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Research Article

Radiological evaluation of central venous catheter tip malposition

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ABSTRACT

Background: Malposition of central venous catheters is a potentially severe but often preventable complication. This study aimed to assess the radiological distribution of central venous catheter tip positions and to discuss malposition mechanisms based on anatomical and radiographic literature.

Methods: A retrospective analysis of 374 patients who underwent intraoperative central venous catheter insertion between January 2022 and December 2023 was conducted. Radiographs were evaluated using a carina-based classification system: Zones A–C (normal) and Zone D (malposition). Data were analyzed retrospectively.

Results: The right internal jugular vein was the most commonly preferred access site, used in 80.0% of cases. Zone A: 52.3%, Zone B: 18.5%, Zone C: 17.8%, Zone D (malposition): 11.4%. There was no statistically significant association between catheter size and malposition ($p>0.05$).

Conclusion: Utilizing the carina as a reference point during post-procedural imaging is essential for accurate catheter tip localization. Adjunctive modalities—including intracavitary ECG, ultrasound, and radiography—contribute to complication reduction and procedural safety.

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1. Introduction

Central venous catheters (CVC) are fundamental to modern intensive and perioperative care. Despite the widespread use of ultrasound guidance, catheter malposition remains a frequent and clinically relevant complication, with reported rates between 5% and 15%. Accurate tip positioning is essential to prevent serious outcomes such as vascular erosion, thrombosis, retrograde cerebral infusion, or cardiac tamponade [1,2].

Malposition often reflects anatomical variability or physiological factors—such as thoracic vein angulation, patient positioning, or respiratory motion—rather than procedural error. Left-sided insertions, particularly via the internal jugular (IJV) or subclavian veins (SV), carry a higher risk due to the longer, angled course of the left brachiocephalic vein. Additionally, tip migration may occur post-procedure due to body movement or intrathoracic pressure changes [1,3].

Raptis et al. [3] proposed a radiographic classification based on tip position relative to the midline, which aids in identifying malposition. Although ultrasound is integral to placement, chest radiography remains the standard for verifying position and detecting complications. This study evaluates catheter tip positions using the carina as a radiological landmark and explores contributing factors to malposition through anatomical and clinical analysis.

2. Materials and Methods

This retrospective single-center observational study was conducted from January 2022 to December 2023 at

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a tertiary academic hospital. Postoperative chest radiographs and patients' archival data were reviewed, and tip positions, as illustrated in Fig. 1, were classified as follows:

- Zone A: Optimal position (1–2 cm above/below carina),
- Zone B: Superior deviation from the carina,
- Zone C: Caudal deviation,
- Zone D: Malposition (e.g., carotid artery, azygos vein, thoracic duct).

It was determined that Thoracic CT was evaluated in 15 of 325 patients, based on abnormal chest X-ray or clinical suspicion of malposition.

Patients without post-procedural chest imaging, inaccessible data, or femoral catheter placement were excluded. Demographic data, insertion site, catheter type, and radiological findings were recorded. SPSS 23.0 was used. Chi-squares test was applied ($p<0.05$ significant).

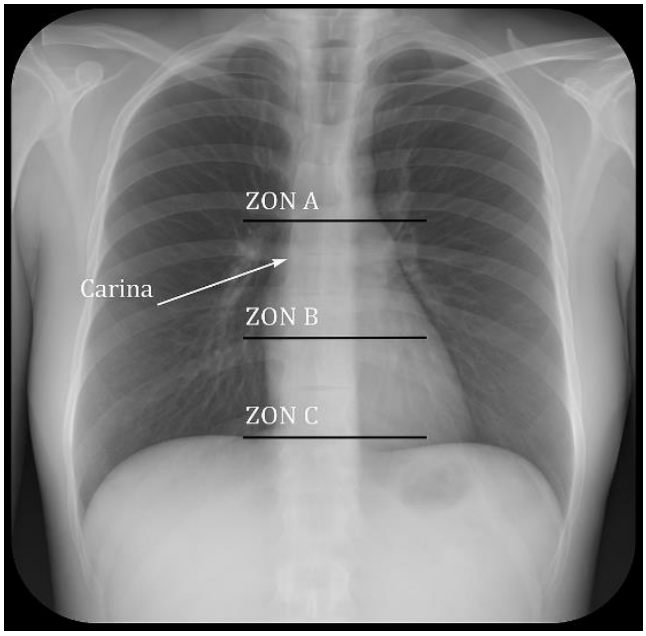

Fig. 1. Zone classification of CVC tip positions on chest radiograph.

3. Results

A total of 374 patients were initially considered for inclusion in the study. However, 49 patients (13.1%) were excluded due to missing or non-diagnostic imaging, inaccessible data, or femoral catheter placement, resulting in a final cohort of 325 patients. The mean age of 59.4 ± 16.5 years; 40.61% (n=132) of the cohort were female and 59.38% (n=193) were male. Among the 325 central venous catheters analysed, the majority were inserted via the right internal jugular vein (269 cases, 80.0%), followed by the right subclavian vein (45 cases, 13.8%), the left internal jugular vein (13 cases, 4.0%), the left subclavian vein (7 cases, 2.2%). There was no statistically significant difference in malposition rates between thoracic vascular access routes, such as jugular and subclavian catheterizations (p=0.342).

