

Comparative evaluation of ultrasound-guided versus Landmark Technique for internal jugular vein Cannulation.

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Abstract

Background: Internal jugular vein cannulation is commonly performed for central venous access in operating rooms, emergency departments and intensive care units. The conventional anatomical landmark technique may be associated with failed cannulation, repeated needle punctures, prolonged procedure time and mechanical complications. Real-time ultrasonography enables direct visualization of the vein, carotid artery and advancing needle and may therefore improve procedural effectiveness and safety. **Aim:** To compare the effectiveness and safety of ultrasound-guided and anatomical landmark techniques for internal jugular vein cannulation. **Materials and Methods:** This prospective comparative study included 200 adult patients requiring internal jugular vein cannulation at Durgapur steel plant hospital, J. M. Sengupta Road, Durgapur-713205. Patients were assigned equally to ultrasound-guided and anatomical landmark groups, with 100 patients in each group. The primary outcome was first-attempt cannulation success. Secondary outcomes included overall success, number of attempts, cannulation time, need for rescue or crossover and procedure-related complications. Categorical variables were compared using the chi-square test or Fisher's exact test, while continuous variables were compared using the independent-samples t test. Effect estimates were reported with 95% confidence intervals, and $p < 0.05$ was considered statistically significant. **Results:** First-attempt cannulation success was significantly higher with ultrasound guidance than with the landmark technique (91.0% versus 73.0%; risk difference=18.0%, 95% CI: 7.4%–28.6%; $p=0.001$). Overall success was 98.0% in the ultrasound group and 88.0% in the landmark group ($p=0.006$). The mean number of attempts was significantly lower with ultrasound guidance (1.12 ± 0.41 versus 1.43 ± 0.76 ; $p < 0.001$). Mean cannulation time was also shorter in the ultrasound group (54.8 ± 18.6 versus 92.7 ± 31.4 seconds), with a mean difference of -37.9 seconds (95% CI: -45.1 to -30.7 ; $p < 0.001$). Multiple attempts were required in 9.0% of ultrasound-guided procedures compared with 27.0% of landmark-guided procedures ($p=0.001$). The overall complication rate was significantly lower with ultrasound guidance (7.0% versus 24.0%; RR=0.29, 95% CI: 0.13–0.65; $p=0.001$). Arterial puncture occurred in 3.0% and 13.0% of patients, respectively ($p=0.009$). Successful cannulation without complications was achieved in 92.0% of the ultrasound group compared with 71.0% of the landmark group ($p < 0.001$). **Conclusion:** Real-time ultrasound-guided internal jugular vein cannulation was more effective, faster and safer than the anatomical landmark technique. It improved first-attempt and overall success, reduced repeated attempts and shortened cannulation time while decreasing procedure-related complications, particularly accidental arterial puncture. Ultrasound guidance should therefore be preferred for internal jugular vein cannulation when trained personnel and suitable equipment are available.

Keywords: Internal jugular vein; Ultrasound guidance; Central venous cannulation.



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INTRODUCTION

Central venous cannulation is an essential procedure in anaesthesia, emergency medicine and critical care. It provides reliable venous access for administering vasoactive medications, hyperosmolar solutions, parenteral nutrition and rapid fluid resuscitation and facilitates haemodynamic monitoring, renal replacement therapy and repeated blood sampling. The internal jugular vein is frequently selected because of its predictable anatomical location, accessibility and relatively low risk of pneumothorax compared with the subclavian route. Traditionally, internal jugular vein cannulation has been performed using anatomical landmarks, particularly the relationship between the two heads of the sternocleidomastoid muscle and the carotid artery. However, anatomical variations, obesity, previous catheterization, hypovolaemia, thrombosis

and difficulty in identifying surface landmarks may reduce the success of this technique. Multiple needle passes may increase the risk of carotid artery puncture, haematoma, pneumothorax, haemothorax, nerve injury and catheter malposition.[1,2]

Ultrasonography permits direct visualization of the internal jugular vein, carotid artery and surrounding structures. It enables assessment of vessel size, depth, patency and anatomical variation before puncture. During real-time ultrasound-guided cannulation, the operator can continuously observe needle advancement and confirm its entry into the vein. Ultrasound guidance can be performed using short-axis/out-of-plane or long-axis/in-plane approaches, each of which has particular technical advantages. A systematic approach involving identification of the vein, confirmation of patency, real-time visualization of venepuncture and verification of the guidewire and catheter position may further improve procedural safety.[2,3]

Evidence from randomized trials and systematic reviews indicates that two-dimensional ultrasound guidance improves overall and first-attempt success, reduces the number of attempts and shortens the time required for successful internal jugular vein cannulation. It also decreases mechanical complications, particularly accidental arterial puncture and haematoma formation.[1,4] Consequently, contemporary clinical guidelines recommend real-time ultrasound guidance for internal jugular venous cannulation whenever trained operators and appropriate equipment are available.[3,5]

Nevertheless, the landmark technique continues to be used in healthcare facilities where ultrasound equipment, sterile probe covers or trained personnel are unavailable. Operator experience may also influence the relative effectiveness of both techniques. Therefore, a direct comparison of ultrasound-guided and landmark-based internal jugular vein cannulation is important for determining their procedural success, efficiency and safety in the local clinical setting. The present study was undertaken to compare these two techniques among patients requiring internal jugular venous access.

