Cross-Sectional Study

ANNALS OF MEDICINE & SURGERY

OPEN

Assessing anatomical knowledge and confidence in central venous catheter insertion: a single-center cross-sectional study among physicians in a resource-limited setting

Alsadig Suliman, MBBS, MSc[a,*], Amir Mohamed, MBBS, BVs, MSc, PhD[b], Mohamed Saadeldein, MD, MSc[c]

Background: Central venous catheterization (CVC) is a vital but technically demanding procedure that requires understanding of vascular anatomy to minimize complications and enhance patient safety. This study evaluates physicians' anatomical knowledge and confidence in CVC placement, focusing on the internal jugular vein (IJV), subclavian vein (SCV), and femoral vein (FV). It aims to identify critical knowledge gaps, assess their impact on procedural competency, and explore their association with complications. This research uniquely examines a low-resource setting where the reliance on anatomical landmarks is crucial due to limited ultrasound availability. The findings will inform targeted educational interventions to improve training, enhance procedural expertise, and ultimately optimize patient outcomes.

Materials and methods: A single-center, hospital-based descriptive cross-sectional study was conducted among 164 medical practitioners using a structured questionnaire, validated through expert review and pilot testing. The questionnaire included image-based anatomical questions and a confidence scale to assess knowledge and self-reported proficiency in CVC insertion. Participants were randomized ensuring balanced subgroup representation. Statistical analyses, including chi-square tests, effect size calculations (Cohen's *d* and Cramer's *V*), and confidence intervals, were performed to evaluate associations between demographic factors, anatomical knowledge, and confidence levels.

Results: The study population had near-equal gender distribution (51.22% female, 48.78% male), with participants primarily being early-career physicians. The average knowledge accuracy was 86.03% for IJV, 82.9% for FV, and 86.9% for SCV. Significant associations were observed between anatomical knowledge and job title ($P = 0.03$), specialty ($P = 0.02$), and clinical experience ($P = 0.02$). Gender disparities were noted, with male participants scoring significantly higher for IJV ($P = 0.04$) and FV ($P = 0.03$), although no significant difference was found for SCV ($P = 0.12$). Confidence levels correlated with knowledge but did not necessarily reflect procedural competence, particularly in SCV insertion. The most frequently reported challenges included difficulty in vein identification (25.6%), and insufficient training (23.2%), reinforcing the need for structured educational interventions.

Conclusion: This study highlights the critical need for improved anatomical education and standardized training to enhance patient safety in catheterization. It uniquely contributes to the literature by identifying challenges specific to resource-limited settings, where clinicians rely heavily on anatomical knowledge due to the limited availability of imaging technology. The study's limitations include its single-center design, self-reported data, and cross-sectional nature, limiting generalizability and long-term trend analysis. Procedural competence was not directly assessed, emphasizing the need for objective evaluations. Future studies should focus on larger, multi-center designs with direct competency assessments to better identify training gaps. Additionally, exploring advanced educational methods, such as simulation-based training and virtual reality, could offer valuable insights into improving clinical skills in environments with constrained resources. Ultimately, this study highlights substantial knowledge gaps in CVC insertion, particularly among physicians with limited procedural exposure. Addressing these gaps through structured, evidence-based training programs is essential for patient safety.

Keywords: anatomical knowledge, central venous catheter, femoral vein, internal jugular vein, subclavian vein, Sudan

[a]Department of General Surgery, Sudan Medical Specialization Board, Isbitalia Street, Downtown, Khartoum, Khartoum, Sudan, [b]Anatomy and Embryology, Department of Anatomy, Faculty of Medicine, University of Gezira, Isbitalia Street, Wad Madani, Gezira, Sudan and [c]Faculty of Medicine, University of Gezira, Isbitalia Street, Wad Madani, Gezira, Sudan

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

*Corresponding author. Address: Department of General Surgery, Sudan Medical Specialization Board, Isbitalia Street, Downtown, Khartoum, Khartoum,13315 Sudan. Tel.: +249 925119682.
E-mail: alsadighashash1995@gmail.com (A. Suliman).

Annals of Medicine & Surgery (2025) 87:1930–1940

Received 20 December 2024; Accepted 3 March 2025

Published online 18 March 2025

http://dx.doi.org/10.1097/MS9.0000000000003169

Introduction

Background

Anatomy, derived from the Greek words *ana* (up) and *temnein* (to cut), has long been a cornerstone of medical education. Since the pioneering work of Andrea Vesalius, the systematic study of human anatomy has been integral to medical practice. Across diverse educational systems and cultural contexts, a comprehensive understanding of anatomy remains essential for ensuring patient safety, accurate diagnoses, and the successful execution of medical and surgical procedures[1]. Clinicians rely heavily on anatomical knowledge for interpreting radiological images, making precise diagnoses, and effectively collaborating within medical teams. This expertise is particularly critical in procedures such as central venous catheterization (CVC), where a detailed understanding of surface and procedural anatomy is paramount for precision and complication prevention[1,2].

The internal jugular vein (IJV), subclavian vein (SCV), and femoral vein (FV) are the primary access sites for CVC insertion due to their accessibility and large caliber. The IJV, located within the carotid sheath alongside the carotid artery and vagus nerve, is commonly accessed in the triangle formed by the sternocleidomastoid muscle near the clavicle. The right IJV is often preferred due to its straight trajectory to the superior vena cava and right atrium, which reduces the risk of catheter misplacement[3]. The SCV, positioned beneath the clavicle and anterior to the first rib, is associated with lower infection rates but carries an increased risk of pneumothorax due to its proximity to the lung apex[4,5]. The FV, situated within the femoral triangle adjacent to the femoral artery, is frequently selected in emergencies due to its ease of access; however, it carries a higher risk of infection and thrombosis given its anatomical location in the groin[6,7]. Despite the benefits of CVCs, complications such as arterial puncture, hematoma, and catheter malposition remain significant concerns, particularly in settings where ultrasound guidance is unavailable. Most studies assessing anatomical knowledge in procedural medicine have been conducted in high-resource environments where advanced imaging technologies are widely accessible. In resource-limited settings, procedural success heavily relies on clinicians' anatomical expertise due to the unavailability of real-time imaging[8,9]. Mastery of venous structures is essential for safe CVC placement, yet anatomical variations like vein duplication and obesity-related challenges can hinder landmark identification[8,9]. Site selection depends on clinical factors and operator expertise, with each site posing unique anatomical and procedural challenges. In the absence of ultrasound or advanced imaging, clinicians must depend entirely on anatomical landmarks, further complicated by anatomical variability and patient factors like obesity[8].

The role of CVCs and the importance of anatomical knowledge

CVCs play a pivotal role in the management of critically ill patients, facilitating interventions such as medication administration, hemodynamic monitoring, total parenteral nutrition, and dialysis[7,10]. The absence of real-time imaging necessitates strong reliance on landmark-based techniques to ensure procedural accuracy and minimize complications[11].