Radiological evaluation of catheter tip location, as illustrated in Fig. 2(a–b), revealed the following distribution across predefined zones: Zone A in 52.3% (n=170), Zone B in 18.5% (n=60), Zone C in 17.8% (n=58), and Zone D in 11.4% (n=37). The overall malposition rate was 11.3%, consistent with the 5–15% range reported in prior studies.

All central venous catheterizations were performed using the Seldinger technique. In 34% of the cases, catheter insertion was guided by real-time ultrasound, whereas in 66%, anatomical landmark guidance was utilized. All procedures were conducted by an anesthesiology specialist or residents with a minimum of 1 year of supervised clinical training. The intracavitary electrocardiographic (ECG) confirmation technique was not employed for tip verification. Additionally, statistical comparison revealed no significant difference in the rate of catheter malposition between ultrasound-guided and landmark-guided insertion (p=0.217).

Among the catheters classified as Zone D, 29 extended caudally into the inferior vena cava (IVC); 3 were malpositions into the carotid artery, and 5 had traversed into the contralateral IJV. These findings emphasize the role of over-insertion and right-sided access in catheter malposition.

No significant difference in malposition rates was observed among the catheter types—7F 20 cm: 10.0% (13/130), 7F 16 cm: 9.4% (9/96), and 8F 20 cm: 17.1% (12/70)—with χ^2=2.91 and p=0.234. Collectively, these three catheter types accounted for 91.9% (34/37) of all malposition cases. Similarly, there was no statistically significant association between malposition and either patient sex, catheter entry site, body length, patient height, or body mass index.

4. Discussion

The malposition rate observed in this study is consistent with the literature, which reports rates ranging from 5% to 15%, depending on access site, insertion technique, and imaging confirmation protocols. The most frequent malposition pattern was caudal advancement of the catheter into the IVC. This was likely caused by excessive insertion length or undetected resistance during guidewire advancement, particularly in right-sided access. Similar findings have been reported by Yilmazlar et al. [4], emphasizing that right atrial or IVC positioning remains a persistent issue despite ultrasound guidance.

Although less common, arterial malposition—such as inadvertent cannulation of the carotid artery—remains a high-risk complication that requires immediate recognition and prompt management. If arterial puncture is suspected, especially during right IJV access, pressure transduction, pulsatile blood flow, or bright red blood return should raise concern. In cases where a large-bore catheter has already been inserted into the carotid artery, blind removal is contraindicated due to the risk of catastrophic hemorrhage, stroke, or pseudoaneurysm formation. Current guidelines and expert consensus rec-

ommend urgent consultation with vascular or cardiothoracic surgery when such an event occurs. Surgical intervention is generally preferred for definitive repair, especially in hemodynamically stable patients, and should ideally take place in a controlled operative setting. Endovascular repair—such as covered stent placement—may be considered in selected cases or high-risk surgical candidates, particularly when performed in hybrid operating suites with imaging guidance. Ultrasound-guided insertion and real-time verification methods (e.g., dynamic needle tip positioning, compressibility tests) significantly reduce the likelihood of arterial injury. Still, awareness and readiness for immediate surgical involvement remain essential in managing this life-threatening complication [4–7].

In the present study, cases of carotid artery cannulation were promptly evaluated and managed by cardiovascular surgery teams, and catheter removal was performed under surgical supervision to minimize the risk of complications.

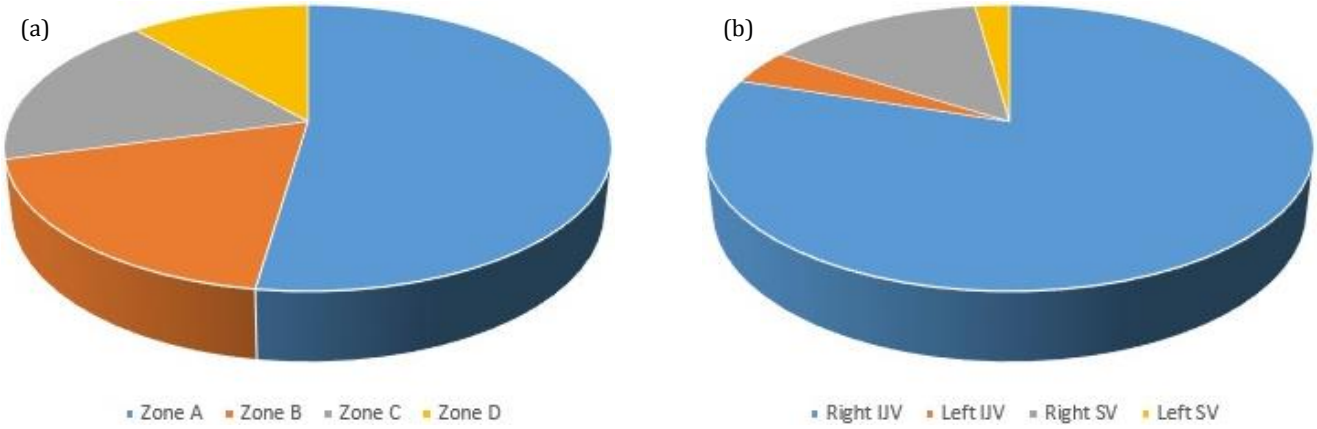

Fig. 2. (a) Zone-based evaluation of CVC tip positions in jugular and subclavian insertions (Zone A 52.3%, Zone B 18.5%, Zone C 17.8%, Zone D 11.4%);
(b)Vascular access site distribution of all thoracic central venous catheters (Right IJV 80% (269), Left IJV 4.0% (13), Right SV 13.8% (45), Left SV 2.2% (7)).