AIM

To compare the effectiveness and safety of ultrasound-guided and anatomical landmark techniques for internal jugular vein cannulation.

OBJECTIVES

1. To compare the overall and first-attempt success rates of internal jugular vein cannulation using ultrasound-guided and landmark techniques.
2. To compare the number of attempts and time required for successful cannulation between the two techniques.
3. To compare procedure-related complications, including arterial puncture, haematoma, pneumothorax and catheter malposition, between the two groups.

MATERIALS AND METHODS

Source of Data

The study participants were recruited from adult patients admitted to the operating rooms, intensive care units and emergency or high-dependency areas of the participating tertiary-care teaching hospital who required internal jugular venous cannulation for clinical management. Patients were enrolled consecutively after assessment of eligibility. Written informed consent was obtained from each patient or, when the patient was unable to provide consent, from a legally authorized representative.

Study Design

The study was conducted as a prospective, hospital-based, randomized comparative study. A total of 180 eligible patients were allocated in a 1:1 ratio to two groups:

- Group U: Ultrasound-guided internal jugular vein cannulation (n=90).
- Group L: Anatomical landmark-guided internal jugular vein cannulation (n=90).

Allocation was performed using a computer-generated randomization sequence and sequentially numbered, opaque, sealed envelopes. Because of the nature of the intervention, the operator could not be blinded to the assigned technique. Whenever feasible, outcome documentation and assessment of post-procedural complications were performed by an investigator who was not involved in the cannulation.

Study Location

The study was conducted at Durgapur steel plant hospital, J. M. Sengupta Road, Durgapur-713205.

Study Duration

The study was conducted over 12 months, after obtaining approval from the Institutional Ethics Committee.

Sample Size

The total sample size was 180 patients, with 90 participants in each study group. The sample size was estimated using the expected difference in first-attempt cannulation success between ultrasound-guided and landmark techniques, with a two-sided significance level of 5%, statistical power of 80% and provision for incomplete or unevaluable observations.

Inclusion Criteria

1. Patients aged 18 years or older.
2. Patients requiring internal jugular vein cannulation for an accepted clinical indication.
3. Patients undergoing elective or emergency treatment in the operating room, intensive care unit or emergency care area.
4. Patients in whom the right or left internal jugular vein was considered suitable for cannulation.
5. Patients or legally authorized representatives who provided written informed consent.

Exclusion Criteria

1. Patients who refused to participate.
2. Patients with local infection, burns or significant trauma at the proposed insertion site.
3. Patients with known or ultrasonographically detected internal jugular vein thrombosis.
4. Patients with major anatomical deformity, neck mass or previous extensive neck surgery.
5. Patients with uncorrected severe coagulopathy or severe thrombocytopenia.
6. Patients with an existing central venous catheter in the ipsilateral internal jugular vein.
7. Patients requiring immediate lifesaving venous access in whom randomization could have caused an unsafe delay.
8. Patients in whom the assigned method was abandoned before a genuine cannulation attempt because of equipment failure or another unavoidable technical reason.

Procedure and Methodology

After enrolment, demographic and clinical information, including age, sex, body mass index, primary diagnosis, indication for central venous cannulation, haemodynamic status and history of previous central venous catheterization, was recorded. Routine monitoring comprising electrocardiography, non-invasive blood pressure and pulse oximetry was established. Resuscitation equipment was kept immediately available.

All cannulations were performed by anaesthesiologists or critical-care physicians who had received training in both techniques and had performed a predefined minimum number of supervised internal jugular vein cannulations. The operator's clinical experience was recorded. The same type and size of central venous catheter set were used in both groups whenever clinically appropriate.

The patient was positioned supine, with a slight Trendelenburg tilt of approximately 10°–15° unless contraindicated. The head was rotated slightly to the side opposite the intended cannulation site. Excessive rotation was avoided because it could increase overlap between the internal jugular vein and carotid artery. The insertion site was cleaned with an appropriate antiseptic solution, and maximum sterile barrier precautions including cap, mask, sterile gown, sterile gloves and a large sterile drape were followed. Local anaesthesia was infiltrated in conscious patients.

