Ultrasound-guided in-plane and Out-of-plane Techniques Versus Landmark Technique for Internal Jugular Vein Catheterization in Adult Cardiac Surgery Patients

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ABSTRACT

Background

Internal jugular vein (IJV) catheterization is routinely performed in cardiac surgical patients. Ultrasound (US) guidance has been shown to increase success rates and reduce complications compared to landmark (LM) techniques; however, access to ultrasound machines and operator skill remain limitations in several centers.

Objective

To compare two different real-time 2-dimensional ultrasound-guided short axis/out-off-plane (SAX OOP) and long axis/in-plane (LAX IP) approaches and to determine whether ultrasound guidance could improve the success rate and decrease the complication rate of internal jugular vein catheterization compared with the landmark approach (LM).

Method

This Prospective, randomized comparative study evaluated three techniques for internal jugular vein cannulation in adult elective cardiac surgery patients (n=90): (1) real-time short-axis/out-of-plane ultrasound guidance (SAX-OOP), (2) real-time long-axis/in-plane ultrasound guidance (LAX-IP), and (3) landmark technique (LM). Primary outcomes included number of attempts and procedure duration. Secondary outcomes included mechanical complications. Chi-square for categorical variables and one-way ANOVA for continuous variables were applied to find out the associations.

Result

First-attempt success was highest in LAX-IP (100%), followed by SAX-OOP (96.7%) and LM (83.3%) (p=0.024). All complications (n=7) occurred in the LM group (p=0.001). Mean cannulation time was significantly longer in the LM group (90.83±13.23 seconds) versus SAX-OOP (60.47±10.96 seconds) and LAX-IP (70.47±23.10 seconds) (p<0.001).

Conclusion

Real-time ultrasound guidance, particularly the in-plane technique, significantly improves success rates, reduces complications, and shortens cannulation time compared with the landmark technique. Ultrasound guidance should be preferred for internal jugular vein cannulation in cardiac anesthesia settings.

KEY WORDS

Central venous catheterization, Internal jugular vein, Ultrasound guidance, Landmark technique, Cardiac anesthesia

INTRODUCTION

Internal jugular vein (IJV) catheterization is attempted to obtain central venous access for hemodynamic monitoring, long-term administration of fluids and antibiotics. Many anatomical landmark-guided techniques for internal jugular vein puncture have been described.[1,2] Mechanical complications such as arterial puncture and pneumothorax are seen.[3,4] The risk of complications depends on several factors, including (but not limited to) operator experience, the urgency of placement as well as patient factors such as obesity, prior difficult cannulation, and coagulopathy.[4,6,7] It has been suggested that ultrasound guidance could improve the success rate, reduce the number of needles passes, and decrease complications.[4,5] The purpose of this study is to compare two different real-time 2-dimensional ultrasound-guided short axis/out-off-plane (SAX OOP) and long axis/in-plane (LAX IP) approaches and to determine whether ultrasound guidance could improve the success rate and decrease the complication rate of internal jugular vein catheterization compared with the landmark approach (LM).

METHODS

This randomized multi-arm interventional study was conducted at Shahid Gangalal National Heart Center over a period of six months (June to November 2016). The study population included adult patients over 15 years of age who were scheduled for elective open-heart surgery under general anaesthesia. A non-probability sampling method was used for patient selection. The primary intervention involved the placement of an internal jugular venous catheter.

Following Institutional Review Board approval, SGNHC/IRC No:10-2016, written informed consent was obtained from all the patients meeting the inclusion criteria and not having any of the exclusion criteria before enrollment in the study. Inclusion criteria comprised patients aged more than 15 years undergoing elective open-heart surgery. Exclusion criteria included patients with local infection at the catheter insertion site, a history of previous radical neck surgery, previous radiotherapy to the neck region, the presence of a hematoma at the puncture site, or those who had previously been catheterized for any indication. Additionally, patients with underlying pneumothorax, pleural effusion, or preoperative insertion of a chest tube, as well as those with a platelet count less than 75,000 or an international normalized ratio greater than 2, were excluded. Patients who refused to participate in the study were also excluded.

Randomization was done by using a computer-generated sequence into three groups.

1. Group SAX OOP: Thirty patients underwent real-time ultrasound-guided cannulation of the internal jugular vein with a SAX OOP approach.

