Ultrasound-Guided Central Venous Catheter Placement in a Hemodialysis Unit: A Prospective Case Series and Pedagogical Experience

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Abstract

Background: Central venous catheter (CVC) placement is a cornerstone procedure in acute hemodialysis units, serving as the primary vascular access for patients with acute kidney injury and for chronic hemodialysis patients without functional peripheral access. Although traditionally performed using anatomical landmarks, this approach is limited by anatomical variations and unrecognized venous thrombosis, leading to preventable complications.

Methods: We conducted a prospective observational case series of 171 short-term CVC placements in adult patients at a single hemodialysis unit in Algiers, Algeria, between September 2010 and April 2011. All procedures were performed using a standardized six-step ultrasound-guided approach. Data were collected on patient demographics, indication for CVC, anatomical site, number of attempts, success rates, complications, changes in planned implantation site, and operator experience, which was categorized as 'junior' (fellow/resident) or 'senior' (attending) based on years of training and prior experience with ultrasound-guided CVC placement.

Results: The internal jugular vein was the most frequently used site (81%), with the right side preferred (58%). First-attempt success rates were 87% for the right internal jugular vein and 80% for the left. Femoral vein access was successful in all cases, with a first-attempt success rate of 82% .Overall success reached 100% by the second attempt. Pre-procedural ultrasound led to a change in the planned implantation site in 56 cases (33%), primarily due to detection of thrombosis or stenosis. Major complications were minimal: arterial puncture occurred in 1.2% and hematoma in 1.8%, with no pneumothorax or deaths. Junior physicians achieved higher success rates and reported greater confidence when using ultrasound compared with historical landmark-based practice.

Conclusion: Ultrasound-guided CVC placement, when performed using a systematic and structured approach, is safe, highly effective, and offers substantial pedagogical value. We advocate its routine use in hemodialysis units and recommend formal integration of ultrasound training into nephrology curricula.

Keywords: Central venous catheter, interventional ultrasonography, hemodialysis, internal jugular vein, femoral vein, vascular access, medical education, case series.

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1. Introduction

Central venous catheter (CVC) placement is among the most frequently performed procedures in intensive care, emergency medicine, and hemodialysis units, with an estimated 5 to 8 million insertions worldwide each year [1, 2]. In our hemodialysis unit, 250–300 CVCs are placed annually, serving as the primary vascular access for patients with acute kidney injury and for chronic hemodialysis patients lacking functional peripheral access [3].

Despite its prevalence, CVC placement carries significant risks, including arterial puncture, hematoma, pneumothorax, hemothorax, and catheter-related bloodstream infections [1, 2, 4]. Traditionally, the landmark technique has been the standard approach, relying on surface anatomy and arterial pulse palpation. However, this method does not account for frequent anatomical variations—reported in up to 30% of patients for the internal jugular vein—nor does it detect pre-existing venous thrombosis, which is common in critically ill and oncologic populations [5-9] .

Over the past two decades, ultrasound guidance has emerged as a transformative tool. Twodimensional ultrasound enables both static pre-procedural assessment of vascular anatomy and dynamic real-time needle visualization during cannulation [1, 10]. Numerous randomized controlled trials and meta-analyses have demonstrated that ultrasound guidance reduces complications, increases first-attempt success, and shortens procedural time, particularly for the internal jugular vein [11-15]. A recent 2024 meta-analysis further confirmed that ultrasoundguided CVC placement significantly reduces the risk of catheter-related infections compared to the landmark technique (RR = 0.68, 95% CI 0.53–0.88).

Accordingly, major professional societies now strongly recommend routine ultrasound use for CVC placement. The 2020 French expert consensus guidelines, using GRADE methodology, recommend ultrasound guidance to reduce mechanical complications for internal jugular access

(GRADE 1), subclavian access (GRADE 2), and femoral access (expert opinion). The European Federation of Societies for Ultrasound in Medicine and Biology and the Association of Anaesthetists of Great Britain and Ireland similarly endorse routine ultrasound use [5, 16].

Despite these guidelines, adoption remains variable across specialties and regions [1, 17-19]. Beyond its clinical benefits, ultrasound guidance offers a distinct pedagogical advantage: it provides real-time visual feedback, which accelerates the learning curve for junior physicians and improves their confidence and competence [1, 10, 19] . As noted in a 2021 review on ultrasound in hemodialysis access, although the learning curve is usually fast, formal training and certification for beginners are strongly recommended .

In this manuscript, we report our experience with ultrasound-guided CVC placement in a hemodialysis unit over an 8-month period. We present a detailed description of our systematic six-step approach, evaluate clinical outcomes (success and complication rates), and specifically highlight the pedagogical implications for training junior physicians in this essential skill.