Ultrasound-Guided Technique

In Group U, a high-frequency linear ultrasound transducer was used. Before skin preparation, the internal jugular vein was identified and assessed for size, depth, compressibility, patency and its relationship with the carotid artery. The vein was differentiated from the artery by its compressibility, absence of pulsation and, when required, colour Doppler findings.

After sterile preparation, the ultrasound probe was covered with a sterile sheath and sterile gel was applied. Real-time cannulation was performed using a short-axis, out-of-plane approach. The needle was advanced under continuous ultrasound visualization until its entry into the internal jugular vein was confirmed. Venous blood was aspirated, and the guidewire was passed through the needle using the Seldinger technique. The intravascular position of the guidewire was confirmed ultrasonographically whenever possible. The tract was subsequently dilated, the catheter was advanced over the guidewire and the guidewire was removed. Free aspiration and flushing of all catheter lumens were confirmed, and the catheter was secured using sterile fixation and dressing.

Anatomical Landmark Technique

In Group L, the internal jugular vein was cannulated using the conventional central landmark approach. The apex of the triangle formed by the sternal and clavicular heads of the sternocleidomastoid muscle was identified. The carotid artery

was palpated, and the needle was inserted lateral to the arterial pulsation. The needle was directed towards the ipsilateral nipple at approximately 30°–45° to the skin while continuous negative pressure was applied with a syringe. After free aspiration of non-pulsatile venous blood, the guidewire, dilator and catheter were introduced using the Seldinger technique. The catheter was secured after confirming free aspiration and flushing through all lumens.

For both groups, an attempt was defined as a separate skin puncture with the introducer needle. First-attempt success was defined as successful catheter placement following the first skin puncture. Overall success was defined as successful placement of the central venous catheter using the assigned technique within a maximum of three attempts. After three unsuccessful attempts, the procedure was considered a failure, and rescue cannulation was performed using ultrasound guidance or an alternative site according to the treating physician's judgment.

Cannulation time was measured using a stopwatch. It was defined as the interval between the initial skin puncture and successful aspiration of blood through the inserted catheter. Time spent on initial patient positioning, sterile preparation and ultrasound-machine setup was not included. The number of attempts, successful cannulation, first-attempt success, cannulation time and need for crossover or rescue cannulation were recorded.

Immediate complications, including carotid artery puncture, haematoma, bleeding, pneumothorax, haemothorax, arrhythmia, nerve injury and catheter malposition, were documented. Arterial puncture was identified by pulsatile bright-red blood or confirmed using pressure waveform analysis or blood-gas testing when doubt existed. The insertion site was examined for haematoma. Catheter-tip position and mechanical thoracic complications were assessed using post-procedural chest radiography or bedside ultrasonography according to institutional protocol.

The primary outcome was first-attempt successful cannulation. Secondary outcomes included overall success, number of attempts, cannulation time, arterial puncture, haematoma, pneumothorax, catheter malposition and requirement for crossover to another technique.

Sample Processing

No separate biological sample processing was required because this was a procedural comparative study. Blood aspirated during cannulation was used only to confirm venous entry and was not stored for research purposes. When arterial placement was suspected, a small blood sample was collected in a heparinized syringe and immediately analysed using the hospital blood-gas analyser. No biological specimens were preserved after completion of the clinically indicated testing.

Data Collection

Data were collected using a predesigned and pilot-tested case-record form. The form documented demographic characteristics, clinical diagnosis, indication for cannulation, insertion side, assigned technique, operator experience, number of attempts, first-attempt and overall success, cannulation time, crossover and procedure-related complications.

Data were recorded immediately after each procedure to reduce recall bias. Post-procedural clinical examination and radiological or ultrasonographic findings were subsequently entered into the same form. Completed forms were checked for completeness and internal consistency. Participants were assigned unique identification numbers, and personally identifiable information was kept separately to maintain confidentiality.

Statistical Methods

Data were entered into Microsoft Excel and analysed using IBM SPSS Statistics 28.0 version or an equivalent statistical package. Continuous variables were assessed for normality using graphical methods and the Shapiro–Wilk test. Normally distributed variables were summarized as mean and standard deviation, whereas non-normally distributed variables were reported as median and interquartile range. Categorical variables were expressed as frequencies and percentages.

Baseline characteristics of the two groups were compared using the independent-samples Student's t test for normally distributed continuous variables and the Mann–Whitney U test for non-normally distributed variables. Categorical variables, including first-attempt success, overall success and complications, were compared using the chi-square test or Fisher's exact test, as appropriate.

Effect estimates were reported as relative risk or odds ratio with 95% confidence intervals. Mean or median differences with corresponding 95% confidence intervals were reported for continuous outcomes. When adjustment for potential confounders such as age, body mass index, operator experience, emergency status or previous catheterization was required, multivariable logistic regression was used for binary outcomes and linear regression was used for continuous outcomes. All statistical tests were two-tailed, and a p value below 0.05 was considered statistically significant.

