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Comparison of Ultrasound-real time Guidance and Vascular Mapping (Mix-method) in Central Venous Catheter (CVC) Placement for Hemodialysis

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Abstract

BACKGROUND: The increasing prevalence of chronic kidney disease (CKD) and end-stage renal disease (ESRD) has heightened the demand for central venous catheter (CVC) placement in hemodialysis patients. Two primary techniques—real-time ultrasound (USG-RT) guidance and vascular mapping (Mix-method)—are utilized, each with distinct advantages and limitations. USG-RT enhances accuracy and reduces complications, while the Mix-method offers practicality. This study compares these techniques in CVC placement success and complication rates, aiming to optimize patient safety and procedural efficacy in hemodialysis care.

METHODS: This cross-sectional study at Dr. Wahidin Sudirohusodo Hospital, Makassar (July 2023 – July 2024) included CKD and AKI patients needing temporary CVC placement. USG-RT and Mix-method techniques were compared for first-attempt success and complications. Data were analyzed using IBM SPSS 25, with Chi-Square and Fisher's Exact tests ($p < 0.05$).

RESULTS: The Mix-method posed higher risks than USG-RT. Arterial puncture risk was nearly five times higher (OR 4.99, $p = 0.00$), affecting 87.50% of cases. Hematoma risk was also elevated (OR 3.81, $p = 0.00$), occurring in 84.60% of Mix-method cases. All misplacement cases (100%) were observed in the Mix-method ($p = 0.03$). Repeated puncture risk (OR 2.35, $p = 0.00$) was also higher in the Mix-method (75.80%).

CONCLUSIONS: The Mixed method poses higher risks of arterial puncture and hematoma than USG-RT, while USG-RT has a greater risk of misplacement. Repeated puncture risk remains unclear. Due to greater safety and efficiency, USG-RT is preferred. Further research is needed to assess clinical factors affecting CVC placement efficacy.

Keywords: central venous catheters, ultrasonography, mixed-method, hemodialysis

Introduction

The global demand for central venous catheter (CVC) placement for hemodialysis has increased significantly due to the rising prevalence of chronic kidney disease (CKD) and end-stage renal disease (ESRD). As the aging population grows and comorbidities such as diabetes and hypertension escalates, the necessity for reliable vascular access in hemodialysis patients has become a crucial aspect of nephrological care [1]. CVCs remain an essential temporary or long-term solution for vascular access when arteriovenous fistulas (AVF) or grafts are not viable. However, the procedural complications and risks associated with CVC placement necessitate continuous advancements in guidance techniques to ensure safer and more effective outcomes [2,3].

Two primary techniques are employed in CVC placement: real-time ultrasound (USG-RT) guidance and vascular mapping, commonly referred to as the mix-method. USG-RT enables continuous visualization of the target vessel and surrounding structures, significantly improving first-attempt success rates and reducing mechanical complications such as arterial puncture and hematoma [4,5]. However, it requires technical expertise and equipment availability, which can limit its widespread use. Conversely, the mix-method, which combines ultrasound for initial vascular mapping with landmark-based insertion, is often preferred in settings where continuous ultrasound guidance is not feasible [1,6]. Despite its practicality, the mix-method is associated with higher rates of misplacement and repeated needle insertions, increasing the risk of vascular trauma [3,5].

Despite the advancements in guidance techniques, challenges remain regarding the optimal approach to minimizing procedural risks such as arterial puncture, hematoma formation, catheter misplacement, and repeated needle insertions. This study aims to compare the effectiveness of USG-RT guidance and the mix-method in CVC placement for hemodialysis, focusing on their impact on procedural success rates and complication risks [4,6]. By evaluating these techniques, this research seeks to provide evidence-based recommendations to optimize CVC placement, enhance patient safety, and reduce the burden of complications associated with vascular access for hemodialysis [1,3].

Materials and methods

Subject and data collections

This is a cross-sectional study conducted at Dr. Wahidin Sudirohusodo Hospital and its affiliated hospitals in Makassar, Indonesia, from July 2023 to July 2024. The study

population consists of patients with CKD or acute kidney injury (AKI) requiring temporary CVC placement for hemodialysis. Participants were selected using consecutive sampling, excluding those who did not meet the study criteria. The study compared two CVC placement techniques: USG-RT guidance and vascular mapping (Mix-method). Procedural success was determined based on first-attempt insertion, while complications such as arterial puncture, hematoma, and catheter misplacement were recorded. This study was approved by the Research Ethics Commission of the Faculty of Medicine, Hasanuddin University (No: /UN4.6.4.5.31/PP36/202).