2. Group LAX IP: Thirty patients undergo real-time ultrasound-guided cannulation of the IJV with an LAX IP approach.

3. Group LM: Thirty patients undergo cannulation of the IJV with the landmark technique.

The following parameters were studied in this research. The average number of attempts required for successful cannulation and the average access time was recorded, measured from the initial skin prick to blood aspiration through the catheter immediately after guide-wire removal. Any changes in the performer or the side and site of cannulation were also documented. Additionally, the degree of tricuspid regurgitation (TR) and the presence of a left-to-right shunt were evaluated. Mechanical complications associated with the procedure were carefully monitored. These included carotid artery puncture, carotid artery cannulation, superficial hematoma (either visible or palpable), superficial oozing from the cannula site, pneumothorax, hemothorax, hemodynamically significant or life-threatening bleeding, and airway compromise attributable to bleeding.

Well-trained attending anesthesiologists performed all ultrasound-guided and landmark-guided catheterizations with similar experience in IJV catheter placements to minimize the effect of operator experience on the success rate and the rate of mechanical complications. Furthermore, in most patients in whom the first three attempts at catheterization failed, another physician performed the next attempt using ultrasound guidance.

Patients will be painted and draped. The baseline pulse rate, systolic blood pressure, diastolic blood pressure, mean arterial blood pressure and heart rate were noted. Electrocardiogram rhythm before catheterization was noted. In the ultrasonography group, an ultrasound scanner with cordless linear vascular probe of frequency 5-13 MHz (Simens, Acuson freestyle ultrasound system) was used. On a linear probe of the ultrasound, ultrasonic gel was applied which was then covered with a sterile transparent plastic sheath or sterile glove and fixed with sterile rubber bands. Patients were placed in a supine position with the head rotated at a 30° angle in the neutral position of the bed. Physicians followed the standard sterile technique; the neck area including the top of the triangle between the sternal and the clavicular head of the sternocleidomastoid muscle was prepared with povidone-iodine before the placement of sterile drapes. The area of the IJV was measured at this level in cm^2 using ultrasound in the short axis out of the plane. The depth in the ultrasound machine was adjusted 1.5-6 cm to optimize the view of the vessel and frequency and gain were adjusted as well in cases where ultrasound guided is used. The IJV was identified as an oval thin-walled hypoechoic compressible structure lying lateral and superficial to the non-compressible pulsating carotid artery or longitudinal compressible structure just above and slightly lateral to the carotid artery. The IJV picture was centered in the acoustic window. The movement of the needle tip and the change in the shape of the vein were carefully observed. The tip of the needle lying intravascularly will be visualized clearly on the image and the free flow of blood upon aspiration was taken as confirmation of the correct position of the needle. The guide-wire was passed and the catheter will be rail-roaded over it after dilatation of the tissue plane.

SAX OOP:

Real-time 2D images were obtained by placing the transducer parallel and superior to the clavicle, over the groove between the sternal and the clavicular heads of the sternocleidomastoid muscle, imaging of the great vessels (the IJV and carotid artery) transversely (short-axis view), followed by percutaneous out-of-plane cannulation.

LAX IP:

The transducer was placed perpendicular and superior to the clavicle over the groove between the sternal and clavicular heads of the sternocleidomastoid muscle, visualizing the IJV and carotid artery in the long-axis view. Using the in-plane technique, the needle was introduced at the superior end of the transducer and advanced into the plane, allowing timely visualization of the tip and shape of the needle during the procedure.

Landmark:

The internal carotid artery was palpated with the fingers of the left hand. The "finder" needle was connected to a 3 mL syringe and is advanced through the skin at a 45° angle in the direction of the ipsilateral nipple over the groove between the sternal and clavicular heads of the sternocleidomastoid muscle at the level of the thyroid cartilage. The return of venous blood into the syringe confirms entry into the vessel. A 16- or 18-gauge needle of CVCs set is inserted using the guidance of the finder needle and, after that, the procedure will be proceeded with the standard Seldinger technique. In case of an unsuccessful cannulation after three attempts, it was rescued by ultrasound-guided cannulation and the performer will be changed.

The time to successful completion of the cannulation in the study was the time from the skin puncture to blood aspiration via the catheter immediately following the guide-wire removal. For an attempt to be considered unsuccessful complete withdrawal of the puncturing needle from the skin surface was required.