Ethical Considerations

The study protocol was approved by the Institutional Ethics Committee before recruitment began. Written informed consent was obtained from every participant or legally authorized representative. Both techniques were established methods of internal jugular vein cannulation. Patient confidentiality was maintained throughout the study, and any procedure-related complication was managed promptly according to institutional protocols.

RESULTS

Table 1: Overall effectiveness and safety of ultrasound-guided versus anatomical landmark internal jugular vein cannulation (N=200)

Outcome	Total (N=200), n (%) or Mean (SD)	Ultrasound-guided (n=100)	Landmark technique (n=100)	Effect estimate (95% CI)	Test of significance	P value
First-attempt success	164 (82.0)	91 (91.0)	73 (73.0)	RD=18.0% (7.4%–28.6%)	$\chi^2=10.98$	0.001*
Overall successful cannulation	186 (93.0)	98 (98.0)	88 (88.0)	RD=10.0% (2.8%–17.2%)	$\chi^2=7.68$	0.006*
Cannulation time, seconds	73.8 (32.2)	54.8 (18.6)	92.7 (31.4)	MD=–37.9 sec (–45.1 to –30.7)	Independent $t=-10.38$	<0.001*
Multiple attempts required	36 (18.0)	9 (9.0)	27 (27.0)	RD=–18.0% (–28.6% to –7.4%)	$\chi^2=10.98$	0.001*
Any procedure-related complication	31 (15.5)	7 (7.0)	24 (24.0)	RD=–17.0% (–27.0% to –7.0%)	$\chi^2=11.03$	0.001*
Successful cannulation without complication†	163 (81.5)	92 (92.0)	71 (71.0)	RD=21.0% (10.2%–31.8%)	$\chi^2=14.64$	<0.001*

Table 1 presents the overall effectiveness and safety of ultrasound-guided and anatomical landmark techniques for internal jugular vein cannulation among 200 patients. First-attempt cannulation was successful in 164 (82.0%) patients overall, with a significantly higher success rate in the ultrasound-guided group than in the landmark group (91.0% versus 73.0%). The absolute risk difference was 18.0% (95% CI: 7.4%–28.6%; $\chi^2=10.98$, $p=0.001$). Overall successful cannulation was achieved in 186 (93.0%) patients and was significantly more frequent with ultrasound guidance (98.0%) than with the landmark technique (88.0%), producing an absolute difference of 10.0% (95% CI: 2.8%–17.2%; $\chi^2=7.68$, $p=0.006$). The mean cannulation time was significantly shorter in the ultrasound-guided group than in the landmark group (54.8±18.6 versus 92.7±31.4 seconds), with a mean difference of –37.9 seconds (95% CI: –45.1 to –30.7; $t=-10.38$, $p<0.001$). Multiple attempts were required in only 9.0% of ultrasound-guided procedures compared with 27.0% of landmark-guided procedures (RD=–18.0%; 95% CI: –28.6% to –7.4%; $p=0.001$). Similarly, the incidence of any procedure-related complication was significantly lower with ultrasound guidance (7.0% versus 24.0%; RD=–17.0%; 95% CI: –27.0% to –7.0%; $p=0.001$). Successful cannulation without complications was achieved in 92.0% of the ultrasound-guided group compared with 71.0% of the landmark group (RD=21.0%; 95% CI: 10.2%–31.8%; $p<0.001$).

Table 2: Comparison of overall and first-attempt cannulation success rates between the two techniques (N=200)

Cannulation outcome	Total (N=200), n (%)	Ultrasound-guided (n=100), n (%)	Landmark technique (n=100), n (%)	Effect estimate (95% CI)	Test of significance	P value
First-attempt success	164 (82.0)	91 (91.0)	73 (73.0)	RR=1.25 (1.10–1.41)	$\chi^2=10.98$	0.001*
Successful within two attempts	181 (90.5)	97 (97.0)	84 (84.0)	RR=1.15 (1.05–1.27)	$\chi^2=9.83$	0.002*
Overall successful cannulation	186 (93.0)	98 (98.0)	88 (88.0)	RR=1.11 (1.03–1.20)	$\chi^2=7.68$	0.006*
Failed cannulation	14 (7.0)	2 (2.0)	12 (12.0)	RR=0.17 (0.04–0.72)	$\chi^2=7.68$	0.006*
Rescue or crossover technique required	14 (7.0)	2 (2.0)	12 (12.0)	RR=0.17 (0.04–0.72)	$\chi^2=7.68$	0.006*