HIGHLIGHTS

- Evaluated clinicians' anatomical knowledge and confidence in landmark-based central venous catheterization.
- Identified key knowledge gaps and their association with specialty, job title, and clinical experience.
- Provided data-driven insights into training deficiencies and procedural challenges in a resource-limited setting.
- Proposed targeted educational strategies, including simulation and virtual reality, to enhance procedural competence.

Simulation-based and virtual reality training in CVC education

In recent years, simulation-based learning and virtual reality (VR) training have emerged as valuable tools in medical education, particularly for high-risk procedures such as CVC insertion. Research has demonstrated that simulation-based training significantly improves anatomical knowledge, procedural accuracy, and confidence among trainees. For example, a randomized controlled trial found that residents who underwent simulation-based CVC training demonstrated higher success rates and superior in-hospital performance compared to those trained using traditional methods[12]. Virtual reality platforms provide an immersive, risk-free environment where clinicians can repeatedly practice catheterization techniques before performing procedures on actual patients. A feasibility study integrating VR simulation into CVC training reported high satisfaction among novice trainees, particularly in understanding procedural steps and developing spatial awareness[13]. Furthermore, studies suggest that physicians trained using simulation-based models exhibit fewer errors, shorter procedural times, and improved patient outcomes compared to those trained with conventional techniques. A systematic review and meta-analysis concluded that simulation-based education for CVC insertion enhances both learner proficiency and clinical outcomes, including reduced complication rates[14]. Additionally, VR technology enables hands-on practice without patient risk, further refining catheterization techniques and procedural confidence[13,15].

Despite these advantages, implementing simulation-based and VR training in resource-limited settings remains challenging due to financial constraints, limited faculty expertise, and inadequate infrastructure. As a result, many physicians in such environments continue to rely exclusively on landmark-guided techniques, increasing the risk of procedural complications. Given these challenges, cost-effective strategies are needed to integrate simulation-based training into medical curricula, particularly in low-resource settings. By assessing knowledge gaps and confidence levels in CVC insertion, this study aims to provide a foundation for developing targeted educational interventions that incorporate simulation-based learning to enhance procedural safety and effectiveness.

The need for enhanced training in low-resource settings

The feasibility of integrating advanced training interventions, such as simulation and VR, in resource-limited settings remains underexplored. While these techniques have been proven to improve procedural competency, financial and infrastructural barriers hinder their widespread adoption. Additionally, real-world studies have highlighted significant variations in anatomical knowledge across specialties and experience levels, which directly impact procedural confidence and patient safety. In our hospital, located in a low-resource country, CVC-related complications such as arterial punctures, hematomas, and pneumothoraxes have been frequently observed over the past 4 years. We propose that these complications often arise from inadequate anatomical knowledge and improper insertion techniques, emphasizing the urgent need for enhanced procedural training to improve patient safety.

Study hypothesis and objectives

This study hypothesizes that improving physicians' anatomical knowledge will significantly reduce complication rates associated with landmark-guided CVC insertions. Additionally, we hypothesize that physicians with a stronger understanding of CVC insertion sites will report greater confidence in performing the procedure. However, confidence alone does not guarantee procedural success or a reduction in complications. The null hypothesis posits that no significant correlation exists between anatomical knowledge and procedural outcomes.

The primary objective of this study is to assess the anatomical knowledge and procedural challenges faced by doctors at a tertiary hospital in Sudan regarding CVC insertion. By evaluating their familiarity with the anatomical landmarks of the IJV, SCV, and FV, this research seeks to identify key knowledge gaps and propose targeted educational interventions. Ultimately, the study aims to improve procedural accuracy and patient safety in a resource-constrained healthcare setting, where anatomical expertise is crucial for successful CVC placement.

Study design and methodology

Study site

This study was conducted at a major tertiary care hospital in Sudan, which serves as both a medical education hub and a high-volume referral center. Its comprehensive services across multiple specialties provided an ideal setting for assessing CVC insertion practices[16].

Study design and materials

Study design

A single-center, descriptive, hospital-based cross-sectional study was conducted to evaluate the anatomical knowledge, confidence, and challenges faced by physicians performing CVC insertions using anatomical landmarks. This study uniquely integrates image-based anatomical assessments with self-reported confidence levels, enabling a nuanced analysis of the relationship between perceived competence and actual anatomical knowledge[16]. This study adheres to the Strengthening the Reporting of Cohort Studies in Surgery criteria[17].

Survey design and validation

The primary data collection tool for this study was a structured questionnaire, designed and validated by experts in anatomy, vascular surgery, intensive care, and anesthesiology. It aimed to assess participants' anatomical knowledge, procedural confidence, and experience with CVC insertion. Given that ultrasound guidance is not routinely available in our hospital, the questionnaire primarily assessed landmark-based CVC insertion techniques. To ensure content validity, the questionnaire underwent a multi-stage validation process, including expert review, content validity assessment, and pilot testing. Five specialists from relevant fields independently evaluated the questionnaire for clarity, relevance, and completeness. The Content Validity Index (CVI) was calculated, with an item-level CVI (I-CVI) threshold of ≥0.78 and a scale-level CVI (S-CVI) of ≥0.90, ensuring strong agreement among reviewers. Additionally, the questionnaire was pilot-tested with 10 physicians from various specialties to assess clarity, feasibility, and response variability. Based on their feedback, minor refinements were made to enhance comprehensibility and applicability. Reliability testing using Cronbach's alpha (0.82) confirmed good internal consistency, supporting its suitability as an assessment tool. To minimize self-reporting bias, the questionnaire assured participant anonymity, used neutral phrasing for confidence-related questions, and withheld specific study objectives to reduce response bias. A sample question and the full questionnaire are available as Supplemental Digital Content [URL] https://figshare.com/s/6fd4751a11b02ec5e973?file=51299216. The structured questionnaire consisted of 5 key sections:

- Demographic Information—Gender, age, years of experience, medical specialty, and job title.
- Knowledge of Anatomical Landmarks—Evaluated via multiple-choice and image-based questions, covering:
- Vein position
- Anatomical relationships
- Recognition of complications
- Clinical applications of anatomical landmarks
- Confidence Levels—Assessed on a 5-point Likert scale. However, confidence levels were not measured pre- and post-knowledge assessment, limiting the ability to determine whether knowledge acquisition directly influenced confidence.
- Challenges Faced—Open-ended responses regarding difficulties encountered during landmark-based CVC insertion.
- Training and Resources—Evaluated exposure to ultrasound-guided CVC training and formal anatomical education.

Sampling method

A stratified random sampling approach was used to ensure fair representation across job titles, specialties, and experience levels. Participants were randomly selected from the hospital's official registry of licensed medical doctors.