Statistical analysis

All collected data were analyzed using the Statistical Program for Social Sciences (IBM SPSS 25, IL, USA). Frequency distributions were calculated, and statistical comparisons were conducted using the Chi-Square and Fisher's Exact tests. Statistical significance was determined at a p-value < 0.05.

Results

The study analyzed 639 patients (mean age 50.79 years, SD 13.35) with a nearly equal gender distribution (49.40% male, 50.60% female). Chronic kidney disease was the primary indication (92.00%). The mix technique was used in 61.70% of cases, while 38.30% underwent real-time ultrasound. Catheter tips were placed in the right atrium (66.70%) or cavoatrial junction (33.30%). The mix technique was faster (16.05 vs. 27.36 min), but complications included arterial puncture (11.30%), hematoma (10.20%), and misplacement (1.30%). Most patients (76.10%) required one attempt, while 23.90% needed multiple attempts.

The study highlights that the Mixed method poses significantly higher risks compared to USG-RT in vascular access procedures. The risk of arterial puncture was nearly five times higher (OR 4.99, p-value = 0.00) in the Mixed method, with 87.50% of cases occurring in this group. Similarly, hematoma formation was significantly elevated (OR 3.81, p-value = 0.00), affecting 84.60% of cases in the Mixed method. All instances of misplacement (100%) were also observed in the Mixed method, with a p-value of 0.03. However, odds ratio estimation was unavailable due to no reported cases in the USG-RT group. Furthermore, the risk of repeated puncture was significantly higher (OR 2.35, p-value = 0.00) in the Mixed method, accounting for 75.80% of cases.

Discussion

The application of the Mixed method and USG-RT in the placement of CVC has significant epidemiological implications for patient safety, particularly in individuals with indications of chronic kidney disease (CKD). Studies have demonstrated that USG-RT is highly effective in reducing complications such as pneumothorax and catheter malposition, which are frequently encountered with the conventional landmark-based approach [7,8]. This method also exhibits a high first-attempt success rate, thereby minimizing the risk of tissue trauma in high-risk patients such as those suffering from CKD [9].

Additional research reinforces the superiority of USG-RT in reducing procedural duration and the risk of catheter-related infections compared to conventional methods, which is crucial in the management of critically ill patients [3]. Conversely, the Mixed method, which integrates ultrasound guidance with supplementary techniques such as radiographic confirmation, remains highly relevant in clinical practice, particularly in cases involving anatomical challenges. The implementation of the Mixed method allows for direct visualization of catheter positioning, thereby mitigating the risk of misplacement in patients with complex anatomical structures or preexisting conditions such as edema and vascular anomalies [10,11].

Epidemiological studies highlight that the Mixed method can significantly reduce complication rates and expedite response times in emergency scenarios, making it more ideal for patients requiring swift and secure vascular access [12,13].

Risk of Arterial Puncture

The Mixed method in arterial puncture procedures, which combines palpation and intermittent ultrasound guidance, has been associated with an increased risk of complications compared to the USG-RT approach. In the Mixed method, the accuracy of needle placement is often lower, thereby elevating the likelihood of arterial injury or hematoma due to the difficulty in detecting blood vessels in real-time [14–16].

Studies comparing various techniques have demonstrated that USG-RT significantly reduces the number of repeated punctures, procedural duration, and patient discomfort caused by tip misplacement [11,17,18].

Implementing USG-RT guidance in clinical practice enhances accuracy and minimizes the risk of severe complications, such as arterial perforation and hematoma formation. Research indicates that real-time USG results in a higher first-attempt success rate

while reducing the need for needle repositioning, often leading to additional vascular trauma [19–22].

Risk of Hematoma

The Mixed method in arterial puncture procedures elevates the risk of hematoma compared to USG-RT guidance. Research indicates that conventional techniques relying on manual palpation often necessitate multiple puncture attempts, significantly increasing the likelihood of hematoma formation [23,24]. The reduced accuracy inherent in the Mixed method leads to greater trauma to the arterial wall, thereby heightening the risk of vascular complications such as hematoma and other hemorrhagic events [25,26].

