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Malposition in central venous catheterization and the use of ultrasonography: Is the presence of turbulent flow an alternative to chest radiography?

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ABSTRACT

Aim: To evaluate the rate of malposition in central venous catheterization (CVC) procedures performed by expert physicians in our intensive care units using ultrasound (US). Additionally, we investigated whether the assessment of turbulent flow via USG could eliminate the need for chest radiography and whether USG could serve as a viable alternative to radiographic confirmation.

Methods: This prospective observational study was conducted between June 2024 and January 2025 in the intensive care units of Mardin Training and Research Hospital. A total of 162 adult patients who underwent CVC placement were included. Patients were divided into three groups: (1) Conventional CVC placement (n = 53), (2) US-guided CVC placement (n = 51), and (3) US-guided CVC placement with turbulent flow assessment (n = 58). The presence of turbulent flow in the right atrium was evaluated using a rapid injection of saline. The malposition rate and complications were compared among groups.

Results: The malposition rate was significantly lower in the US + Turbulent Flow Group (1.5%, n = 1/58) compared to the Conventional CVC Group (7.5%, n = 4/53) and the USG-Guided Group (4.3%, n = 2/51) (p = 0.022). Additionally, no complications were observed in the US-Guided and US + Turbulent Flow Groups, whereas the complication rate in the Conventional CVC Group was 6.67% (n = 4/53) (p = 0.010). Regression analysis showed that turbulent flow detection was significantly associated with correct catheter positioning (p = 0.018, Beta = 2.361).

Conclusion: Our findings suggest that US, particularly with turbulent flow assessment, is a highly effective method for confirming CVC placement and may reduce the need for routine chest radiography. The use of US-guided techniques significantly lowers the malposition rate and enhances patient safety. Incorporating turbulent flow assessment into clinical protocols may improve the accuracy of catheter placement and minimize complications.

Keywords: Central venous catheterization, malposition, ultrasonography, turbulent flow, direct radiography.

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1. Introduction

Central venous catheterization (CVC) is a widely used invasive procedure in intensive care units for various indications, including hemodynamic monitoring, long-term intravenous therapy, and central venous pressure measurement [1]. However, catheter malposition is a significant complication in CVC procedures, with reported incidence rates ranging from 3.6% to 14% in previous studies [2, 3]. Malposition can lead to hemodynamic instability, complications in drug and fluid infusion, and an increased risk of mechanical thrombosis, posing a considerable threat to patient safety [4].

Traditionally, chest radiography is the standard method for assessing the correct placement of CVCs. However, radiography can result in delayed diagnosis, radiation exposure, and increased workload in the intensive care setting [5]. Ultrasonography (US) has become increasingly utilized for anatomic guidance during CVC placement and is emerging as an alternative method for confirming catheter positioning [6]. US may enhance catheter placement accuracy and facilitate early detection of malposition, thereby reducing the risk of complications [7].

Furthermore, US can be used to assess the presence of turbulent flow in the central venous system. Turbulent flow is a potential indicator of improper catheter placement and could serve as an alternative method to reduce reliance on chest radiography [8]. However, there is no clear consensus in the literature regarding whether US can fully replace chest radiography in confirming CVC placement.

This study aims to evaluate the rate of malposition in CVC procedures performed by expert physicians in our intensive care units using US. Additionally, we investigated whether the assessment of turbulent flow via US could eliminate the need for chest radiography and whether US could serve as a viable alternative to radiographic confirmation.

2. Materials and methods

This prospective observational study was approved by the Mardin Artuklu University Ethics Committee on June 11, 2024 (Decision No: 2024/6-2). The study was conducted in the adult intensive care units and operating rooms of Mardin Training and Research Hospital between June 20, 2024, and January 20, 2025.

Adult patients (≥18 years old) who underwent central venous catheterization (CVC) were included in the study. Exclusion criteria were patients under 18 years of age, pregnant women, those with congenital heart disease or severe cardiopulmonary dysfunction, patients with coagulopathy in whom CVC placement was contraindicated, and cases where technical failure or patient-related complications occurred during the procedure.