2. Patients and Methods

2.1. Study Design and Setting

This was a prospective, observational, single-center case series conducted in the Hemodialysis Unit of CHU Hussein -Dey, Algiers, Algeria, between September 2010 and April 2011. The study was approved by the institutional review board, and written informed consent was obtained from all patients or their legal representatives.

2.2. Study Population

We included all adult patients (≥18 years) who underwent short-term, non-tunneled CVC placement during the study period. A total of 171 catheters were placed in 171 patients.

Tunneled catheters and procedures in pediatric patients were excluded.

2.3. Indications for CVC Placement

Indications were classified as follows:

- **Primary vascular access for end-stage renal disease presenting emergently:** 54% (n = 92).
- **Temporary access following arteriovenous fistula complications** (while awaiting creation or maturation of permanent access): 24% (n = 41).
- **Acute kidney injury requiring hemodialysis:** 21% (n = 38).

2.4. Ultrasound Equipment and Technique

A portable ultrasound machine with a high-frequency linear probe (5–15 MHz) was used for all procedures. The probe was covered with a sterile cover, and sterile gel was applied to maintain aseptic technique. All cannulations were performed using the **free-hand single-operator technique**, where the operator holds the probe with the non-dominant hand and advances the needle with the dominant hand. Needle guides were not used [1, 10].

2.5. Anatomical Sites

Site selection was based on pre-procedural ultrasound assessment and clinical judgment. The distribution was:

- Right internal jugular vein: 58% (n = 99)
- Left internal jugular vein: 23% (n = 39)
- Right femoral vein: 12% (n = 21)
- Left femoral vein: 10% (n = 12)

Overall, the internal jugular vein was preferred (81%), consistent with guidelines that favor the right internal jugular vein as the first choice for central venous access [1, 10].

2.6. Patient Positioning

Patients were placed supine for all procedures, except those with pulmonary edema, who were semi-recumbent. For internal jugular vein cannulation, the head was rotated contralaterally to optimize vein exposure and minimize carotid overlap. For femoral vein cannulation, the leg was abducted and externally rotated to maximize vein diameter [1, 10].

2.7. Detailed Description of the Six-Step Ultrasound-Guided Technique

We adopted a structured **six-step approach** to standardize the procedure and facilitate teaching:

1. **Pre-procedural vascular assessment:** The operator performed a thorough ultrasound examination in both short-axis (transverse) and long-axis (longitudinal) views to identify the target vein, adjacent artery, and surrounding structures. This identified the optimal puncture site, vein depth, and anatomical relationships.
2. **Confirmation of venous patency:** The vein was assessed for compressibility under gentle probe pressure. A normal vein collapses completely; a thrombosed vein remains non-compressible. Color Doppler was used to confirm spontaneous phasic flow.
3. **Real-time needle advancement:** The needle was advanced under continuous ultrasound visualization. The operator maintained alignment of the needle with the ultrasound plane using the single-operator technique.
4. **Needle tip visualization:** In short-axis view, the needle appeared as a bright echogenic dot; in long-axis view, as an echogenic line with ring-down artifacts. Both views were used to confirm the tip entering the vein lumen and to avoid posterior wall penetration.
5. **Guidewire confirmation:** After successful venipuncture, the guidewire was advanced. Its position within the vein was confirmed by visualizing two parallel echogenic lines in short-axis and a continuous echogenic line in long-axis view.
6. **Final catheter position confirmation:** After catheter advancement over the guidewire, its position was verified in both views to ensure correct placement within the central venous system.

2.8. The Pedagogical Approach

Ultrasound guidance transformed the training of junior physicians in our unit. We implemented a progressive, structured training program:

- **Phase 1:** Junior physicians learned ultrasound physics, machine operation, and identification of vascular structures on ultrasound.
- **Phase 2:** They practiced pre-procedural assessment and venous patency testing under supervision on simulation models and patients.
- **Phase 3:** They progressed to performing the full six-step procedure under direct supervision, receiving real-time feedback on probe positioning, needle trajectory, and anatomical recognition.

This approach offered several pedagogical advantages:

- **Immediate visual feedback** allowed trainees to learn from errors in real time.
- The **systematic six-step framework** provided a clear, assessable structure for learning.
- **Reduced anxiety** resulted from the ability to visualize target structures and confirm success before proceeding.

- **Accelerated learning curve:** Junior physicians achieved acceptable success rates after shorter supervised training compared with the landmark technique. This is consistent with the literature, which notes that while the learning curve for ultrasound-guided CVC placement is usually fast, formal training and certification for beginners are strongly recommended.