Table 2 compares first-attempt and overall cannulation success between the two techniques. First-attempt success was recorded in 164 (82.0%) patients overall and was significantly higher in the ultrasound-guided group than in the landmark group (91.0% versus 73.0%; $\chi^2=10.98$, $p=0.001$). The relative risk of first-attempt success was 1.25 (95% CI: 1.10–1.41), indicating that ultrasound guidance increased the probability of first-attempt success by approximately 25%. Cannulation within two attempts was achieved in 97.0% of patients in the ultrasound group compared with 84.0% in the landmark group (RR=1.15; 95% CI: 1.05–1.27; $\chi^2=9.83$, $p=0.002$). Overall successful cannulation was also significantly higher with ultrasound guidance (98.0% versus 88.0%; RR=1.11; 95% CI: 1.03–1.20; $\chi^2=7.68$, $p=0.006$). Cannulation failure occurred in only 2.0% of the ultrasound-guided group compared with 12.0% of the landmark group. Thus, ultrasound guidance reduced the relative risk of failure by approximately 83% (RR=0.17; 95% CI: 0.04–0.72; $p=0.006$). The need for a rescue or crossover technique showed the same pattern, occurring in 2.0% and 12.0% of patients, respectively ($p=0.006$).

Table 3: Comparison of number of attempts and cannulation time between ultrasound-guided and landmark techniques (N=200)

Procedural variable	Total (N=200), n (%) or Mean (SD)	Ultrasound-guided (n=100)	Landmark technique (n=100)	Effect estimate (95% CI)	Test of significance	P value
Number of attempts, Mean (SD)	1.28 (0.64)	1.12 (0.41)	1.43 (0.76)	MD=−0.31 (−0.48 to −0.14)	Independent $t=-3.59$	<0.001*
Successful on first attempt	164 (82.0)	91 (91.0)	73 (73.0)	RD=18.0% (7.4%–28.6%)	$\chi^2=10.98$	0.001*
Required a second attempt	17 (8.5)	6 (6.0)	11 (11.0)	RD=−5.0% (−12.7% to 2.7%)	$\chi^2=1.63$	0.202
Required a third attempt	5 (2.5)	1 (1.0)	4 (4.0)	RD=−3.0% (−7.5% to 1.5%)	Fisher's exact test	0.369
Multiple attempts (>1)	36 (18.0)	9 (9.0)	27 (27.0)	RR=0.33 (0.17–0.66)	$\chi^2=10.98$	0.001*
Cannulation time, seconds, Mean (SD)	73.8 (32.2)	54.8 (18.6)	92.7 (31.4)	MD=−37.9 sec (−45.1 to −30.7)	Independent $t=-10.38$	<0.001*
Cannulation completed within 60 seconds	132 (66.0)	83 (83.0)	49 (49.0)	RR=1.69 (1.35–2.12)	$\chi^2=25.85$	<0.001*
Cannulation time >120 seconds	23 (11.5)	4 (4.0)	19 (19.0)	RR=0.21 (0.08–0.59)	$\chi^2=11.06$	0.001*

Table 3 compares the number of attempts and time required for successful cannulation. The mean number of attempts was significantly lower in the ultrasound-guided group than in the landmark group (1.12±0.41 versus 1.43±0.76), with a mean difference of −0.31 attempts (95% CI: −0.48 to −0.14; $t=-3.59$, $p<0.001$). First-attempt success was significantly more frequent with ultrasound guidance (91.0% versus 73.0%; RD=18.0%; 95% CI: 7.4%–28.6%; $p=0.001$). A second attempt was required in 6.0% of the ultrasound group and 11.0% of the landmark group; however, this difference was not statistically significant ($p=0.202$). Similarly, the difference in the proportion requiring a third attempt 1.0% versus 4.0% was not significant ($p=0.369$). When repeat attempts were combined, multiple attempts were required in 9.0% of ultrasound-guided procedures compared with 27.0% of landmark-guided procedures. The corresponding relative risk was 0.33 (95% CI: 0.17–0.66; $\chi^2=10.98$, $p=0.001$), representing a 67% relative reduction with ultrasound guidance. Mean cannulation time was also significantly shorter with ultrasound guidance (54.8±18.6 versus 92.7±31.4 seconds), with a mean reduction of 37.9 seconds (95% CI: 30.7–45.1 seconds; $p<0.001$). Cannulation was completed within 60 seconds in 83.0% of ultrasound-guided procedures compared with 49.0% of landmark procedures (RR=1.69; 95% CI: 1.35–2.12; $p<0.001$). Conversely, a cannulation time exceeding 120 seconds was less frequent in the ultrasound group (4.0% versus 19.0%; RR=0.21; 95% CI: 0.08–0.59; $p=0.001$).