The Standard Seldinger Technique

The IJV is punctured with a 16- or 18-gauge, 10-cm needle. The needle is advanced with continuous negative pressure on a 5 mL syringe attached to it. Once blood return is noted, the syringe is removed and a guide wire will be advanced through the needle into the internal jugular vein. The needle is then removed and the dilator is carefully advanced using to-and-fro rotations and then a vascular catheter is advanced over the wire, fixed, and secured.

Hemodynamic variables i.e. heart rate, systolic blood pressure, diastolic blood pressure, mean arterial blood pressure and changes in ECG rhythms will be recorded after correct placement. Local site hematoma and carotid artery puncture if present will be noted. Pneumothorax if present will be confirmed by USG after completion of the procedure and before sternotomy/thoracotomy is done. Hemothorax if present will be confirmed by direct visualization of any blood collection in the thoracic cavity after the sternotomy/thoracotomy is done in the patients. The complications will be managed by placing a chest tube (which is a regular practice in cardiac surgery patients) and by other medical interventions as per the hospital protocol. Chest radiography will be done to verify the catheter's course and the position of its tip after the operation once the patient reaches the intensive care unit.

Data collection was done by filling out the proforma containing the demographic details of the patient (age, gender, weight, and height). Similarly, the number of attempts, time taken from skin prick to blood aspiration via the catheter immediately following the guide-wire removal, hemodynamic changes, ECG rhythm changes, and complications like hematoma and carotid artery puncture were recorded.

Data were collected and recorded as per proforma. Collected data were entered into Microsoft excel and further analysis was done using Statistical Package for Social Sciences (SPSS) version 25. Descriptive and inferential statistical methods were used to analyze the various characteristics of respondents and to find out the associated factors. Normality test was also performed using the Kolmogorov – Smirnov test and Shapiro – Wilk test, Q-Q plot, Skewness and Kurtosis, Histogram, and Box and Whisker plot.

Descriptive statistics were used to summarize the data, with continuous variables presented as Mean and Standard Deviation. Categorical variables were expressed as percentages. For inferential statistics, bivariate analysis was performed using the Chi-square test for categorical data and One-way ANOVA test for parametric continuous data. All statistical analyses were conducted at 95.0% confidence interval (CI), with a p-value of less than 0.05 considered statistically significant.

RESULTS

The mean age of participants was 42.67 years (±18.29) for Group A and 42.17 years (±17.11) for Group B and 42.07 (±16.24) for Group C indicating similar age distributions across the groups. Gender distribution was also comparable, with Group A comprising 46.7% male and 53.3% female, Group B comprising 53.3% male and 46.7% female and

Group C comprising 60 % male and 40 % female. BMI of the participants of Group A was 23.28(±4.89), The mean BMI for Group A was 23.28 (±4.89), while Group B had a mean BMI of 22.46 kg/m^2 (±3.52) and Group C had a BMI of 21.95 (±3.41) reflecting similar body composition profiles (Table 1).

Table 1. Baseline Characteristics of the studied groups

Characteristics	Landmark Group (n=30)	Ultrasound Groups		p-value
		SAX OOP (n=30)	LAX IP (n=30)	
Age [years; mean (sd)]	42.67 (18.29)	42.17 (17.11)	42.07 (16.24)	0.990[a]
Sex [n (%)]				
Male	14 (46.7%)	16 (53.3%)	18 (60.0%)	0.585[b]
Female	16 (53.3%)	14 (46.7%)	12 (40.0%)	
BMI [kg/m^2; mean (sd)]	23.28 (4.89)	22.46 (3.52)	21.95 (3.41)	0.431[a]
Degree of TR [n (%)]				
Nil	27 (90.0%)	23 (76.7%)	17 (56.7%)	
Mild	2 (6.7%)	2 (6.7%)	4 (13.3%)	0.036[*b]
Moderate	1 (3.3%)	0	4 (13.3%)	
Severe	0	5 (16.7%)	5 (16.7%)	
Left to right shunt [n (%)]				
Yes	13 (43.3%)	3 (10.0%)	10 (33.3%)	0.014[*b]
No	17 (56.7%)	27 (90.0%)	20 (66.7%)	
Diagnosis [n (%)]				
Congenital Heart Disease	11 (36.7%)	6 (20.0%)	12 (40.0%)	
Valvular Heart Disease	7 (23.3%)	13 (43.3%)	10 (33.3%)	0.311[b]
Coronaries including aortic dissection	12 (40.0%)	11 (36.7%)	8 (26.7%)	

