting the potential value of ultrasound not only as an imaging modality but also as an important procedural safety tool.[16]

In the present study, ultrasound guidance also significantly improved procedural efficiency. Mean access time decreased from 58.6 ± 27.4 s with landmark guidance to 37.8 ± 17.2 s with ultrasound guidance ($P < 0.001$), while total catheterization time decreased from 211.3 ± 68.5 s to 151.6 ± 42.8 s ($P < 0.001$). These findings demonstrate that the additional step of ultrasound imaging does not necessarily prolong the procedure. Instead, accurate localization of the vein and real-time guidance of the needle may compensate for initial scanning time by reducing unsuccessful punctures and needle redirections. Rando *et al.* similarly demonstrated higher successful catheter placement with ultrasound guidance than without ultrasound and noted an important interaction between ultrasound use and operator experience.[17]

Safety is one of the principal reasons for adopting USG central venous access. In our study, at least one mechanical complication occurred in only 4.3% of patients undergoing USG catheterization compared with 20.0% in the landmark group ($P = 0.004$). This corresponds to an RR of approximately 0.21 and an absolute risk reduction of 15.7 percentage points. Thus, the observed results suggest that ultrasound guidance was associated with an approximately 79% relative reduction in the composite risk of mechanical complications. From a clinical perspective, approximately seven patients would need to undergo USG rather than LMG catheterization to prevent one additional composite mechanical complication based on the observed absolute difference.

Accidental carotid artery puncture occurred in 1.4% of patients in the ultrasound group compared with 10.0% in the landmark group. Although this difference did not reach conventional statistical significance ($P = 0.063$), the marked numerical reduction is clinically meaningful. The absence of statistical significance should therefore not be interpreted as evidence of equivalence. The relatively small number of arterial puncture events limited statistical power for this individual complication. Dolu *et al.* also compared USG and LMG internal jugular cannulation and demonstrated advantages associated with ultrasound guidance in procedural performance.[18] Fathi *et al.* subsequently observed a significantly lower carotid artery puncture rate with USG internal jugular cannulation, even when several other procedural outcomes were comparable between groups.[19]

A similar pattern was observed for hematoma, pneumothorax, hemothorax, catheter malposition, and guidewire-related difficulties. Local hematoma occurred in 1.4% of USG procedures compared with 8.6% of LMG procedures. Pneumothorax occurred in three patients in the landmark group and in none in the ultrasound group, while hemothorax occurred in one LMG case. These individual outcomes were uncommon and consequently did not achieve statistical significance. Nevertheless, their consistent direction toward reduced complications with ultrasound guidance reinforces the composite safety finding. Rare adverse events generally require substantially larger studies to demonstrate statistically significant differences individually.

The mechanisms underlying the improved safety of ultrasonography are biologically and technically plausible. Real-time ultrasound enables identification of the internal jugular vein before puncture, assessment of vessel patency and size, recognition of anatomical variation, differentiation of the vein from the carotid artery, and continuous guidance of the needle toward the intended vessel. A structured review by Saugel *et al.* concluded that evidence clearly supports gains in safety and procedural quality when ultrasound is used for internal jugular central venous catheter placement.[20] The authors further emphasized that ultrasound can be used not only to locate the vessel but also to assess patency and guide needle advancement and subsequent vascular-access steps.

The present results are therefore consistent with professional recommendations supporting real-time ultrasound-guided central venous access. Guidelines from the American Society of Echocardiography and Society of Cardiovascular Anesthesiologists recommend ultrasound guidance as an important strategy for vascular cannulation, with particular evidence supporting its use for internal jugular venous access.[21] The American Society of Anesthesiologists' 2020 practice guidelines similarly incorporated ultrasound into contemporary central venous access practice with the aim of improving successful placement and reducing adverse outcomes.[22] Furthermore, expert consensus guidelines for intravascular catheter management recommend ultrasound guidance for internal jugular access specifically to reduce mechanical complications.[23]

An important aspect of the present findings is that the difference in overall success was smaller than the difference in first-attempt success. Overall successful catheterization within three attempts was achieved in 98.6% of patients in the ultrasound group and 91.4% in the landmark group, and this difference did not achieve statistical significance. This indicates that experienced

clinicians can eventually obtain central venous access using anatomical landmarks in many patients. However, overall eventual success alone does not adequately represent procedural quality. A catheter inserted after several punctures cannot necessarily be considered equivalent, from a safety and patient-comfort perspective, to one placed successfully during the first puncture. Therefore, first-attempt success, number of attempts, procedural time, and complications provide clinically more informative measures when comparing the two techniques.

The findings also have implications for training. Ultrasound guidance should not be considered merely a rescue technique for patients with difficult anatomy. Rather, regular use allows clinicians to develop the hand-eye coordination and needle-visualization skills required for safe real-time vascular access. The findings of Airapetian *et al.* and Rando *et al.* indicate that operator experience substantially affects CVC outcomes and that ultrasound may be particularly valuable for less-experienced clinicians.[16,17] However, adequate training remains essential because possession of an ultrasound machine alone does not guarantee correct identification of structures or continuous needle-tip visualization.

From a clinical perspective, our findings suggest that real-time ultrasound guidance offers advantages at several stages of CVC. It facilitates identification of an appropriate puncture site, increases the probability of successful venous entry at the first attempt, reduces repeated tissue puncture, shortens procedural duration, and decreases the aggregate incidence of mechanical complications. These benefits are particularly relevant in critically ill or hemodynamically unstable patients, in whom prolonged or repeated attempts at vascular access may delay essential treatment.

Conclusion

USG internal jugular CVC was associated with a significantly higher first-attempt success rate, fewer needle-puncture attempts, and shorter access and total catheterization times compared with the conventional anatomical LMG technique. The overall incidence of mechanical complications was also significantly lower with ultrasound guidance, with fewer arterial punctures, hematomas, pneumothoraces, catheter malpositions, and guidewire-related difficulties.

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