The 2-step stratification process involved the following:

- Categorization: Physicians were grouped based on:
- Job title: House officers, medical officers, registrars.
- Specialty: Surgery, internal medicine, others.
- Years of experience: ≤1 year, 1–3 years, >3 years.
- Random Selection: Within each category, a computer-generated randomization sequence (*Random.org*) was applied to ensure proportional representation[18].

Stratification was performed based on the hospital's physician registry, categorizing participants into house officers, medical officers, registrars, and consultants. This ensured balanced subgroup representation and minimized selection bias. This method prevented the overrepresentation of any single group, enhancing the study's applicability to broader clinical settings. Participants were not informed about the study's objectives beforehand to reduce bias.

Sample size

From a total of 286 eligible physicians, the sample size was determined using Cochran's formula[19], resulting in 164 participants. This ensured a 95% confidence level with a 5% margin of error.

Data collection period

Data collection occurred from October to December 2023. Questionnaires were distributed via Google Forms, with each participant receiving a unique invitation. Google Forms was selected for its ability to

- Maintain respondent anonymity by disabling e-mail tracking, Internet Protocol recording, and duplicate submissions.
- Prevent identification bias, ensuring honest responses.

Participants

Inclusion criteria

- Licensed medical doctors.
- Affiliated (current or past) with the study hospital in 2023.

Exclusion criteria

- Medical students or unlicensed doctors.
- Physicians not affiliated with the study hospital in 2023.

Statistical analysis and interpretation

Data were cleaned and analyzed using SPSS version 25.0[20].

Descriptive statistics

- Frequencies and percentages for categorical variables.
- Means and standard deviations for continuous variables.

Inferential statistics

- Chi-square tests assessed relationships between demographics, knowledge, and confidence ($P < 0.05$ threshold).
- Effect sizes (*Cohen's d* for continuous variables, *Cramer's V* for categorical comparisons) and 95% confidence intervals enhanced interpretation.
- Multiple regression analysis evaluated the interaction effects between job title, specialty, and anatomical knowledge in predicting procedural confidence.

Challenges analysis

- Thematic analysis categorized open-ended responses into
- Technical barriers (e.g., vein identification difficulties).
- Training-related challenges (e.g., lack of structured teaching).
- Systemic limitations (e.g., resource constraints).
- Patient-related factors (e.g., obesity complicating insertion).

The sample was stratified to ensure proportional representation across different job titles and specialties. This approach minimized bias and improved the generalizability of subgroup comparisons.

Ethical considerations

This study complied with the Declaration of Helsinki and received Institutional Review Board approval on 8 August 2023. Participation was entirely voluntary, with informed consent obtained from all participants. To minimize self-reporting bias, participants were assured that their responses would remain anonymous, the data collected would not influence their clinical evaluations, and the study's focus on the relationship between knowledge and confidence was not disclosed until after questionnaire completion to prevent expectancy bias. Confidentiality was strictly maintained, and participants had the right to withdraw from the study at any stage without any repercussions. Regarding image usage, permissions for anatomical images were secured through formal licensing agreements, institutional approvals, and direct communication with copyright holders[21-23].

Results

Demographic analysis

The study involved 164 participants with a nearly equal gender distribution of 51.22% female ($N = 84$) and 48.78% male ($N = 80$). Graduates from 26 universities were represented, with most aged 26-30 years, 62.80% ($N = 103$). Predominant specialties were surgery 38.41% ($N = 63$) and internal medicine 22.56% ($N = 37$). Regarding job titles, 37.2% ($N = 61$) were house officers, 33.54% ($N = 55$) were general practitioners, and 20.73% ($N = 34$) were residents. Clinical experience varied, with 43.90% ($N = 72$) having less than 1 year and 27.44% ($N = 45$) having 1-2 years of experience.

Anatomical knowledge analysis

The analysis revealed varying levels of accuracy across these 3 veins. For the IJV questions, the average accuracy was 86.03%, indicating a strong understanding. For the FV questions, the average accuracy was 82.9%, reflecting slightly lower but still solid knowledge. Finally, for the SCV questions, the average accuracy was 86.9%, demonstrating a good overall grasp (Fig. 1). A 2-way analysis of variance was conducted to examine interaction effects between job title and specialty on anatomical knowledge scores. The interaction effect was statistically significant

[F (6, 158) = 3.14, $P = 0.02$, $\eta^2 = 0.05$], indicating that while specialty and job title each independently affected knowledge levels, their combined influence was particularly notable in procedural specialties such as surgery and emergency medicine. Post hoc analysis using Tukey's honestly significant difference test revealed that general surgeons (mean score = 82.6, standard deviation [SD] = 4.3) had significantly higher knowledge scores than internal medicine physicians (mean score = 74.2, SD = 5.6, $P = 0.01$), particularly in identifying FV landmarks.

Gender-based comparison of anatomical knowledge

Males had higher average knowledge than females for the IJV, FV, and SCV. The differences were statistically significant for the IJV ($P = 0.04$) and FV ($P = 0.03$), while the difference for SCV was

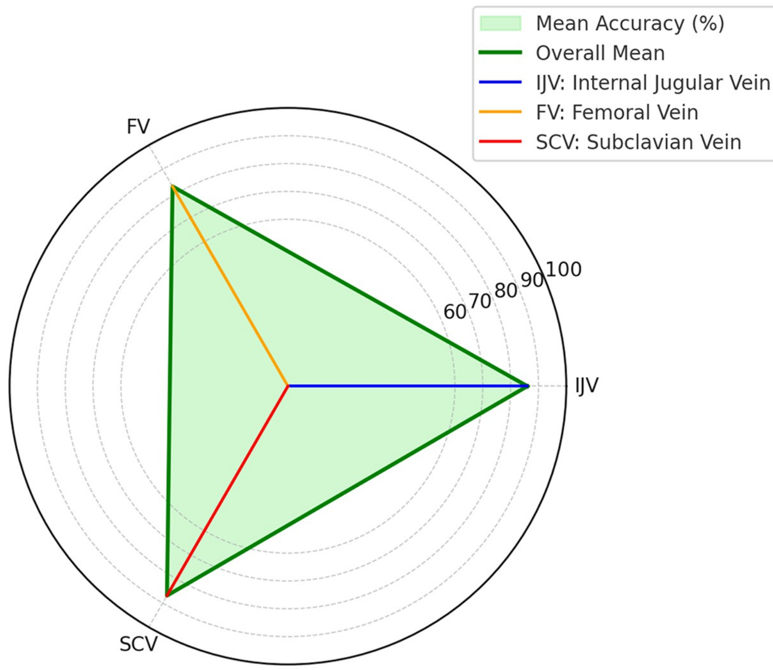

Figure 1. Radar chart of mean anatomical knowledge accuracy across major veins (IJV, FV, and SCV). FV, femoral vein; IJV, internal jugular vein; SCV, subclavian vein

not statistically significant (P = 0.12). The analysis revealed statistically significant gender disparities in anatomical knowledge for the IJV (P = 0.04) and FV (P = 0.03), with male participants scoring higher on average. However, for the SCV, no significant difference was observed (P = 0.12).