2.9. Data Collection

For each procedure, we recorded: patient age and sex; indication for CVC; anatomical site; number of puncture attempts; success at first and second attempts; complications (arterial puncture, hematoma, pneumothorax); reasons for changing the planned site; and operator experience (senior vs. junior physician).

2.10. Statistical Analysis

Descriptive statistics were used. Continuous variables were expressed as means ± standard deviations or medians with ranges. Categorical variables were presented as frequencies and percentages. Analyses were performed using SPSS version 20.0.

3. Results

3.1. Patient Characteristics

A total of 171 CVCs were placed in 171 patients (mean age 56 ± 15 years, range 18–85). Males comprised 58% of the cohort.

3.2. Success Rates

- **Right internal jugular vein:** First-attempt success rate 87% (86/99). All failures were successfully cannulated on the second attempt, yielding an overall success rate of 100%.
- **Left internal jugular vein:** First-attempt success rate 80% (31/39). Overall success was 100% by the second attempt.
- **Femoral vein access (22% of cases, n=33)** was used when both jugular veins were inaccessible due to thrombosis/stenosis, in hypercoagulable states or patients on anticoagulation, or after failed jugular attempts. Femoral vein cannulation was successful in all cases, with a first-attempt success rate of 82% (27/33) and overall success of 100% by the second attempt.
- **Of the 39 cases where the left internal jugular vein was selected**, the right internal jugular was thrombosed in 70% (27/39), of small caliber in 10% (4/39), and stenosis prevented guidewire progression in 20% (8/39).

3.3. Impact of Ultrasound on Site Selection

Pre-procedural ultrasound led to a change in the planned implantation site in 56 cases (33%).

Reasons included:

- Detection of thrombosis or stenosis at the planned site
- Small vein caliber or abnormal anatomical relationship to the artery
- Identification of a more suitable vein

3.4. Complications

Complications were minimal:

- Arterial puncture: 2 cases (1.2%)
- Hematoma formation: 3 cases (1.8%)
- Pneumothorax, hemothorax, air embolism, or death: 0 cases

3.5. Operator Experience and Pedagogical Outcomes

Compared to a historical landmark-based cohort of 50 procedures from the preceding year in our unit, junior physicians using ultrasound guidance demonstrated improved first-attempt success rates (85% vs. 68%, respectively) and required fewer supervised procedures to reach competency (a mean of 12 supervised procedures vs. 20 with the landmark technique). All junior physicians reported greater confidence and security in their choice of implantation site and in performing the procedure independently. The systematic six-step approach was universally adopted and proved highly effective for both procedural standardization and teaching.

4. Discussion

4.1. Rationale for Ultrasound Guidance

Landmark-based CVC placement relies on the assumption of normal vascular anatomy, which is frequently absent. Anatomical variations in the internal jugular vein—in size, position, and relation to the carotid artery- occur in up to 30% of patients[5, 6, 8] . Additionally, venous thrombosis is common in critically ill patients and those with prior CVCs [5, 20]. In our series, 33% of planned sites were changed after ultrasound revealed previously unrecognized thrombosis, stenosis, or unfavorable anatomy. This demonstrates the critical value of preprocedural ultrasound in preventing failed attempts and avoiding complications.

4.2. Evidence for Ultrasound Guidance

Our findings align with a robust body of evidence. A Cochrane meta-analysis (Brass et al., 2015) of 35 trials (5,108 patients) found that ultrasound for internal jugular vein cannulation reduced total complications from 13.5% to 4.0% (RR 0.29) and increased overall success from 87.6% to 97.6% (RR 1.12) [11, 21]. For the femoral vein, ultrasound increased first-attempt success from 48.7% to 85.0% (RR 1.73)[11] .

A recent 2024 systematic review and meta-analysis by Boulet et al., pooling 12 studies with 5,092 CVC procedures, demonstrated that ultrasound-guided CVC placement significantly reduces catheter-related infections compared with the landmark technique (RR = 0.68, 95% CI 0.53–0.88). This effect was more pronounced in procedures performed by experienced operators (RR = 0.60, 95% CI 0.41–0.89) . Additionally, a 2018 meta-analysis showed that bedside ultrasound is an accurate and feasible diagnostic modality to detect CVC malposition and iatrogenic pneumothorax, with a pooled specificity of 98.9% and sensitivity of 68.2%, and can be performed much faster than chest X-ray (2.83 min vs. 34.7 min) .

Our results find that 87% first-attempt success and a complication rate below 2% are consistent with these benchmarks.

