Dynamic ultrasound-guided hemodialysis catheter insertion

Assem Mohamed Herzallah[a], Mohamed T. Yousuf[a],
Mohamed M. Gouda Wahdan[a], Wael M.H. Eldarandaly[b]

Departments of [a]Vascular Surgery, [b]Anesthesiology and Critical Care, Mataria Teaching Hospital, Cairo, Egypt

Correspondence to Assem Mohamed Herzallah, MD, Department of Vascular Surgery, Mataria Teaching Hospital, Elmataria, Taha Khandil Street, Cairo, Egypt.
Tel: +20 100 171 4960;
e-mail: assemherz010@hotmail.com

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Background
Hemodialysis catheters are broadly used for both short-term and long-term angioaccess for hemodialysis. Conventional methods of catheter insertion were based on anatomical landmarks but were associated with higher failure rates, more attempts, and higher rate of complications. Dynamic ultrasound (US) guidance for insertion of hemodialysis catheters is described in the recent guidelines and can provide higher success rate, faster access, and significantly lower complication rates.

Purpose
The objective was to assess the effectiveness and safety of dynamic US guidance during insertion of hemodialysis catheters.

Patients and methods
This prospective interventional study included 40 patients with end-stage renal disease in need for regular or acute hemodialysis who underwent insertion of hemodialysis catheters by one operator (for each procedure) under dynamic short-axis US guidance.

Results
A total of 40 hemodialysis catheters were inserted in 40 patients by one operator for each procedure using dynamic short-axis US guidance. Overall, 22 (55%) catheters were inserted through the right internal jugular vein, six (15%) were inserted through the left internal jugular vein, and 12 (30%) were inserted through the femoral veins (nine in the right side and three in the left side). The first-attempt success rate was 85% (catheters were inserted at first attempt in 34 patients), the second-attempt success rate was 5% (in two cases), and the third-attempt success rate was 5%. Catheters were inserted after more than three attempts in 5% of cases.

Conclusion
The use of one-operator dynamic short-axis US guidance for hemodialysis catheter insertion makes procedure faster and safer. It is important to be familiar with the US techniques, which have become the current standard of care and should be used in all cases.

Keywords:
duplex, ultrasounds, hemodialysis catheters, end-stage renal disease

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Introduction

Dialysis is the lifeline for most patients with end-stage renal disease (ESRD) in Egypt. Vascular access dysfunction is the ‘Achilles’ heel’ of lifelong hemodialysis. The maintenance of an adequately functioning vascular access is one of the most significant clinical challenges of lifelong hemodialysis. As more individuals are diagnosed with ESRD and become chronically dependent on hemodialysis, efforts to preserve vascular access become even more critical [1]. The native arteriovenous fistula (AVF) is the first-choice vascular access for most hemodialysis patients because AVF has a lower incidence of complications when compared with other types of hemodialysis vascular access [2]. Failed AVF or difficult AVF creation has increased because of the epidemic of diabetes and aging of the dialysis population, leading to the need for temporary or permanent hemodialysis catheters [3]. Catheters are also indicated in patients who need acute hemodialysis. A recent report suggested that in ∼80% of patients with ESRD, a hemodialysis catheter is required at some point in long-term care [4].

Hemodialysis catheter insertion is a high-risk procedure that needs trained operators, strict aseptic conditions, and ultrasound (US) and fluoroscopy guidance. Early interventional complications may occur after catheter insertion such as arterial puncture, hematoma, and pneumohemothorax. Moreover, there is a higher risk of long-term complications like central venous stenosis, occlusion, thrombosis, and infections [5]. Conventional methods of hemodialysis catheter insertion rely on anatomical landmarks. Successful cannulation is indicated by the dark color of venous blood and absence of pulsatile flow. Success rates based on landmarks range from 60 to more than 90%, with reported complication rates ranging from 5 to 20% [6]. Anatomical landmark techniques are associated with higher failure rates, more attempts, and higher rate of complications [7].

US guidance has been used to minimize the risk of arterial puncture and complications [8]. Hence, the National Kidney Foundation-KDOQI clinical practice guidelines for vascular access recommend real-time (dynamic) US to guide insertion of central venous catheters to increase the success rate and decrease insertion-related complications [2].

US can be used to take static or dynamic (real time) images of a target blood vessel. Static technique refers to US use before the procedure to identify the anatomy of the target vein and adjacent anatomic structures (including the patency of the vein and its dimensions and depth from the skin). Then, the entry point is marked on the skin, the US probe is removed, and the procedure is done without US guidance at the marked entry point. This approach of preprocedural US evaluation is referred to as 'US-assisted' central venous catheter (CVC) placement [9].