Job title-based comparison of anatomical knowledge

The data show significant differences in IJV and FV knowledge by job title (P = 0.03 and 0.05), with higher knowledge observed in senior roles. Subclavian vein knowledge differences are not statistically significant (P = 0.08). The findings highlight a need for focused training, particularly for junior roles (Table 1). Consultants and registrars demonstrated superior anatomical understanding, possibly due to increased procedural experience and exposure to CVC insertions. Conversely, house officers and general practitioners showed moderate knowledge gaps, reinforcing the need for targeted training in early-career stages.

Table 1

Job-based correlation of average anatomical knowledge scores for IJV, FV, and SCV among doctors participating in the study.

Job title	IJV knowledge (%)	FV knowledge (%)	SCV knowledge (%)	Participants (*N*)
Consultants	100.00	50.00	66.67	4
Specialists	82.50	60.00	56.67	10
Registrar	75.74	61.03	50.00	34
General Practitioners	66.36	58.64	47.88	55
House Officers	65.62	49.22	46.88	61
***P*-value**	**0.03**	**0.05**	**0.08**	

FV, femoral vein; IJV, internal jugular vein; SCV, subclavian vein.

Medical specialty-based comparison of anatomical knowledge

The data show significant variation in IJV and FV knowledge across specialties (P = 0.02 and 0.03). General Surgery, the largest group, demonstrates moderate knowledge, while Obstetrics and Gynecology has notably low FV knowledge (43.42%). Subclavian vein knowledge differences are not significant (P = 0.07), with Radiology scoring the highest (Table 2). These findings highlight the need for targeted training in specialties with lower knowledge levels. Surgeons exhibited the highest anatomical knowledge levels, particularly in IJV and FV identification, whereas physicians from less procedure-intensive specialties (e.g., psychiatry and dermatology) scored lower. The lowest FV knowledge was observed in Obstetrics and Gynecology (43.42%), indicating potential training gaps in this specialty.

Experience level-based comparison of anatomical knowledge

Participants with more than 6 years of experience showed the highest knowledge of the IJV, FV, and SCV, as shown in Figure 2. Statistically significant differences were noted for the IJV (P = 0.02) and FV (P = 0.04), while the SCV showed no significant difference (P = 0.06). These results indicate that anatomical knowledge improves with clinical exposure. However, structured training may be necessary to accelerate knowledge acquisition for early-career physicians.

Table 2

Medical specialty-based correlation of average anatomical knowledge scores for IJV, FV, and SCV among doctors participating in the study.

Medical specialty	IJV knowledge (%)	FV knowledge (%)	SCV knowledge (%)	Participants (*N*)
Anesthesiology and Intensive Care	75.00	50.00	33.33	9
Clinical Immunology	100.00	75.00	0.00	3
Dermatology	56.25	62.50	33.33	4
Emergency Medicine	75.00	50.00	50.00	8
Internal Medicine	75.00	48.65	50.45	37
Obstetrics and Gynecology	63.16	43.42	52.63	19
Ophthalmology	50.00	62.50	58.33	4
Pediatrics	58.33	52.78	51.85	9
Psychiatry	68.75	62.50	50.00	4
Radiology	75.00	50.00	66.67	4
General Surgery	68.25	61.90	48.68	63
***P*-value**	**0.02**	**0.03**	**0.07**	

FV, femoral vein; SCV, subclavian vein.

Confidence level-based comparison of anatomical knowledge

For the IJV, average accuracy was highest among very confident individuals, with a significant difference ($P = 0.03$). In the FV, very confident individuals also had the highest accuracy ($P = 0.04$). For the SCV, confidence levels showed no significant difference ($P = 0.06$) (Table 3). Participants who reported higher confidence levels also demonstrated higher knowledge scores for IJV and FV. However, this correlation was weaker for SCV, suggesting that confidence in SCV catheterization may not accurately reflect actual knowledge.

Challenges faced during CVC insertion

Participants reported several challenges related to CVC insertion, with difficulty in locating veins (25.6%) being the most frequently cited issue, particularly among house officers and general practitioners. Insufficient training (23.2%) and procedural anxiety (18.9%) were also significant concerns, reinforcing the need for structured educational programs (Fig. 3). Limited access to ultrasound (16.5%) emerged as a critical barrier, especially for SCV catheterization, where reliance on anatomical landmarks increases procedural difficulty. Time constraints (15.9%) further compounded these challenges, particularly in emergency settings. Notably, the correlation between confidence and actual knowledge was weaker for SCV insertions, suggesting that self-reported confidence in SCV catheterization may not reliably reflect anatomical proficiency. These findings highlight the necessity of competency-based training and improved access to ultrasound to enhance procedural accuracy and reduce complications.