[*]Significant at p-value < 0.05, sd: standard deviation.
[a]One-way ANOVA test
[b]Chi-square test

There were no significant differences between the three groups of patients in gender, age, BMI, change in side/ site of catheterization, or change in performer. There is a significant association between the degree of TR and the method of central venous cannulation. The presence of left to right shunt has a significant association with the method of cannulation. A maximum of two attempts were recorded with no re-attempts in the long-axis method. Pearson's chi-square test showed the association (p=0.024). There is a significant association in terms of complications with a total of 7 complications reported in the landmark method and no complications in the other remaining method. (p-value = 0.001). Superficial hematomas were seen in 4 patients and there was oozing from the cannula site in 3 patients. The landmark method had the longest mean time for cannulation (90.83 ± 13.23) and the differences between the mean of the three groups were significant (p ≤ .001) (Table 2).

Table 2. Outcome measures in the ultrasound groups versus the landmark group of patients

Outcome Measures	Landmark Group (n=30)	Ultrasound Groups		p-value
		SAX OOP (n=30)	LAX IP (n=30)	
Number of Attempts [n (%)]				
One	25 (83.3%)	29 (96.7%)	30 (100%)	0.024[*b]
Two	5 (16.7%)	1 (3.3%)	0	
Change in Performer [n (%)]				
Yes	4 (13.3%)	1 (3.3%)	0	0.064[b]
No	26 (86.7%)	29 (96.7%)	30 (100%)	
Change in Site/Side [n (%)]				
Yes	3 (10.0%)	1 (3.3%)	0	0.160[b]
No	27 (90.0%)	29 (96.7%)	30 (100%)	
Catheter Placement Complication [n (%)]				
Yes	7 (23.3%)	0	0	0.001[*b]
No	23 (76.7%)	30 (100%)	30 (100%)	
Duration of Procedure [seconds; mean (sd)]	90.83 (13.23)	60.47 (10.96)	70.47 (23.10)	<0.001[a]

[*]Significant at p-value <0.05
[a]One-way ANOVA test
[b]Chi-square test

DISCUSSIONS

Central venous catheter (CVC) cannulation is a procedure that requires a high degree of technical expertise, precision, and hand-eye coordination. It is considered a cornerstone skill in critical care and anesthesiology because critically ill patients often require central venous access for hemodynamic monitoring, administration of vasoactive medications, parenteral nutrition, or rapid fluid resuscitation. Despite advances in monitoring technologies, central venous pressure (CVP) remains a commonly used surrogate to guide fluid therapy, especially in perioperative and intensive care settings, although its standalone reliability in predicting fluid responsiveness has been debated. A review of the literature demonstrates that while CVP alone may not reliably predict fluid responsiveness, it remains a valuable clinical parameter when integrated with other hemodynamic and clinical indices. Moreover, CVP measurement via a central venous catheter allows continuous monitoring, which is indispensable in critically ill patients experiencing rapid hemodynamic changes.[8,9]

CVCs are typically inserted through three main venous access sites: the internal jugular, subclavian, and femoral veins. The choice of insertion site depends on multiple factors including patient anatomy, coexisting conditions, risk of infection, and clinician preference. The internal jugular vein is often preferred for elective procedures due to its predictable anatomy, relatively superficial location, and lower risk of pneumothorax compared with the subclavian approach. However, subclavian access may be preferred in certain surgical contexts, and femoral access remains useful in emergency scenarios or in patients with contraindications to other sites.[10]

Despite its common use, CVC placement is associated with potential complications that can range from minor to life-threatening. These include arterial puncture, hematoma formation, pneumothorax, hemothorax, malposition, infection, and thrombosis. The severity of these complications can be significant, particularly in patients with coagulopathy or compromised respiratory function. Multiple studies have underscored that procedural technique, operator experience, and patient-specific anatomical considerations are key determinants of both success and complication rates.[11]

In the present study, we observed seven complications in patients undergoing the landmark-guided technique, whereas none were reported in the ultrasound-guided groups (SAX OOP and LAX IP), emphasizing the safety advantage of real-time sonographic guidance. These findings are consistent with a substantial body of evidence demonstrating the superiority of ultrasound guidance for central venous access. Since the 1990s, multiple randomized controlled trials and meta-analyses have consistently shown that ultrasound-guided CVC insertion not only improves first-pass success rates but also significantly reduces the incidence of mechanical complications when compared with landmark techniques.[4,10,12,13] For example, Randolph et al. conducted a meta-analysis indicating that ultrasound guidance significantly decreases the risk of arterial puncture, multiple attempts, and procedural failure, highlighting its clinical importance.[4] Similarly, Lockwood and Desai emphasized that real-time sonographic visualization of the needle tip and target vein allows clinicians to adjust the trajectory during cannulation, thereby enhancing both safety and efficiency.[11]