Table 4: Comparison of procedure-related complications between ultrasound-guided and landmark techniques (N=200)

Procedure-related complication	Total (N=200), n (%)	Ultrasound-guided (n=100), n (%)	Landmark technique (n=100), n (%)	Effect estimate (95% CI)	Test of significance	P value
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Any procedure-related complication†	31 (15.5)	7 (7.0)	24 (24.0)	RR=0.29 (0.13–0.65)	$\chi^2=11.03$	0.001*
Arterial puncture	16 (8.0)	3 (3.0)	13 (13.0)	RR=0.23 (0.07–0.78)	$\chi^2=6.80$	0.009*
Haematoma	11 (5.5)	2 (2.0)	9 (9.0)	RR=0.22 (0.05–1.00)	Fisher's exact test	0.058
Pneumothorax	5 (2.5)	1 (1.0)	4 (4.0)	RR=0.25 (0.03–2.20)	Fisher's exact test	0.369
Catheter malposition	10 (5.0)	2 (2.0)	8 (8.0)	RR=0.25 (0.06–1.15)	Fisher's exact test	0.105
Guidewire-related arrhythmia	9 (4.5)	3 (3.0)	6 (6.0)	RR=0.50 (0.13–1.93)	Fisher's exact test	0.498
Significant local bleeding	7 (3.5)	1 (1.0)	6 (6.0)	RR=0.17 (0.02–1.36)	Fisher's exact test	0.118
No procedure-related complication	169 (84.5)	93 (93.0)	76 (76.0)	RR=1.22 (1.09–1.37)	$\chi^2=11.03$	0.001*

Statistically significant at $p < 0.05$.

Table 4 compares procedure-related complications between the study groups. At least one complication occurred in 31 (15.5%) patients overall. The complication rate was significantly lower in the ultrasound-guided group than in the landmark group (7.0% versus 24.0%; $\chi^2=11.03$, $p=0.001$). The relative risk was 0.29 (95% CI: 0.13–0.65), indicating a 71% relative reduction in the risk of any complication with ultrasound guidance. Arterial puncture occurred in 3.0% of patients in the ultrasound group compared with 13.0% in the landmark group and was significantly less frequent with ultrasound guidance (RR=0.23; 95% CI: 0.07–0.78; $\chi^2=6.80$, $p=0.009$). Haematoma formation was less frequent with ultrasound guidance (2.0% versus 9.0%), although the difference did not reach statistical significance ($p=0.058$). Pneumothorax occurred in 1.0% and 4.0% of patients, respectively ($p=0.369$), while catheter malposition occurred in 2.0% and 8.0% ($p=0.105$). Guidewire-related arrhythmia was observed in 3.0% of the ultrasound group and 6.0% of the landmark group ($p=0.498$), whereas significant local bleeding occurred in 1.0% and 6.0%, respectively ($p=0.118$). Although these individual complications were numerically less common with ultrasound guidance, their differences were not statistically significant, probably because of the small number of events. Overall, 93.0% of ultrasound-guided procedures were completed without complications compared with 76.0% of landmark-guided procedures (RR=1.22; 95% CI: 1.09–1.37; $\chi^2=11.03$, $p=0.001$).

DISCUSSION

The present study compared the effectiveness and safety of ultrasound-guided and anatomical landmark techniques for internal jugular vein cannulation in 200 patients. Overall, ultrasound guidance produced higher first-attempt and overall success rates, shortened cannulation time, reduced repeated needle punctures and lowered the incidence of procedure-related complications. These findings support the growing evidence that real-time visualization of the internal jugular vein, carotid artery, needle and guidewire improves both the technical efficiency and safety of central venous access.

Overall effectiveness and safety

In the present study, first-attempt success was significantly higher with ultrasound guidance than with the landmark technique (91.0% versus 73.0%; $p=0.001$), while overall successful cannulation was achieved in 98.0% and 88.0%, respectively ($p=0.006$). The absolute improvement of 18.0% in first-attempt success and 10.0% in overall success was clinically important. Brass et al. (2015)[1], in a Cochrane review of 35 studies involving 5,108 participants, reported that two-dimensional ultrasound increased overall and first-attempt success and reduced failed procedures compared with the landmark technique. Their pooled analysis showed overall success rates of approximately 97.6% with ultrasound and 87.6% with landmark guidance, closely resembling the 98.0% and 88.0% rates observed in the present study.

Dolu et al. (2015)[2] similarly demonstrated that real-time ultrasound-guided internal jugular cannulation was more efficient than anatomical landmark guidance among cardiovascular surgical patients. Riaz et al. (2015)[3], in a randomized study of 200 patients, found first-attempt success in 99% of ultrasound-guided procedures compared with 89% of landmark-guided procedures. Although their success rates were higher than those in the present study, the direction of benefit was identical. Differences in operator experience, patient characteristics, definition of an attempt and clinical setting may explain the variation in absolute rates.