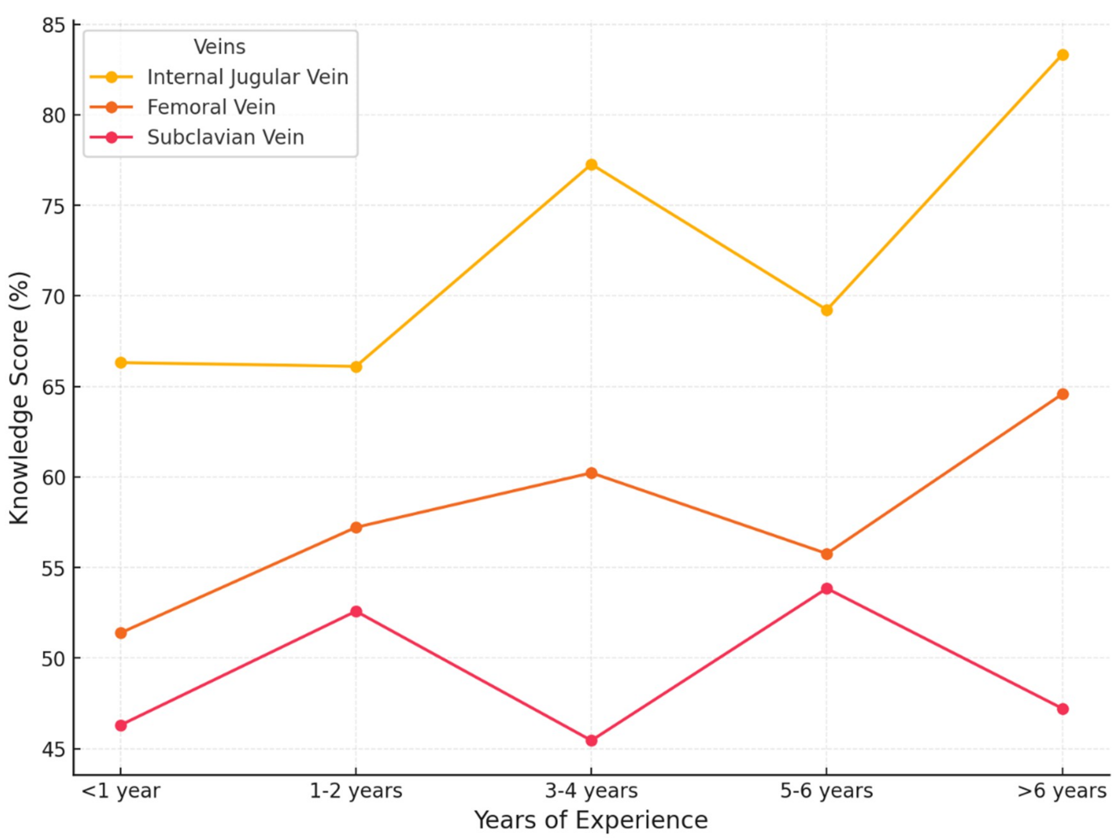

Figure 2. Correlation between years of experience and knowledge scores for IJV, FV, and SCV. FV, femoral vein; IJV, internal jugular vein; SCV, subclavian vein

Table 3

Average knowledge (%) of IJV, FV, and SCV stratified by confidence level among doctors participating in the study.

Confidence level	IJV accuracy (%)	FV accuracy (%)	SCV accuracy (%)	Participants (*N*)
Very Confident	75.00	63.33	51.11	15
Confident	74.00	55.00	50.67	50
Somewhat Confident	64.39	52.65	47.98	65
Not Confident	68.94	58.33	45.45	34
***P*-value**	**0.03**	**0.04**	**0.06**	

FV, femoral vein; IJV, internal jugular vein; SCV, subclavian vein.

Discussion

This study highlights significant variability in anatomical knowledge and confidence among clinicians performing CVC insertions. Key factors influencing these differences include gender, medical specialty, job title, years of experience, and university of graduation. These findings underscore the challenges faced in resource-limited settings, where targeted educational interventions tailored to improve procedural competency could lead to better clinical outcomes.

What differentiates this study is its specific focus on the unique challenges faced in Sudan, including inconsistent availability of sterilization equipment, surgical instruments, and reliance on traditional training models. These challenges are compounded by limited access to cutting-edge educational technologies.

Challenges in CVC placement and training deficiencies

Participants reported various challenges associated with landmark-based CVC insertion, with difficulty in locating veins (25.6%) and insufficient training (23.2%) being the most frequently cited. Procedural anxiety (18.9%), limited access to ultrasound (16.5%), and time constraints in emergency settings (15.9%) further complicated the insertion process. The high prevalence of these issues aligns with previous research demonstrating that landmark-based CVC placement has a greater failure rate and higher complication risks compared to ultrasound-guided techniques. A Cochrane review confirmed that 2-dimensional ultrasound significantly enhances safety and success rates over traditional anatomical landmark techniques[5]. Limited access to ultrasound was particularly concerning for SCV catheterization, where the risk of misplacement and vascular injury is high. Expanding access to portable ultrasound devices and integrating ultrasound training into medical curricula could significantly improve procedural safety. A study comparing ultrasound-guided CVC placement with the anatomical landmark technique found that ultrasound guidance reduced complications and decreased the number of placement attempts, reinforcing the importance of accessible imaging technologies in resource-limited settings[24]. However, this correlation was weaker for SCV, suggesting that confidence in SCV catheterization may not accurately reflect actual knowledge.

The role of confidence vs. procedural competence

The relationship between clinician confidence and actual procedural competence remains complex. A study examining gender differences in resident physicians found that female trainees reported lower confidence in performing CVC insertions both before and after simulation-based training. However, there was no significant difference in skill-based outcomes, suggesting that self-reported confidence does not always correlate with procedural competence[25]. Similarly, research on technical errors in SCV placement found that nearly half of the surgical residents committed multiple errors, with a negative correlation between technical proficiency and their ability to anticipate procedural challenges. This suggests that overconfidence without adequate decision-making

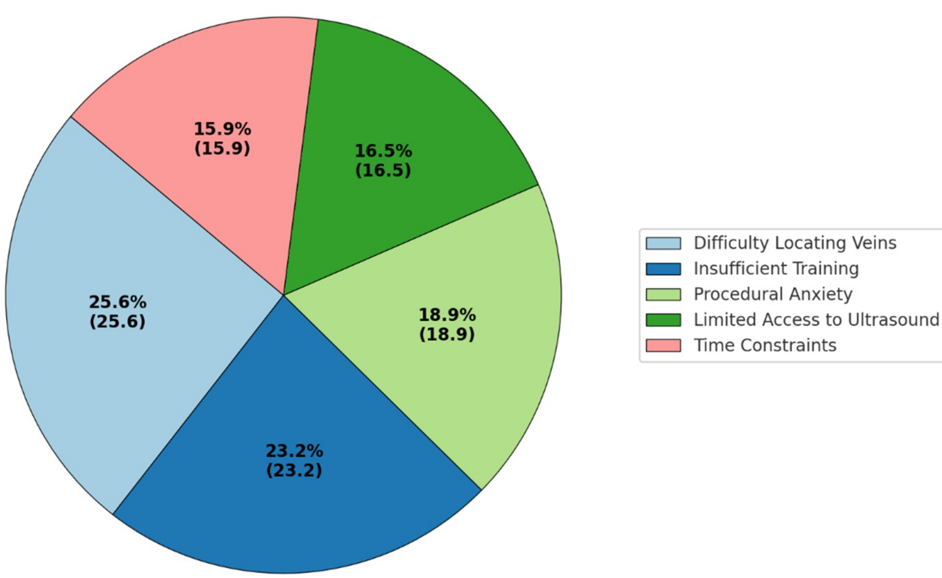

Figure 3. Proportional distribution of challenges in CVC insertion. CVC, central venous catheterization

skills can lead to avoidable errors[26]. These findings reinforce the need for competency-based training programs that assess both anatomical knowledge and procedural skills before allowing independent practice. Implementing such standardized training methods ensures that clinicians possess both confidence and technical proficiency, ultimately improving patient safety.