The included patients were divided into three groups based on the CVC insertion method:

- The first group consisted of patients who underwent CVC placement without ultrasound guidance (Conventional = P-A Chest X-ray) (Figure 1.).
- The second group included patients who underwent CVC placement under ultrasound guidance.
- The third group consisted of patients who underwent CVC placement followed by an ultrasound evaluation to assess the presence of turbulent flow at the junction of the inferior vena cava (IVC) and the right atrium, indicating correct catheter positioning.

While ultrasound was not used in femoral and subclavian vein catheterizations, some patients who underwent jugular vein catheterization had the procedure performed under ultrasound guidance, whereas others had it performed without ultrasound assistance.

During central venous catheterization, 7Fr 16 cm triple-lumen central venous catheters and 12Fr 20 cm double-lumen hemodialysis catheters were used. To confirm the correct placement of the catheter, a chest radiograph was obtained for all patients to verify the catheter tip position.

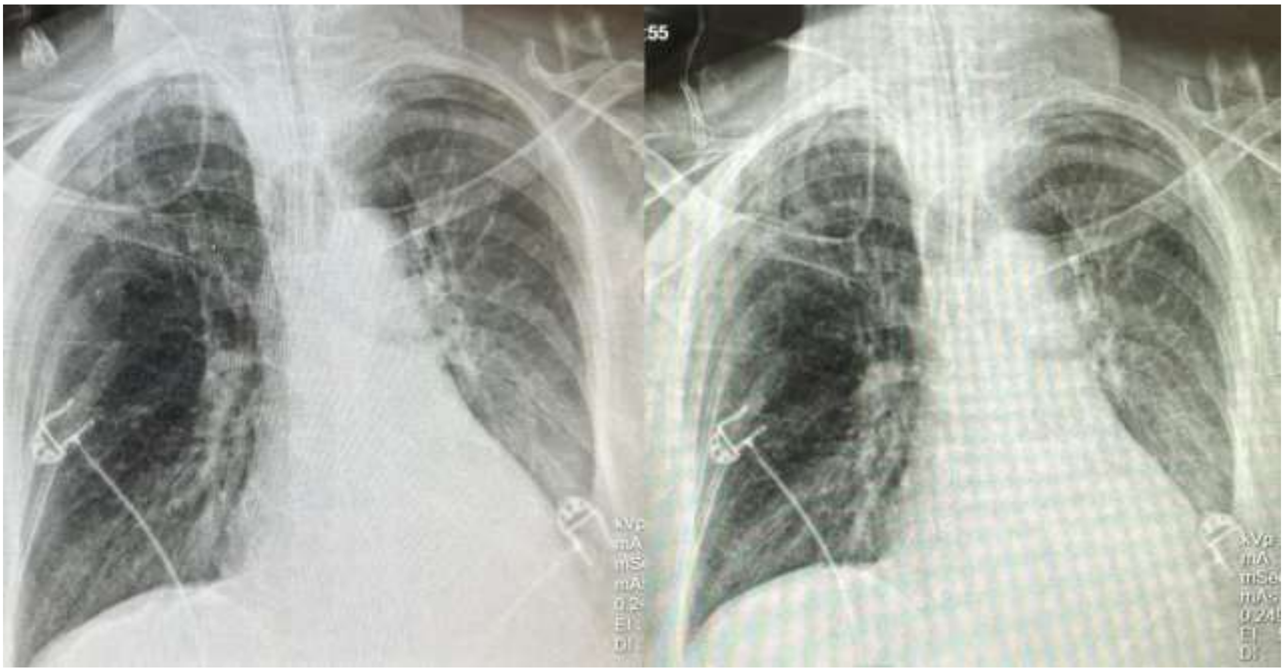

Figure 1. Chest X-rays demonstrating malpositioned central venous catheters.

Figure 2. Ultrasound evaluation of turbulent flow at the IVC–right atrium junction after CVC placement.