Dynamic technique refers to real-time US use to guide and navigate needle entry into the vein while keeping an eye on the artery. The real-time ultrasonography clarifies the relative position of the needle, the vein, and the structures surrounding the vein. This is referred to as 'US guidance' [10]. In the dynamic technique, the US probe can be placed in a transverse position relative to the vessel, resulting in a short-axis view on the US screen (a cross-sectional image of the vessel) or can be placed in a longitudinal position relative to the vessel, resulting in a long-axis view on the screen [11].

Whether or not one approach is superior to the other cannot be answered accurately based on the existing literature data. The advantage of the short-axis imaging approach is that it allows better visualization of the vein in relation to the artery and other anatomic structures and might help to avoid accidental arterial puncture [12]. The short-axis imaging approach is easier to learn for physicians not familiar with US [13]. Among experienced US operators, the short-axis approach seems to result in a higher success rate with the first attempt for catheter placement in the internal jugular vein (IJV) and femoral vein (FV) [14,15]. However, in the short-axis approach, the needle is only visualized as an echogenic point (that must not necessarily be the tip of the needle). In contrast, when using the long-axis approach, the entire needle in its complete course and the depth of the needle tip can be visualized on the US image, thereby minimizing posterior venous wall puncture [16].

There are two techniques regarding the number of operators performing the procedure one-operator technique, where one operator holds both a probe and needle, and two-operator technique, with one holding the US probe and one performing the venous puncture. In the one-operator technique, by scanning the probe dynamically with coordinated advancement of the needle, highly precise cannulation is possible [11]. For real-time (dynamic) US guidance, different US approaches can be used, but most studies have recommended the transverse imaging one-operator approach, and our preference is also this approach [10].

Aim

The objective was to assess effectiveness and safety of dynamic (real time) US guidance during insertion of hemodialysis catheters.

Patients and methods

This is a prospective interventional study.

The study was approved by the Ethics Board of our hospital.

A total of 40 patients with ESRD in need for hemodialysis underwent insertion of hemodialysis catheters in internal jugular or FVs by one operator for each procedure by dynamic short-axis ultrasound-guided (USG) technique. Static technique was not used in the study.

All the operators had at least 5 years of experience in vascular surgery and especially in central venous catheters insertion.

All procedures were performed in the main operating theater using SonoSite-S-Nerve (Fujifilm Sonosite: Bothell, Washington, United States) portable US equipment and Ziehm Vision R C-arm machine (Orlando, United States). The study was conducted between January 2018 and January 2020. Patients underwent full history taking and detailed examination. Patients were examined for age, sex, primary disease causing renal failure, the type of renal failure (acute or chronic), the type of the hemodialysis catheter (permanent or temporary), and determination of the intended access vein. Before the procedure, all patients had complete blood count and international normalized ratio evaluation.

A written informed consent for the procedure and the study was taken from all patients.

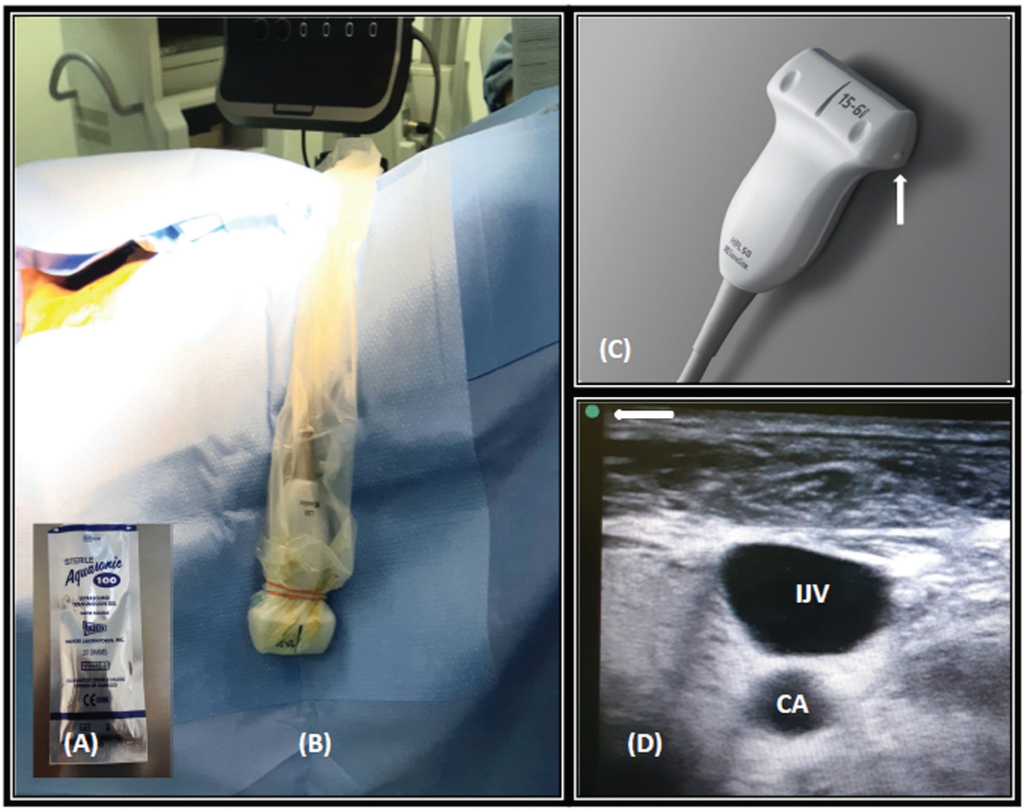
While the patient in supine position, the working field is prepared and covered with a sterile drape. A 7.5-MHz linear-array US probe connected to the US equipment is ideal for these procedures. The probe is covered by a sterile sheath to maintain a sterile field. A sterile gel is applied after infiltration of lidocaine 1%. After proper orientation of the probe and screen image, the operator measures the depth and caliber of the vein and identifies any sign of thrombi in the vein (Fig. 1).