Systemic barriers to equal training opportunities

Gender-based differences in anatomical knowledge and procedural confidence, particularly concerning IJV and FV catheterization, raise important concerns about clinical exposure, mentorship, and training structures. Previous studies suggest that male trainees often receive more procedural training opportunities than their female counterparts. Workplace assignments and mentorship biases may contribute to this disparity, as male trainees are more frequently encouraged to perform invasive procedures, while female trainees are sometimes steered toward non-invasive specialties. Implicit bias may also influence procedural confidence, with male trainees often reporting higher confidence levels in invasive techniques, which may lead supervisors to assign them more hands-on cases, thereby further widening the knowledge gap[27]. Addressing these systemic biases is crucial for ensuring equal training opportunities and improving procedural competence across all genders in medical education and clinical practice[28]. Although gender differences in anatomical knowledge were statistically significant ($P < 0.05$), their clinical relevance requires further exploration. Previous studies suggest that gender disparities in procedural training opportunities may contribute to confidence differences[27]. However, no significant difference was observed in real-world complication rates for CVC insertions between male and female physicians in prior research[28]. These findings indicate that while knowledge gaps exist, structured competency-based training could help mitigate potential clinical discrepancies between genders.

Impact of landmark-guided CVC placement in low-resource settings

Benhamou et al. (2023) emphasize the effectiveness of an observer tool in enhancing the skills of incoming anesthesia residents during simulation training for CVC insertion. This study supports the growing emphasis on simulation-based learning in medical education.[29]

In resource-limited environments, reliance on anatomical landmark techniques is often necessary due to restricted access to ultrasound. However, properly executed landmark-based techniques can still be effective. A large-scale database analysis of CVC insertions via the IJVs found that Sedillot's triangle technique was both safe and reliable, reducing the need for ultrasound or fluoroscopy in 93% of cases[30]. Despite this, male participants in our study scored slightly higher in anatomical knowledge assessments than female participants. This trend has been observed in previous studies, such as those by Tzamaras et al., but the differences were not clinically significant, suggesting that additional research is needed to explore the underlying factors contributing to these variations[31].

Specialty-based variability in anatomical knowledge and confidence

Anatomical knowledge and confidence in performing CVC insertions varied significantly among medical specialties. Surgeons demonstrated the highest levels of anatomical knowledge, particularly in relation to the IJV and FV, whereas radiologists exhibited a superior understanding of the SCV, likely due to their frequent use of imaging technologies. Conversely, physicians in non-invasive specialties such as psychiatry and dermatology scored lower, highlighting the need for targeted anatomical training tailored to different clinical demands[32]. Confidence levels also differed across job titles, with consultants and specialists reporting the highest confidence, likely due to their extensive procedural experience. Registrars expressed confidence in FV catheterization but were less confident with IJV insertions. House officers and general practitioners had the lowest confidence levels, reflecting their limited procedural exposure and underscoring the importance of structured hands-on training for early-career clinicians[25].

Bridging the gap between knowledge and procedural competence

Our findings highlight that while greater anatomical knowledge correlates with increased confidence in CVC insertion, confidence alone does not ensure procedural success. Despite 51.8% of participants reporting high confidence, 27.4% demonstrated insufficient anatomical knowledge, raising concerns about overconfidence. This misalignment underscores the need for structured, competency-based training to ensure that confidence aligns with actual procedural proficiency. Existing literature supports this concern, emphasizing that technical proficiency—rather than self-assessed confidence—is a stronger predictor of procedural success and lower complication rates. A study on medical students performing CVC insertions reported a 67.3% success rate, illustrating that confidence does not always equate to competence[33]. In our study, knowledge gaps were particularly evident in relation to the SCV, further reinforcing the need for continuous education and refresher courses to enhance anatomical understanding and reduce procedural risks[8]. Participants also identified patient-specific challenges, such as obesity and anatomical variations, which complicated landmark identification during CVC insertion. The lack of real-time imaging, particularly ultrasound, in resource-limited settings exacerbated these difficulties, increasing reliance on anatomical knowledge. This highlights the need for improved access to imaging technologies or enhanced anatomical training to better equip clinicians for challenging environments[34,35]. A systematic review by Koppes et al. found significant variability in anatomical knowledge among medical professionals, with reported proficiency ranging from 22.5% to 82.4%[32]. Similarly, our study observed that more experienced doctors, such as consultants and registrars, exhibited higher anatomical knowledge levels. Rowland et al. emphasized the critical role of robust anatomical understanding in ensuring safe clinical practice, noting that deficiencies in anatomical knowledge can contribute to errors during procedures like CVC insertion[36]. Moreover, Tzamaras et al. demonstrated that self-reported confidence often exceeds actual performance, with clinicians sometimes overestimating their abilities despite knowledge gaps. This discrepancy, also observed in our study, is particularly concerning in resource-limited settings where training opportunities are scarce[31]. Addressing these gaps requires a systematic approach to anatomical education, ensuring that clinicians develop both the knowledge and technical proficiency necessary for safe and effective CVC insertion.

Proposed educational interventions for enhancing CVC training

Targeted educational interventions can significantly improve anatomical knowledge and procedural confidence in CVC insertion, particularly in resource-limited settings. Simulation-based learning has been shown to enhance knowledge retention, procedural accuracy, and complication avoidance. Yang et al. emphasized the need for structured training programs incorporating didactic lessons, simulation exercises, formal assessments, and supervised practice[37]. A systematic review and meta-analysis further highlighted that simulation-based education improves procedural proficiency, confidence, and patient safety[14].

Given the financial and infrastructural constraints in resource-limited settings, cost-effective training solutions such as peer mentorship, hands-on anatomical workshops, and structured bedside training with expert feedback provide feasible alternatives for skill enhancement[13]. Cadaver-based training remains one of the most effective methods for teaching procedural anatomy, yet its accessibility is often limited. Institutions should collaborate with anatomy departments to facilitate periodic cadaver-based workshops, enabling trainees to gain hands-on experience in vein localization and catheter insertion. Faculty-led competency assessments using procedural checklists can ensure both confidence and technical accuracy.

The integration of ultrasound-guided CVC insertion into training programs is essential, as studies consistently demonstrate that ultrasound reduces complication rates[38]. While ultrasound availability is limited in many low-resource settings, training physicians to use portable, low-cost ultrasound devices could enhance procedural safety. Emerging VR training modules offer a promising, cost-effective alternative to traditional procedural education. A recent study found that novice trainees reported high satisfaction with VR simulation for CVC training, particularly in understanding procedural steps and spatial awareness[13]. While still in early adoption stages in low-resource settings, integrating affordable VR models into medical curricula could provide a long-term solution. Implementing these targeted educational interventions can significantly improve the proficiency of healthcare providers in CVC insertion, ultimately enhancing patient outcomes, particularly in resource-limited settings.

Educational interventions: feasibility in resource-limited settings

Simulation-based learning and VR training have been widely adopted in medical education to improve procedural skills. These methods allow for safe, repeated practice of CVC insertion techniques without putting patients at risk. However, the feasibility of implementing such training programs in resource-limited settings remains uncertain due to financial and infrastructure constraints. To bridge this gap, a hybrid educational approach should be considered, combining cost-effective anatomical training modules with hands-on workshops. Potential solutions include low-cost simulation models using gelatin or cadaver-based training sessions, structured anatomical workshops emphasizing CVC insertion landmarks, supervised procedural training under expert guidance, and portable ultrasound training integrated into residency programs.