2.1. Ultrasound protocol: Ultrasound (US) evaluation was performed immediately after the completion of the CVC placement procedure while the patient was in a supine position with the head elevated at 30°. A GE Logiq A5 ultrasound device was used with a curvilinear (convex) probe (3–5 MHz frequency) for imaging. The probe was positioned over the subxiphoid window, allowing visualization of the right atrium. A rapid injection of 10 mL of sterile normal saline (0.9% NaCl) through any port of the catheter was performed. The presence of turbulent flow, appearing as hyperechoic microbubbles in the right atrium, was recorded as an indication of correct catheter positioning (Figure 2.).

2.2. Outcome measures: The primary outcome measure of this study was the rate of catheter malposition, which was defined as any incorrect positioning of the catheter tip outside the superior vena cava or in an unintended location, such as the subclavian vein, arterial system, mediastinum, or contralateral jugular vein. Malposition was confirmed using chest radiography and ultrasonography when applicable. The secondary outcomes included the detection rate of turbulent flow in the right atrium via ultrasonography, assessed through the rapid injection of saline, and the incidence of procedure-related complications, such as hematoma, pneumothorax, and arterial puncture. Additionally, the study aimed to evaluate the association between the presences of turbulent flow and correct catheter positioning and to compare the malposition and complication rates among different catheterization techniques, including conventional CVC placement, US-guided placement, and US-guided placement with turbulent flow assessment.

A power analysis was conducted to determine the appropriate sample size for detecting a statistically significant difference in malposition rates among the study groups. Based on previous studies, the expected malposition rate in the conventional CVC placement group was estimated at 8%, while the US-guided group was expected to have a lower malposition rate of approximately 3%. To detect this difference with a power of 80% ($1-\beta = 0.80$) and a two-tailed alpha level of 0.05, a minimum sample size of 156 patients (52 per group) was required. To account for potential dropouts or missing data, the final sample size was increased to 162 patients.

2.3. Statistical analysis: All statistical analyses were conducted using SPSS (Statistical Package for the Social Sciences) version 27. Continuous variables were expressed as mean ± standard deviation (SD), while categorical variables were presented as frequencies and percentages. The normality of continuous variables was assessed using the Kolmogorov-Smirnov test. This test was chosen because it is more suitable for larger sample sizes ($n > 50$), as it provides a more stable approximation of the distribution compared to the Shapiro-Wilk test, which is more appropriate for smaller sample sizes. Since our study included 162 patients, the Kolmogorov-Smirnov test was preferred to ensure reliable normality assessment of the data distribution. For comparisons among the three groups, one-way ANOVA was used for continuous variables, while Chi-square tests were applied for categorical variables. Post-hoc analyses were performed when necessary to determine pairwise differences. To evaluate the relationships between USG usage, turbulent flow observation, malposition, and complications, Chi-square tests were used, and correlation analyses were conducted with either Pearson or Spearman correlation tests, depending on data normality. A multivariate logistic regression analysis was performed to identify the independent predictors of correct catheter positioning. The model included variables such as age, height, weight, presence of turbulent flow, use of the Seldinger technique, catheter type, and insertion site. Results were presented with Beta coefficients, standard errors, and p-values. A p-value < 0.05 was considered statistically significant for all analyses.

3. Results

Socio-demographic and clinical characteristics of the included patients were shown in table 1. The mean age of the study population was 68.99 ± 18.32 years, with a majority being male (58.6%). The most common catheter insertion site was the right jugular vein (44.4%), followed by the right femoral vein

(22.2%). Ultrasound (US) was used in 42.6% of cases, and turbulent flow was detected in 40.7% of patients upon US evaluation (Table 1).

Table 1. Socio-demographic and clinical characteristics of the included patients.

Parameters	**Patients (N=162)** (Mean ± SD) or N (%)
Age (Year)	68.99 ± 18.32
Height (cm)	167.50 ± 7.52
Weight (kg)	78.83 ± 15.74
Gender	
Male	95 (58.6%)
Female	67 (41.4%)
US usage rate	69 (42.6%)
Turbulent flow observed in US-ECHO	66 (40.7%)
Use of Seldinger	94 (58.0%)
Catheter insertion site	
Right jugular	72 (44.4%)
Right subclavian	34 (21.0%)
Right femoral	36 (22.2%)
Left jugular	5 (3.1%)
Left subclavian	2 (1.2%)
Left femoral	13 (8.0%)
Inserted catheter type	
16 cm-7F	132 (81.5%)
Dialysis catheter	30 (18.5%)
Resistance during catheter insertion	6 (3.7%)
Malposition condition	10 (6.17%)
Right subclavian	4 (2.5%)
Arterial cannulation	3 (1.8%)
Mediastinum	1 (0.6%)
Right jugular	1 (0.6%)
Left jugular	1 (0.6%)
Complication	4 (2.5%)
Hematoma	3 (1.8%)
Pneumothorax	1 (0.6%)