Conversely, real-time USG guidance in clinical practice mitigates hematoma risk by enhancing vascular visualization throughout the puncture process. Studies focusing on patients requiring complex vascular procedures have shown that USG-RT improves first-attempt success rates while significantly lowering the incidence of hematoma [27–29].

Furthermore, several studies support the effectiveness of ultrasound guidance in reducing complication rates compared to conventional techniques, underscoring the critical role of ultrasound technology in minimizing procedural risks and improving clinical outcomes [30].

Risk of Missing Location

Several studies have highlighted the advantages of real-time visualization in reducing the risk of missing the intended puncture site due to more meticulous pre-procedural preparation. The use of pre-location marking before needle insertion has been shown to enhance access point accuracy without the necessity of constant real-time guidance [31,32]. Additionally, research suggests that this method shortens procedural time, ultimately reducing the risk of complications associated with repeated puncture attempts [24,33].

On the other hand, USG-RT provides superior direct visualization, which enhances precision. However, in certain patient conditions, additional time may be required for probe adjustment and instrument repositioning, potentially increasing the risk of missing the intended location if the operator lacks sufficient proficiency [14,34].

Risk of Repeated Puncture

Repeated punctures are a common issue in the Mixed method due to its limited direct visualization, requiring the operator to estimate the arterial position, which often results in inaccurate and repeated needle insertions [15,25]. This increases the risk of vascular

complications, including hematoma and vascular injury, caused by repeated trauma to the vessel wall. [20,24]

Conversely, USG-RT guidance significantly reduces repeated puncture rates by directly visualizing the needle position, allowing the operator to precisely guide the needle on the first attempt [32,35]. The use of USG-RT not only minimizes the need for repeated punctures but also lowers the risk of vascular complications, which are commonly associated with palpation-based or Mixed methods [19,34].

Conclusions

The Mixed method poses higher risks of arterial puncture and hematoma than USG-RT, while USG-RT has a greater risk of misplacement. Repeated puncture risk remains unclear. Due to greater safety and efficiency, USG-RT is preferred. Further research is needed to assess clinical factors affecting CVC placement efficacy.

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Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Authors' contributions.

All authors contributed equally to the manuscript and read and approved the final version of the manuscript.

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TABLES

Table 1. Distribution of demography

Variable	Mean (SD)	N(%)
Age (years)	50.79 (13.35)	
Gender		
Male		317 (49.40)
Female		322 (50.60)
Indication		
CKD		588 (92.00)
AKI		51 (8.00)
Methods		
Mix method		394 (61.70)
USG-RT		245 (38.30)
Tip location		
Right atrium		426 (66.70)
Cavoatrial junction		213 (33.30)
Installation time (minutes)		
Mix-method	16.05 (9.14)	
USG-RT	27.36 (6.38)	
Puncture		
First time		486 (76.10)
Repeated puncture		153 (23.90)
Complication		
Arterial puncture		72 (11.30)
Hematoma		65 (10.20)
Missing location		8 (1.30)

SD standard of deviation, N number

Table 2. Risk of arterial puncture between methods

Methods	Arterial puncture		OR CI 95%	p-value
	Yes	No		
Mix-method	63 (87.50)	331 (58.40)	4.99 (2.43-10.23)	0.00*
USG-RT	9 (12.50)	236 (41.60)		

Chi-square, *significant

Table 3. Risk of hematoma between methods

Methods	Hematoma		OR CI 95%	p-value
	Yes	No		
Mix-method	55 (84.60)	339 (59.10)	3.81 (1.90-7.63)	0.00*
USG-RT	10 (15.40)	235 (40.90)		

Chi-square, *significant

Table 4. Risk of missing location between methods

Methods	Missing location		OR CI 95%	p-value
	Yes	No		
Mix-method	80 (100.00)	386 (61.20)	NA	0.03*
USG-RT	0 (0.00)	245 (38.80)		

Fischer-exact, NA not available, *significant

Tabel 5. Risk of repeated puncture between methods

Methods	Puncture		OR CI 95%	p-value
	Multiple	First time		
Mix-method	116 (75.80)	278 (57.20)	2.35 (1.55-3.54)	0.00*
USG-RT	37 (24.20)	208 (42.80)		

Chi-square, *significant