Limitations

This study has several limitations that may affect the generalizability and interpretation of its findings. Conducted at a single tertiary care hospital in Sudan, the results may not be fully applicable to institutions with different training structures, resource availability, and patient demographics. Additionally, the cross-sectional design captures data at a single time point, limiting insights into longitudinal trends in knowledge acquisition and confidence development.

Self-reported confidence levels introduce another limitation, as they may not accurately reflect actual procedural proficiency due to social desirability bias. Some participants may have overestimated their skills, while others may have been overly cautious in their assessments. Moreover, while stratified random sampling ensured balanced subgroup representation, the underrepresentation of senior consultants may limit insights into expert-level anatomical knowledge. Gender-based analysis was also constrained by cultural and institutional norms that limit discussions on training disparities. Sociocultural factors may influence access to procedural training, making it difficult to isolate gender alone as a determinant of disparities.

Institutional factors, such as faculty teaching styles, structured training programs, and access to ultrasound guidance, were not explicitly analyzed but significantly influence procedural confidence. Given these limitations, the findings may not be fully generalizable to institutions with different training protocols or resource availability.

Future recommendations

Future research should adopt a multi-center, longitudinal study design to assess knowledge gaps and procedural confidence across diverse training environments. Expanding to multiple institutions will provide a broader perspective on how different settings influence anatomical knowledge. Tracking changes over time will help evaluate the impact of training interventions on skill development. Direct skill assessments should replace sole reliance on self-reported confidence, incorporating real-time procedural monitoring, simulation-based evaluations, OSCEs, and supervised procedural assessments to ensure accurate competence measurement. Additionally, alternative research methodologies, including prospective cohort studies and qualitative analyses of training experiences, should be explored to gain deeper insights into the challenges clinicians face during CVC insertions. Low-cost educational interventions tailored to resource-limited settings should be evaluated for their effectiveness. Implementing blended learning models—such as simulation-based training, hands-on workshops, and peer mentorship—could bridge existing knowledge gaps and improve procedural proficiency. Comparative studies should examine institutional factors, including faculty teaching styles, structured training programs, and access to ultrasound guidance, to better understand training disparities. Expanding the sample to include experienced physicians would provide insights into knowledge retention across career stages. Future studies should also explore gender-related variations in procedural exposure through institutional records and observational analyses. To determine whether enhanced anatomical knowledge translates into safer procedures, research should integrate direct skill assessments, structured training, and retrospective complication analyses. Evaluating the effectiveness of these educational interventions on clinician proficiency, procedural success, and patient safety outcomes will be crucial in optimizing training strategies.

Conclusion

This study reveals significant gaps in anatomical knowledge and procedural confidence among junior doctors performing landmark-based CVC in resource-limited settings. Despite moderate to high confidence levels, notable deficiencies were observed, particularly regarding SCV anatomy. Addressing these gaps through structured anatomical training, competency-based assessments, and targeted mentorship programs is essential to enhancing clinician proficiency and reducing procedural complications. Unlike previous research that predominantly focuses on ultrasound-guided techniques, this study emphasizes the critical role of anatomical expertise in environments where real-time imaging is unavailable. While many participants demonstrated moderate to high levels of anatomical knowledge, notable deficiencies were identified, especially regarding SCV landmarks. It is crucial to address these gaps with focused educational initiatives. Standardized training programs that integrate key anatomical landmark instruction, ultrasound-guided techniques, and hands-on training, such as cadaveric dissections, could significantly enhance clinician proficiency and confidence. Implementing these measures would help reduce complications, improve procedural safety, and optimize patient outcomes, particularly in low-resource healthcare settings.

Ethical approval

All procedures were conducted in compliance with applicable laws and institutional guidelines and received approval on 8 August 2023 from the Institutional Review Board (IRB) of Wad Madani Teaching Hospital (IRB/WMTH/2023/045).

Consent

Written informed consent was obtained from the participants for publication and any accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request. Participation was voluntary. Confidentiality of personal information was strictly maintained, and participants were assured of their right to withdraw at any stage without repercussions.

Sources of funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author's contribution

A.S. contributed to conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, resources, visualization, drafting the manuscript, and revising it critically for important intellectual content. **A.M.** contributed to project administration, supervision, and visualization. **M. S.** contributed to methodology, resources, validation, and revising the manuscript critically for important intellectual content.

Conflicts of interest disclosure

The authors declare no conflicts of interest.

Research registration unique identifying number (UIN)

Not applicable.

Guarantor

Dr. Alsadig Suliman.

Provenance and peer review

This paper was not commissioned and has been externally peer-reviewed.

Data availability statement

The datasets generated and/or analyzed during the current study are available upon reasonable request from the corresponding author, Dr. Alsadig Suliman.

Presentation

None declared.

Acknowledgements

We sincerely thank the staff of Wad Madani Teaching Hospital and the Department of Anatomy at Gezira University for their invaluable support and guidance throughout this study. Special appreciation is extended to Dr. Bushra Hashash, Dr. Abualqasim, and Dr. Eyman Ali for their expertise and contributions. We are also deeply grateful to all participants who dedicated their time and effort to this research.

References

[1] Almizani MS, Alotaibi MA, Bin Askar MF, *et al.* Clinicians' and students' perceptions and attitudes regarding the anatomical knowledge of medical students. Adv Med Educ Pract 2022;13:1251–59.
[2] Sagoo MG, Vorstenbosch MATM, Bazira PJ, *et al.* Online assessment of applied anatomy knowledge: the effect of images on medical students' performance. Anat Sci Educ 2021;14:342–51.
[3] Woodhouse P, Waheed A, Bordoni B. Anatomy, thorax, brachiocephalic (innominate) veins. StatPearls [Internet]. 2022 September 26 [cited 2024 September 19]; Available from: https://www.ncbi.nlm.nih.gov/books/NBK544339/
[4] Ishizuka M, Nagata H, Takagi K, *et al.* Right internal jugular vein is recommended for central venous catheterization. J Invest Surg 2010;23:110–14.
[5] Brass P, Hellmich M, Kolodziej L, *et al.* Ultrasound guidance versus anatomical landmarks for internal jugular vein catheterization. Cochrane Database Syst Rev 2015;1:CD006962.
[6]. Nasr-Esfahani M, Kolahdouzan M, Mousavi SA. Inserting central venous catheter in emergency conditions in coagulopathic patients in comparison to noncoagulopathic patients. J Res Med Sci 2016:21:120.
[7] Ma IW, Sharma N, Brindle ME, *et al.* Measuring competence in central venous catheterization: a systematic-review. Springerplus 2014;3:1–12.