Comparison of patient characteristics and complications among different central venous catheterization (CVC) techniques was shown in table 2. The patients were divided into three groups: 53 patients in the Conventional CVC placement group, 51 patients in the US-guided CVC placement group, and 58 patients in the US-guided CVC placement with turbulent flow assessment group. The most frequently used insertion site was the right internal jugular vein, with a significantly higher proportion of right jugular vein catheterizations in the US + Turbulent Flow Group (50.0%) compared to the Conventional CVC Group (38.0%) and the US-Guided Group (45.1%) (p = 0.041). Regression analysis confirmed that right jugular vein catheterization was significantly associated with correct catheter positioning (p = 0.041, Beta = 2.039). The type of catheter used was also distributed differently among groups, with a higher proportion of 7F triple-lumen catheters in the US-guided groups compared to the Conventional group (p = 0.032). The malposition rate was significantly lower in the US + Turbulent Flow Group (1.5%, 1/58) compared to the Conventional CVC Group (7.5%, 4/53) and the US-Guided Group (4.3%, 2/51) (p = 0.022). The overall complication rate was 6.67% (4/53) in the Conventional CVC Group, while no complications were recorded in the US-Guided and US + Turbulent Flow Groups (p = 0.010) (Table 2).

Relationship between variables based on hypothesis tests was shown in table 3. A statistically significant association was found between US usage and the presence of turbulent flow (p = 0.001), while no significant relationship was observed between malposition and complications ($p > 0.05$) (Table 3).

Regression analysis for determining the effect of parameters on correct positioning was shown in table 4. The presence of turbulent flow in US-ECHO was significantly associated with correct catheter positioning (p = 0.018, Beta = 2.361). Additionally, right jugular vein catheter insertion was significantly associated with proper catheter placement (p = 0.041, Beta = 2.039). However, other parameters such as age, height, weight, Seldinger technique usage, and catheter type did not show significant effects on catheter placement accuracy ($p > 0.05$ for all) (Table 4).

Table 2. Comparison of patient characteristics and complications among different central venous catheterization (CVC) techniques.

Parameters	Conventional CVC Group (n=53)	US-Guided CVC Group (n=51)	US + Turbulent Flow Group (n=58)	*P value*
Age (Years)	69.8 ± 17.5	68.0 ± 19.5	66.5 ± 21.7	*0.807*
Height (cm)	166.7 ± 7.5	168.6 ± 7.4	168.3 ± 7.4	*0.198*
Weight (kg)	78.7 ± 15.7	79.0 ± 15.9	79.5 ± 15.6	*0.119*
Gender (M/F)	29/24 (54.8%)	32/19 (63.8%)	36/22 (62.1%)	*0.120*
Catheter insertion site				*0.041*
- Right internal jugular vein	38.0% (20/53)	45.1% (23/51)	50.0% (29/58)	
- Right subclavian vein	21.5% (11/53)	19.6% (10/51)	20.7% (12/58)	
- Right femoral vein	23.0% (12/53)	17.6% (9/51)	15.5% (9/58)	
- Left internal jugular vein	3.7% (2/53)	3.9% (2/51)	1.7% (1/58)	
- Left subclavian vein	1.9% (1/53)	1.9% (1/51)	1.7% (1/58)	
- Left femoral vein	11.9% (6/53)	11.7% (6/51)	10.3% (6/58)	
Inserted catheter type				*0.032*
- 7F triple-lumen catheter	76.0% (40/53)	82.3% (42/51)	86.2% (50/58)	
- Dialysis catheter	24.0% (13/53)	17.7% (9/51)	13.8% (8/58)	
Malposition state	4 (7.5%)	2 (4.3%)	1 (1.5%)	*0.022*
Complication	4 (6.67%)	0 (0.0%)	0 (0.0%)	*0.010*

Table 3. Relationship between variables based on hypothesis tests.