Previous research has shown that catheter malpositions may appear deceptively appropriate on anterior-posterior chest radiographs, especially in cases where the catheter loops or deviates into mediastinal tributaries. This underscores the potential limitations of standard radiography and supports the use of additional imaging techniques when clinically indicated [8]. Although chest radiography remains the first-line tool for verifying tip location, its two-dimensional limitations can obscure atypical courses, especially in anatomically complex cases. In such scenarios, adjunctive imaging modalities—such as contrast-enhanced studies, computed tomography, or bedside ultrasound—play a crucial role in ensuring accurate assessment. The carina has emerged as a consistently reliable radiological landmark for tip evaluation, offering improved localization accuracy over vertebral body references. Furthermore, multimodal approaches have been advocated, particularly in the presence of anatomical variants or suspected malposition into atypical sites such as the azygos vein, internal mammary vein, or the pericardiophrenic recess [8,9]. Supporting this, Nifong and McDevitt [10] demonstrated that incorporating computed tomography verification can significantly reduce false-negative interpretations associated with standard radiographs in complex clinical situations.

Preventive strategies should include standardized use of real-time ultrasound guidance, enhanced operator training, and deliberate attention to anatomical landmarks during insertion. Recent studies have also demonstrated the effectiveness of intracavitary electrocardiography (IC-ECG) using P-wave amplitude monitoring to identify the cavoatrial junction in real time. As the catheter tip approaches the SVC–RA junction, a rising P-wave amplitude followed by biphasic or negative morphology indicates, respectively, optimal positioning or over-insertion. According to Schummer et al. [11], IC-ECG offers superior tip localization and reduces malposition risk compared to traditional landmark-based techniques.

Furthermore, no statistically significant correlation was identified between catheter size and malposition; however, a subtle trend toward higher malposition frequency was observed in larger size catheters. This may be due to increased stiffness or excessive advancement. Gibson and Bodenham [1] have suggested that catheter diameter and rigidity may influence directional control, especially in angled venous segments. Similarly, while malposition was slightly more common among male patients, this did not reach statistical significance. Differences in thoracic anatomy and vascular angles between the sexes may affect catheter direction and warrant further investigation.

Overall, the findings underscore the need for multimodal verification techniques and tailored insertion strategies to minimize the risk of malposition and enhance procedural safety. Peres has highlighted that combining methods such as IC-ECG and radiographic imaging provides a higher degree of confidence in confirming correct tip location [1,12]. Furthermore, as emphasized by Kornbau et al. [6], malpositioned catheters should not be considered minor technical deviations, as they carry increased risk of thrombosis, cardiac tamponade, and therapeutic failure.

4.1. Limitations

This study has several limitations. Its retrospective, single-center design may limit the generalizability of the findings. In preoperative procedures, data regarding the use of ultrasound guidance, reliance on anatomical landmarks, or the occurrence of possible carotid artery puncture without catheter insertion were not available. Furthermore, the relationship between patient thoracic diameter and the length of the catheter selected could not be systematically assessed.

5. Conclusions

This study underscores the ongoing relevance of carina-referenced imaging in identifying CVC malposition. The observed malposition rate highlights that technical proficiency alone is insufficient without reliable post-placement verification. Notably, the most common malposition pattern observed involved caudal migration of the catheter into the IVC, highlighting the need for increased vigilance, particularly in right-sided insertions. The findings support the routine use of carina-based chest radiography, ideally complemented by adjunctive modalities such as intracavitary ECG and ultrasound, to improve tip localization and minimize the risk of complications. Beyond clinical practice, the integration of these verification strategies into procedural training programs may contribute to reducing malposition rates. Accurate catheter tip positioning is not merely a procedural detail, but a determinant of patient safety, infection risk, and long-term vascular outcomes. Standardizing these verification protocols across surgical and intensive care settings is essential for enhancing procedural safety and improving overall patient care.

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Conflict of Interest
The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

Data Availability
The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate
This study was approved by the ethics committee of Antalya Research Training Hospital (approval number: 1/10; date: 12.01.2023). Written informed consent was obtained from the participants. All methods were performed in accordance with relevant guidelines and regulations.

Author Contributions
Meltem Ceylan Delice: *conceptualization, data curation, investigation, formal analysis, writing – original draft, visualization.*
Nilgun Kavrut Ozturk: *methodology, validation, supervision, writing – review & editing, project administration.*

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