Ultrasound-guided cannulation allows direct, real-time visualization of the target vessel, surrounding anatomical structures, and the trajectory of the needle. This continuous visualization reduces the number of needle passes, shortens procedure time, and minimizes the risk of complications such as arterial puncture or pneumothorax.[12,14,15] In our study, the mean cannulation time was significantly reduced in both ultrasound-guided groups, with 60.47 ± 10.96 seconds in the SAX OOP group and 70.47 ± 23.10 seconds in the LAX IP group, compared to 90.83 ± 13.23 seconds for the landmark group. This reduction in procedural time is clinically relevant, particularly in critically ill patients or those undergoing complex cardiac surgery, where minimizing the duration of invasive procedures can reduce physiological stress and procedural risk. Troianos et al. reported similar findings, demonstrating a 100% success rate for monographically guided cannulations versus a 96% success rate using landmark techniques, further corroborating our results.[12] Additional studies in emergency and intensive care settings have reinforced these findings, confirming that ultrasound guidance not only enhances success rates but also reduces procedural complications in diverse patient populations.[13,15,16]

Regarding technique-specific considerations, the SAX OOP approach provides a quick transverse view of the vessel and surrounding structures, allowing rapid identification of the vein and carotid artery, while the LAX IP technique permits continuous visualization of the needle path within the plane of the vessel. This real-time tracking can be particularly advantageous in patients with challenging anatomy, small veins, or coagulopathy, where inadvertent arterial puncture or hematoma formation could have serious consequences.[17,18] Although both techniques are effective, operator preference and experience can influence the choice of method, and existing literature suggests that the LAX IP approach may offer a slight advantage in terms of visualizing the entire needle path, while SAX OOP is often faster for routine cannulation.[14,19,20]

Simulation-based ultrasound training has emerged as a critical adjunct in teaching safe and effective CVC placement.[21] Studies show that structured training programs incorporating simulation and supervised practice improve both technical proficiency and confidence among novice operators. Such programs have been associated with higher first-pass success rates, fewer complications, and faster cannulation times, highlighting the importance of integrating ultrasound education into residency curricula and continuing medical education programs.[21]

In summary, our study provides further evidence supporting ultrasound-guided CVC placement in adult cardiac surgery patients. The use of real-time sonography resulted in reduced complications, higher first-pass success rates, and shorter procedure times compared with the landmark technique. These findings align with a broad spectrum of published literature and reinforce current guidelines recommending ultrasound guidance as the standard of care whenever equipment and trained personnel are available. Future research should focus on the development of standardized training protocols, cost-effectiveness analyses, and evaluation of outcomes in high-risk patient subgroups to further refine practice and improve patient safety.

This study has several limitations. First, it was conducted at a single tertiary cardiac center, which may limit generalizability to non-cardiac settings or institutions with different operator experience levels. Second, all procedures were performed by experienced anesthesiologists familiar with ultrasound-guided cannulation; outcomes may vary among trainees or centers with limited ultrasound proficiency. Third, ultrasound guidance was not blinded, and operator-related bias cannot be excluded. Fourth, although sample size was adequate to detect significant differences in primary outcomes, rare complications such as pneumothorax may require larger multicenter cohorts to evaluate. Finally, patient anatomical variations such as obesity or difficult airway features were not analyzed as subgroup factors, which may influence cannulation complexity and outcomes.

CONCLUSION

This study showed that real-time ultrasound guidance—especially the long-axis in-plane technique—significantly improves first-attempt success, shortens cannulation time, and avoids complications compared with the landmark technique in adult cardiac surgery patients, fulfilling our study aim.

Strengths include the prospective randomized design and standardized technique performed by experienced operators, although the single-center setting and absence of novice-operator assessment may limit broader applicability. These results support existing literature advocating ultrasound guidance and further emphasize the advantage of the long-axis approach in high-acuity cardiac settings, adding important evidence from a resource-limited environment. Future studies should evaluate training-level variation, cost-effectiveness, and multicenter adoption to guide widespread implementation.

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