4.3. Guidelines and Recommendations

Major professional societies now endorse ultrasound guidance for CVC placement:

- **American Society of Echocardiography / Society of Cardiovascular Anesthesiologists (2012):** Strong recommendation (Category A, Level 1 evidence) for real-time ultrasound for internal jugular vein [4].
- **American Society of Anesthesiologists (2012):** Recommends static and real-time ultrasound for internal jugular cannulation[22] .
- **European Society of Intensive Care Medicine (2012):** Strong recommendation (Level A) for routine ultrasound use[12] .
- **European Federation of Societies for Ultrasound in Medicine and Biology (2016):** Recommends routine real-time ultrasound (Level 1-A evidence) [5].
- **Association of Anaesthetists of Great Britain and Ireland (2016):** Recommends ultrasound for all central venous access sites [16].
- **Expert consensus on intravascular catheters in the ICU (2020):** Using GRADE methodology, recommends ultrasound guidance to reduce mechanical complications for internal jugular access (GRADE 1), subclavian access (GRADE 2), and femoral access (expert opinion).

Despite these guidelines, adoption remains incomplete, often due to equipment availability, perceived time constraints, or concerns about losing landmark skills [1, 17]. Our experience demonstrates that these barriers can be overcome with institutional commitment and structured training.

4.4. The Pedagogical Value of Ultrasound Guidance

One of the most important yet underemphasized benefits of ultrasound guidance is its pedagogical impact. Our structured six-step approach provided a clear, teachable framework that accelerated learning for junior physicians. This is consistent with other studies showing that ultrasound-guided techniques are easier to learn and result in higher first-attempt success rates even for inexperienced operators [1, 11, 19].

The visual nature of ultrasound allows immediate, real-time feedback—trainees can see the needle entering the vein and learn from deviations instantly. This reduces anxiety, builds confidence, and shortens the learning curve. We also observed that trainees felt more secure in their choice of implantation site, as they could confirm venous patency and caliber before puncture. This psychological benefit is particularly valuable in the acute, high-stress hemodialysis setting.

Our experience supports recent recommendations that formal training and certification in ultrasound-guided CVC placement should be integrated into nephrology and critical care curricula. As noted by Forneris et al. (2021), although the learning curve for CVC ultrasound placement is usually fast, formal training and certification for beginners are strongly recommended .

4.5. The Importance of Combining Landmark and Ultrasound Skills

While ultrasound guidance is now our standard, we emphasize that knowledge of landmark techniques remains essential. Ultrasound equipment may not always be available—particularly in emergencies, resource-limited settings, or during equipment failure. Physicians must be competent in both approaches to ensure patient safety in all circumstances [1, 16, 23] Furthermore, in settings where a single-operator real-time technique is not feasible (e.g., due to lack of equipment or assistance), a "two-operator" approach—where one operator performs the scan and the other cannulates- or a "pre-scan only" technique (marking the optimal puncture site) can serve as a compromise when real-time guidance is not possible. However, these alternatives remain superior to pure landmark-based placement. Therefore, we advocate dual training, with ultrasound as the primary method and landmarks as a backup.

4.6. Limitations

This study has several limitations:

- **Single-center, observational design** without a concurrent landmark-based control group, limiting direct comparative conclusions.
- **Relatively small sample size** (n = 171) and older data (2010–2011); however, the principles and findings remain applicable and are supported by more recent metaanalyses .
- **No data on long-term outcomes** such as catheter-related bloodstream infections or catheter durability.
- **Exclusion of tunneled catheters**, which may have different risk profiles.
- **Patient perspectives** were not systematically collected, as this was a retrospective analysis of aggregated procedural data.

Despite these limitations, our findings provide real-world evidence supporting the safety, efficacy, and pedagogical value of ultrasound-guided CVC placement in a hemodialysis setting.

5. Conclusion

This prospective case series of 171 ultrasound-guided CVC placements in a hemodialysis unit demonstrates high success rates (87% first-attempt for right internal jugular vein), low complication rates (no pneumothorax or deaths), and a substantial clinical benefit from preprocedural ultrasound assessment, which changed the planned site in one-third of cases.

Beyond clinical outcomes, ultrasound guidance offers profound pedagogical advantages. Our structured six-step approach accelerated the learning curve for junior physicians, improved their confidence, and provided a clear framework for training and assessment.

We advocate for routine use of ultrasound guidance for all CVC placements in hemodialysis units, supported by formal training programs that integrate both ultrasound and landmark techniques. The adoption of systematic, ultrasound-based approaches is a key step toward improving patient safety and enhancing medical education in vascular access.

6. Consent

Written informed consent was obtained from all patients or their legal representatives for participation in this study and for publication of the aggregated data.

7. Conflict of Interest

The authors declare no conflicts of interest.

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