Test	Chi-Square Value	*p Value*
USG Usage - Malposition	7.235	*0.512*
USG Usage - Turbulent Flow	52.416	***0.001***
Malposition - Turbulent Flow	2.925	*0.087*
Malposition - Complication	0.275	*1.000*
Gender - Malposition	9.361	*0.313*
Gender - Complication	0.552	*0.759*

Table 4. Regression analysis for determining the effect of parameters on correct positioning.

Parameters	B	St. Error	Beta	*P-value*
Age (Year)	0.008	0.026	0.314	*0.753*
Height (cm)	0.066	0.056	1.172	*0.241*
Weight	-0.041	0.026	-1.62	*0.105*
Turbulent flow observed in USG-ECHO	2.852	1.208	2.361	***0.018***
Use of Seldinger	-0.722	1.045	-0.691	*0.490*
Type of Inserted Catheter (16 cm-7F)	0.756	1.27	0.595	*0.552*
Catheter Insertion Site (Right Jugular)	1.178	0.578	2.039	***0.041***

4. Discussion

In this study, we investigated the incidence of malposition in CVC and evaluated whether US assessment of turbulent flow could serve as an alternative to chest radiography for confirming catheter positioning. Our findings suggest that US, particularly with the detection of turbulent flow in the right atrium, may significantly reduce the need for post-procedural chest radiography while maintaining high accuracy in confirming proper catheter placement. Our study revealed that the overall malposition rate was significantly lower in the US + Turbulent flow group (1.5%) compared to the conventional CVC Group (7.5%) and the US-Guided group (4.3%). This finding suggests that incorporating turbulent flow assessment further enhances the accuracy of catheter placement beyond standard US guidance alone. Additionally, complication rates were entirely absent in the US-Guided and US + Turbulent flow groups, whereas the conventional CVC group had a complication rate of 6.67%. These results highlight the potential safety benefits of real-time US guidance in CVC procedures. Furthermore, our regression analysis demonstrated that the presence of turbulent flow in US-ECHO was significantly associated with correct catheter positioning, supporting the idea that turbulent flow could be a reliable indicator of proper catheter placement. In addition, right jugular vein catheter insertion was significantly associated with correct positioning, suggesting that anatomical factors play a role in malposition risk.

CVC is widely used in various clinical settings, including intensive care units, cardiovascular surgery, oncology, anesthesia, and emergency medicine, as a reliable and effective invasive procedure [1]. It is particularly critical for the management of hemodynamically unstable patients, facilitating fluid therapy, administration of parenteral nutrition, inotropic and vasoactive drugs, central venous pressure monitoring, pulmonary artery catheterization, and transvenous pacemaker placement. However, CVC placement is associated with several complications, including mechanical, infectious, and thrombotic risks, which vary depending on the patient's primary pathology and the catheter's intended use [2, 3].

The appropriate selection of the insertion site is crucial for minimizing complications. According to Ruesch et al., after determining the need for CVC, the physician should select the technique with which they have the most experience [9]. Pikwer et al. conducted a study on 1,619 cases, reporting that 52% of catheterization procedures were performed by experienced physicians. The most commonly used insertion site was the internal jugular vein (IJV) in 1,127 cases (1,023 right IJV, 104 left IJV), followed by the subclavian vein (SCV) in 327 cases (287 right SCV, 37 left SCV) [10]. Schummer et al. analyzed 1,794 catheterization cases and reported that 437 patients (24.4%) underwent right IJV catheterization, while other access sites included the left IJV (16.3%), left SCV (9.9%), right SCV (9.0%), femoral veins (1.6%), and external veins (1.1%) [11]. In our study, the most frequently used insertion site was also the right IJV (44.4%), followed by the right femoral vein (22.2%) and the right SCV (21.0%). The preference for the right IJV aligns with previous literature, emphasizing its anatomical advantages, ease of access, and lower complication rates compared to other sites. Additionally, we observed that the right jugular vein catheterization was significantly associated with correct catheter positioning. These findings reinforce the importance of insertion site selection and highlight that right IJV catheterization remains the preferred approach due to its lower malposition risk.