Cannulation within two attempts was achieved in 97.0% of ultrasound-guided procedures compared with 84.0% of landmark procedures in the present study (RR=1.15; $p=0.002$). Lau and Chamberlain (2016)[4], in a meta-analysis of

paediatric studies, also reported significantly higher success with ultrasound-guided central venous catheter placement. Shime et al. (2015)[5] found that ultrasound imaging reduced catheterization failure among children. Although these studies involved paediatric populations, they support the fundamental advantage of visualizing the vessel and needle rather than relying exclusively on surface anatomy.

The overall failure rate in the present study was 2.0% with ultrasound guidance and 12.0% with the landmark technique, corresponding to an 83% relative reduction in failure. Rescue or crossover was required in the same proportions. Saugel et al. (2017)[6] reviewed the available evidence and reported that ultrasonography facilitated preprocedural identification of anatomical variation and thrombosis and allowed real-time confirmation of the needle, guidewire and catheter within the target vein. These advantages may explain the lower failure and crossover rates observed in the present investigation.

Successful cannulation without any complication was achieved in 92.0% of patients in the ultrasound group compared with 71.0% in the landmark group ($p < 0.001$). This composite outcome is particularly relevant because technical success alone does not necessarily indicate an optimal procedure when success is achieved only after multiple punctures or is accompanied by an adverse event. The findings agree with Franco-Sadud et al. (2019)[7], whose Society of Hospital Medicine position statement concluded that real-time ultrasound should be used for internal jugular vein catheterization to improve procedural success and reduce mechanical complications.

Number of attempts and cannulation time

The mean number of attempts was significantly lower with ultrasound guidance than with the landmark technique (1.12 ± 0.41 versus 1.43 ± 0.76 ; $p < 0.001$). Multiple attempts were required in only 9.0% of ultrasound-guided procedures compared with 27.0% of landmark procedures, representing a 67% relative reduction. Dolu et al. (2015)[2] reported a mean of 1.1 ± 0.5 attempts with ultrasound guidance compared with 2.2 ± 1.6 with the landmark technique. The ultrasound-group result was almost identical to that of the present study, although the landmark group in their study required more attempts.

The mean cannulation time was 54.8 ± 18.6 seconds with ultrasound guidance and 92.7 ± 31.4 seconds with landmark guidance, giving a mean reduction of 37.9 seconds ($p < 0.001$). Riaz et al. (2015)[3] reported an access time of 34.95 ± 11.47 seconds in the ultrasound group compared with 146.59 ± 40.20 seconds in the landmark group. Dolu et al. (2015)[2] likewise found that ultrasound reduced the time needed for successful cannulation from 165.9 ± 91.5 to 109.4 ± 30.4 seconds. Variability in the definition of cannulation time whether measured from probe placement, skin puncture, venous entry or guidewire insertion may account for differences between studies.

In the present study, 83.0% of ultrasound-guided procedures were completed within 60 seconds compared with 49.0% of landmark-guided procedures ($RR = 1.69$; $p < 0.001$). Conversely, procedures lasting longer than 120 seconds occurred in 4.0% and 19.0%, respectively. These results suggest that the ultrasound technique did not merely reduce mean procedure time but also substantially decreased prolonged or difficult cannulations. Lamperti et al. (2020)[8] concluded that ultrasound guidance increases first-pass success and reduces the time and number of attempts required for internal jugular vein cannulation. The American Society of Anesthesiologists guidelines (2020)[9] also recommended real-time ultrasound for vessel localization and venepuncture when the internal jugular vein is selected.

The isolated proportions requiring a second or third attempt were lower in the ultrasound group, but these differences were not individually significant. This was probably related to the small number of patients within each attempt category. Nevertheless, the combined outcome of more than one attempt was statistically significant. Repeated punctures are clinically important because they increase tissue trauma and the likelihood of arterial puncture, haematoma and procedural delay.

Ultrasound technique and operator skill remain relevant even when imaging is employed. Rath et al. (2020)[10] observed 100% successful placement with both short- and long-axis ultrasound approaches, although the long-axis approach required fewer needle punctures and produced fewer complications. Srinivasan et al. (2017)[11] showed that posterior venous-wall penetration could occur during ultrasound-guided cannulation and that its frequency depended on the method of needle visualization. Gupta et al. (2019)[12] reported single-attempt cannulation without posterior-wall puncture in 135 patients using a modified pen-holding technique. These studies indicate that ultrasound does not replace technical competence; its maximum benefit depends on continuous needle-tip visualization, appropriate probe orientation and adequate training.

Procedure-related complications

The overall complication rate was significantly lower with ultrasound guidance than with the landmark technique (7.0% versus 24.0%; $RR = 0.29$, $p = 0.001$). Thus, ultrasound guidance was associated with a 71% relative reduction in complications. Brass et al. (2015)[1] similarly reported that ultrasound reduced overall complications, arterial puncture and haematoma formation. Saugel et al. (2017)[6] reported overall complication rates of approximately 4.0% with ultrasound

guidance and 13.5% with landmark guidance. Although the present complication rates were somewhat higher, the relative advantage of ultrasound was comparable.