[8] Saugel B, Scheeren TWL, Teboul JL. Ultrasound-guided central venous catheter placement: a structured review and recommendations for clinical practice. Crit Care 2017;21:1–11.
[9] McGee DC, Gould MK. Preventing complications of central venous catheterization. N Engl J Med 2003;348:1123–33.
[10] Pinsky MR, Cecconi M, Chew MS, *et al*. Effective hemodynamic monitoring. Crit Care 2022;26:294.
[11] Salimi F, Sajjadieh Khajouei A, Keighobadi S, *et al*. Practical anatomical landmark for optimal positioning of left-sided long-term central venous catheter (a pilot study). J Res Med Sci 2020;25:27.
[12] Evans LV, Dodge KL, Shah TD, *et al*. Simulation training in central venous catheter insertion: improved performance in clinical practice. Acad Med 2010;85:1462–69.
[13] Savir S, Khan AA, Yunus RA, *et al*. Virtual reality training for central venous catheter placement: an interventional feasibility study incorporating virtual reality into a standard training curriculum of novice trainees. J Cardiothorac Vasc Anesth 2024;38:2187–97.
[14] Iwy M, Brindle ME, Ronksley PE, *et al*. Use of simulation-based education to improve outcomes of central venous catheterization: a systematic review and meta-analysis. Acad Med 2011;86:1137–47.
[15] Peltan ID, Shiga T, Gordon JA, *et al*. Simulation improves procedural protocol adherence during central venous catheter placement: a randomized controlled trial. Simul Healthc 2015;10:270–76.
[16] Younis A, Hassan A, Dmyatti E, *et al*. Awareness and practice of patients' rights among hospitalized patients at Wad-Medani Teaching Hospital, Sudan. East Mediterr Health J 2017;23:80–86.
[17] Mathew G, Agha R, Albrecht J, *et al*. STROCSS 2021: strengthening the reporting of cohort, cross-sectional and case-control studies in surgery. Ann Med Surg 2021;72:103026.
[18] Random integer generator. https://www.random.org/; 2023.
[19] Ologunagba O, Adekunle O, Oseni E. Effect of bootstrapping dimensions moderated by cost of doing business on performance of Small and Medium Scale Enterprises (SMEs) in South-West, Nigeria. NIU J Soc Sci 2024;10:257–66.
[20] IBM Crop. IBM SPSS Statistics for Windows. Armonk, NY: IBM Corp; 2017.
[21] Demetriades DCRC ERB eds. Color Atlas of Emergency Trauma. Cambridge University Press; 2021:296.
[22] TeachMeAnatomy. Inguinal canal. n.d. Retrieved September 2023, from https://teachmeanatomy.info/abdomen/areas/inguinal-canal/.
[23] Demetriades D, Inaba K, Velmahos G. (Eds.). Atlas of surgical techniques in trauma (2nd ed.). Cambridge University Press; 2020. doi:10.1017/9781108698665.
[24] Eldabaa AA, Said Elgebaly A, Abd Elhafz AA, *et al*. Comparison of ultrasound-guided versus anatomical landmark-guided cannulation of the femoral vein at the optimum position in infants. Ann Pediatr Surg 2012;8:65–68.
[25] Solberg MJ, Wong AH, Ikejiani S, *et al*. Comparing male and female resident physicians in central venous catheter insertion self-confidence and competency: a retrospective cohort study. J Gen Intern Med 2025;40:63–69.
[26] Nathwani JN, Fiers RM, Ray RD, *et al*. Relationship between technical errors and decision-making skills in the junior resident. J Surg Educ 2016;73:e84–90.
[27] Olson EM, Sanborn DM, Dyster TG, *et al*. Gender disparities in critical care procedure training of internal medicine residents. ATS Sch 2023;4:164–76.
[28] Piquette D, Spring J. Gender disparity in procedural training: a persistent problem in need of early interventions. ATS Sch 2023;4:109–12.
[29] Benhamou D, Tant S, Gille B, *et al*. An observer tool to enhance learning of incoming anesthesia residents' skills during simulation training of central venous catheter insertion: a randomized controlled trial. BMC Med Educ 2023;23:942.
[30] Liang H, Guo Y, Chen G, *et al*. Ultrasound guidance combined with C-arm fluoroscopy in selective semilunar ganglion radiofrequency thermocoagulation through the foramen ovale for trigeminal neuralgia: a randomized controlled trial. Pain Med 2023;24:415–24.
[31] Tzamaras H, Sinz E, Yang M, *et al*. Competence over confidence: uncovering lower self-efficacy for women residents during central venous catheterization training. BMC Med Educ 2024;24:1–10.
[32] Koppes DM, Triepels CPR, Notten KJB, *et al*. The level of anatomical knowledge, hard to establish: a systematic narrative review. Med Sci Educ 2022;32:569–81.
[33] Chao A, Lai CH, Chan KC, *et al*. Performance of central venous catheterization by medical students: a retrospective study of students' logbooks. BMC Med Educ 2014;14:168.
[34] Shah S, Bellows BA, Adedipe AA, *et al*. Perceived barriers in the use of ultrasound in developing countries. Crit Ultrasound J 2015;7:11.
[35] Gu Y, Min K, Zhang Q, *et al*. Central venous catheterization site choice based on anatomical landmark technique: a systematic review and meta-analysis. J Anesth 2021;35:801–10.
[36] Rowland S, Ahmed K, Davies DC, *et al*. Assessment of anatomical knowledge for clinical practice: perceptions of clinicians and students. Surg Radiol Anat 2011;33:263–69.
[37] Yang F, Ho KY, Lam KKW, *et al*. Facilitators and barriers to evidence adoption for central venous catheters post-insertion maintenance in oncology nurses: a multi-center mixed methods study. BMC Nurs 2024;23:581.
[38] Tokumine J, Yorozu T, Moriyama K, *et al*. Outcome-based simulation training for ultrasound-guided central venous catheter placement: clinical impact on preventing mechanical complications. BMC Med Educ 2025;25:131.
[39] Uruthiralingam U, Rea PM. Augmented and virtual reality in anatomical education – a systematic review. Adv Exp Med Biol 2020;1235:89–101.
[40] Lugito NPH, Cucunawangsih C, Suryadinata N, *et al*. Readiness, knowledge, and perception towards artificial intelligence of medical students at Faculty of Medicine, Pelita Harapan University, Indonesia: a cross sectional study. BMC Med Educ 2024;24:1044.
[41] Spencer TR, Bardin-Spencer AJ. Pre- and post-review of a standardized ultrasound-guided central venous catheterization curriculum evaluating procedural skills acquisition and clinician confidence. J Vasc Access 2020;21:440–48.