Malposition is one of the most frequently encountered complications following CVC placement. A meta-analysis assessing malposition rates reported that the incidence of malposition during IJV catheterization was 5.3%, whereas it was higher at 9.3% in SCV catheterization [12]. The optimal placement for the catheter tip is 3–5 cm proximal to the cavo-atrial junction within the superior vena cava. However, some studies have demonstrated that the catheter tip may migrate to alternative locations such as the contralateral IJV, innominate vein, contralateral SCV, internal mammary vein, azygos vein, superior intercostal veins, or the right atrium [13-15]. A prospective study conducted by Pikwer et al. on 1,619 patients found that the overall malposition rate detected radiologically was 3.3%. Notably, malposition was observed in 10.5% of right-sided cannulations and only 0.5% of left-sided cannulations. The malposition rate was 5.2% for IJV and significantly higher at 11.8% for SCV cannulations [10]. Similarly, Schummer et al. reported a malposition rate of 6.7% in a prospective study involving 1,794 intensive care patients. They found that left-sided percutaneous CVC insertions were more prone to malposition compared to right-sided insertions. The types of malposition identified included lateral vessel wall compression, innominate vein migration, and aberrant passage into the right atrium [11]. In our study, the malposition rate was significantly lower in the US + Turbulent flow group (1.5%) compared to the Conventional CVC Group (7.5%) and the US-Guided group (4.3%). This finding suggests that the integration of USG with turbulent flow assessment enhances the accuracy of catheter placement and reduces malposition risk. Additionally, we found that right-sided insertions were associated with fewer malposition events, further supporting previous literature emphasizing the anatomical advantages of right IJV catheterization over SCV access.

During catheter insertion, resistance to guidewire advancement may serve as an early warning sign of malposition. Additionally, malposition should be suspected in cases of catheter dysfunction, inadequate blood aspiration, impaired infusion flow, or persistent chest and back pain. In our study, 6 patients (3.7%) experienced resistance during catheter insertion, and all of these cases were confirmed as malpositions via imaging. In such scenarios, the catheter should not be used until its position is verified via imaging modalities such as chest radiography or ultrasonography [5, 16]. Our results indicate that US-guided evaluation of turbulent flow can provide a rapid and accurate alternative to confirm catheter positioning, reducing the need for routine post-procedural radiography.

In the literature, it was reported that the malposition rate varies significantly depending on the catheter insertion site, with higher rates observed in the subclavian and femoral veins compared to the internal jugular vein [6]. In our study, the malposition rate was highest in the right subclavian vein (9.1% in the Conventional Group, 10.0% in the US-Guided Group) and right femoral vein (8.3% overall), while no malposition was observed in the right jugular vein in the US-Guided and US + Turbulent Flow Groups. Pikwer et al. demonstrated that left-sided catheterizations have a lower risk of malposition than right-sided subclavian placements, which is consistent with our study, where no malposition was detected in left jugular or subclavian placements [17]. Schummer et al. found that ultrasound guidance significantly reduces the malposition risk, which we confirmed by showing that the US + Turbulent Flow technique had the lowest overall malposition rate (1.5%) compared to conventional placement (7.5 %) [18]. Our study further expands on these findings by demonstrating that turbulent flow assessment enhances catheter positioning accuracy and may serve as an alternative verification method to chest radiography.