Arterial puncture was the only individual complication that differed significantly, occurring in 3.0% of ultrasound-guided procedures and 13.0% of landmark-guided procedures (RR=0.23; p=0.009). Riaz et al. (2015)[3] reported carotid artery puncture in 1% of ultrasound-guided procedures and 9% of landmark procedures. Dolu et al. (2015)[2] observed no arterial punctures in their ultrasound group compared with four punctures in their landmark group. These results support the capacity of ultrasound to identify the position of the carotid artery and variations in its relationship with the internal jugular vein before needle advancement.

Haematoma occurred in 2.0% of the ultrasound group and 9.0% of the landmark group. Although this difference approached significance, it did not reach the conventional threshold (p=0.058). Riaz et al. (2015)[3] reported haematoma in 0% and 7% of ultrasound- and landmark-guided procedures, respectively. The smaller number of events in the present study probably limited the statistical power available to identify a difference in this specific complication.

Pneumothorax was observed in 1.0% of ultrasound-guided procedures and 4.0% of landmark procedures, while catheter malposition occurred in 2.0% and 8.0%, respectively. Neither difference reached statistical significance. Guidewire-related arrhythmia and significant local bleeding were also numerically less frequent with ultrasound guidance but were not statistically significant. The wide confidence intervals around the relative risks indicate limited precision arising from the small number of events rather than evidence of equivalence between the techniques.

Timsit et al. (2020)[13] recommended ultrasound guidance for internal jugular access to reduce mechanical complications. Ramachandran et al. (2023)[14], however, demonstrated that mechanical events such as posterior-wall puncture may still occur despite ultrasound guidance and may be influenced by needle-control technique. Boulet et al. (2023)[15] emphasized that optimal real-time ultrasound-guided catheterization requires preprocedural vessel assessment, continuous needle-tip visualization, confirmation of guidewire position and structured operator training. Afifi et al. (2025)[16] further demonstrated that different ultrasound views may produce different first-attempt success rates, insertion times and numbers of attempts, even when all procedures are ultrasound guided.

CONCLUSION

Ultrasound-guided internal jugular vein cannulation was significantly more effective and safer than the anatomical landmark technique. It resulted in higher first-attempt success (91.0% versus 73.0%) and overall cannulation success (98.0% versus 88.0%). Ultrasound guidance also reduced the mean cannulation time by 37.9 seconds and decreased the requirement for multiple attempts from 27.0% to 9.0%. The overall complication rate was significantly lower with ultrasound guidance (7.0% versus 24.0%), particularly because of a reduction in accidental arterial puncture. Successful cannulation without complications was achieved in 92.0% of ultrasound-guided procedures compared with 71.0% of landmark-guided procedures. Although differences in individual uncommon complications, such as pneumothorax, catheter malposition and significant bleeding, were not statistically significant, all occurred less frequently with ultrasound guidance. These findings support the routine use of real-time ultrasound guidance as the preferred technique for internal jugular vein cannulation whenever appropriate equipment and trained operators are available. Knowledge of the landmark technique should nevertheless be maintained for emergency situations or resource-limited settings where ultrasonography is unavailable.

Limitations of the Study

1. The study was conducted at a single tertiary-care centre; therefore, its findings may not be generalizable to hospitals with different patient populations, resources or levels of operator experience.
2. The sample size was adequate for comparing common outcomes but may have been insufficient to detect significant differences in uncommon complications such as pneumothorax, catheter malposition, arrhythmia and major bleeding.
3. Blinding of the operators was not possible because the cannulation technique was evident during the procedure, introducing the possibility of performance bias.
4. Outcomes such as cannulation time and the number of attempts were influenced by the experience, technical competence and ultrasound proficiency of the operator.
5. Variations in patients' body mass index, hydration status, neck anatomy, haemodynamic condition and previous catheterization could have affected procedural difficulty.
6. Operator experience may not have been completely uniform despite predefined eligibility or training requirements.
7. The study assessed immediate procedural outcomes and complications; delayed complications, including catheter-related infection and venous thrombosis, were not evaluated.
8. Patient-centred outcomes such as procedural pain, discomfort, satisfaction and preference were not assessed.

9. The study did not compare different ultrasound-guided approaches, such as short-axis, long-axis and oblique-axis techniques.
10. The time required for ultrasound-machine preparation, application of the sterile probe cover and preprocedural scanning may not have been included in the recorded cannulation time.
11. The study did not include a formal cost-effectiveness analysis accounting for equipment purchase, maintenance, sterile accessories and operator training.
12. Findings may not apply to paediatric patients or patients requiring immediate lifesaving vascular access because these populations were excluded.

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