Although US has been increasingly used to improve the accuracy of catheter placement and reduce the need for repeated attempts, its widespread adoption is hindered by cost, training requirements, and availability limitations in certain clinical settings [13]. Despite these challenges, operator experience remains a crucial factor in reducing malposition rates [13]. Although chest radiography has been the gold standard for confirming catheter placement, there is ongoing debate regarding its necessity. Guth et al. suggested that if the clinician does not suspect complications during catheterization, radiographic confirmation may be unnecessary [19]. However, Wicky et al. advocated for routine chest radiography following CVC placement to detect potential complications [20]. Hohlrieder et al. emphasized that the ability to aspirate blood through the catheter lumens does not exclude malposition [21]. In our study, all patients underwent chest radiography to confirm catheter placement. However, our findings demonstrated that the US + Turbulent flow group had the lowest malposition rate (1.5%) compared to the conventional CVC group (7.5%) and the US-Guided group (4.3%). These results suggest that US, particularly with turbulent flow assessment, may reduce the need for routine chest radiographs, aligning with previous literature advocating for US as an alternative imaging modality.

A study by Wilson et al. demonstrated that rapid injection of 5 cc of sterile saline through the CVC port resulted in echogenic turbulent flow in the right atrium, indicating correct catheter positioning. Their results showed that US had a sensitivity of 86.8% (95% CI: 77.1–93.5) and specificity of 100% (95% CI: 15.8–100.0) for verifying CVC placement [22]. In our study, turbulent flow detection was significantly associated with correct catheter positioning, reinforcing the accuracy of US in confirming catheter tip location.

Another study by Mehrnaz et al. reported a US sensitivity of 94.4% for detecting catheter tip position, whereas Matsushima et al. found a lower sensitivity of 50% [23, 24]. Variability in sensitivity across studies may be attributed to pre-existing catheter-related risk factors. Our results support the high sensitivity of US, as turbulent flow assessment effectively identified proper catheter placement with no additional complications recorded in the US-Guided and US + Turbulent flow groups.

Several studies have proposed US as a viable alternative to chest radiography. Blans et al. conducted a study in the Netherlands involving 53 patients and reported a US sensitivity of 98% [6]. Furthermore, Saugel et al. emphasized that US-guided CVC placement reduces complication rates and provides a cost-effective alternative to radiographic confirmation [25]. In our study, the absence of complications in the US-Guided and US + Turbulent Flow Groups further supports the role of US in reducing catheter-related adverse events.

In a large retrospective cohort study involving 6,875 patients, Chui et al. found that US guidance significantly reduced the incidence of pneumothorax and malposition, thereby questioning the necessity of routine chest radiographs following CVC insertion [26]. Similarly, Woodland et al. reported comparable findings, reinforcing the role of US as a reliable alternative imaging modality [27]. Our study aligns with these results, highlighting that the combination of US guidance and turbulent flow assessment significantly enhances catheter placement accuracy and may minimize the reliance on chest radiography in clinical practice.

Our study supports the growing body of evidence that suggests US combined with turbulent flow assessment can serve as an alternative to chest radiography in confirming CVC placement. Given the lower malposition rates observed in the US + Turbulent flow group, we propose that routine post-procedural chest radiography may not be required in patients undergoing US-guided CVC placement when turbulent flow is detected. However, further large-scale, multicenter studies are needed to validate the clinical utility and cost-effectiveness of US-based verification methods.

Despite its strengths, this study has some limitations. First, it was conducted at a single center, which may limit the generalizability of the findings to other institutions with different procedural protocols and patient populations. Second, the study did not include long-term follow-up, meaning potential delayed complications, such as catheter-related thrombosis or infection, were not assessed. Third, while we compared malposition rates among different catheterization techniques, other factors influencing catheter malposition, such as operator experience and anatomical variations, were not extensively analyzed. Additionally, although turbulent flow assessment was found to be a promising indicator of correct catheter placement, its sensitivity and specificity compared to chest radiography require further validation in larger, multi-center studies. Future research should focus on addressing these limitations by incorporating long-term clinical outcomes, multi-center data, and a more comprehensive analysis of operator-dependent variables.

4.1. Conclusion: In conclusion, our findings indicate that ultrasound guidance significantly reduces the risk of catheter malposition. Additionally, turbulent flow assessment may be a promising alternative to routine chest radiography for confirming correct catheter positioning. Incorporating US into standard CVC protocols could enhance patient safety, minimize complications, and reduce unnecessary radiation exposure. Future research should focus on refining US-based techniques and evaluating their applicability in broader patient populations.

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