The operator held the probe with the left hand, localizing the artery and vein on the US image. While centering a large-bore needle (19 G, 10 cm) by the right hand under the middle of the probe by 45° angle to the skin, the operator noticed the trajectory of the needle and attempted venous cannulation. The plane containing the needle appears on the screen as a point (in the short-axis view) and an echogenic line (in the long-axis view) with ring-down artifacts (Fig. 2).

After detecting the trajectory of the needle over the vein, the operator attempts venous puncture. Once a flush of blood is encountered, the US probe was removed and standard Seldinger technique was followed under fluoroscopic monitoring. All catheters were locked with heparin after insertion (Fig. 3). After every procedure, operator recorded the type of catheter inserted, venous access site, number of venous puncture attempts, and any acute complications if occurred.

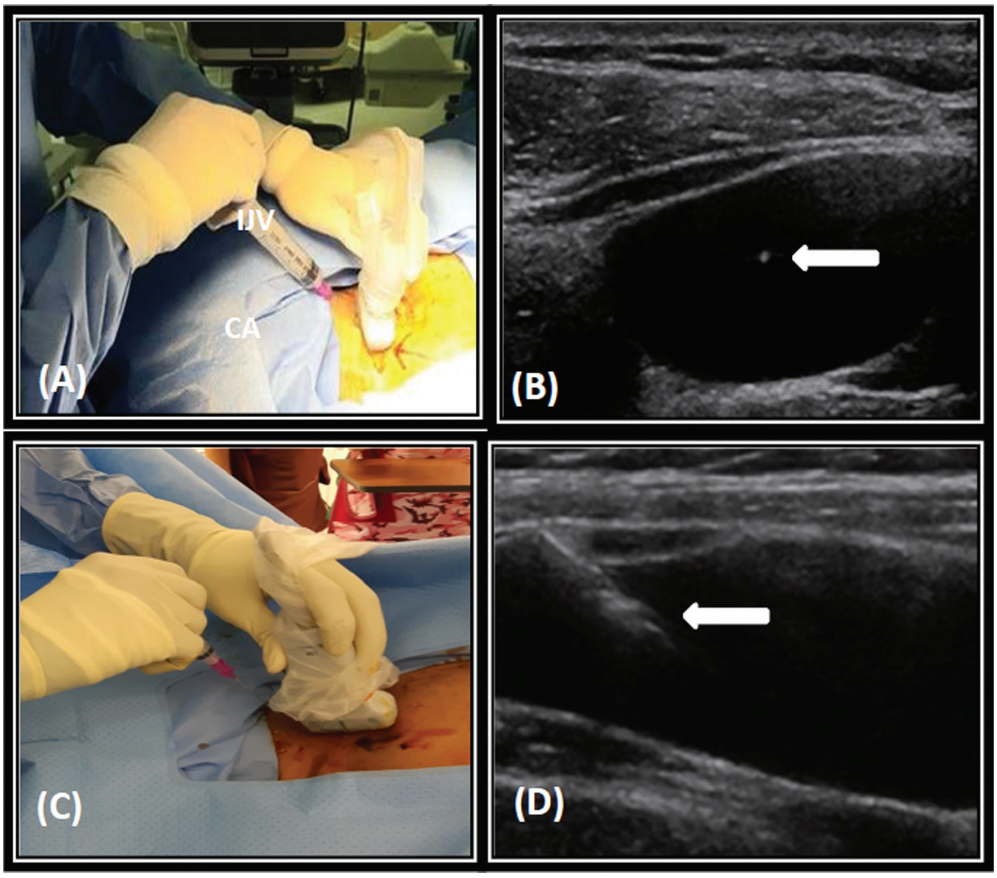
Society of the Interventional Radiology Technology guidelines classified complications that may occur after central venous catheters placement into three groups

Figure 1



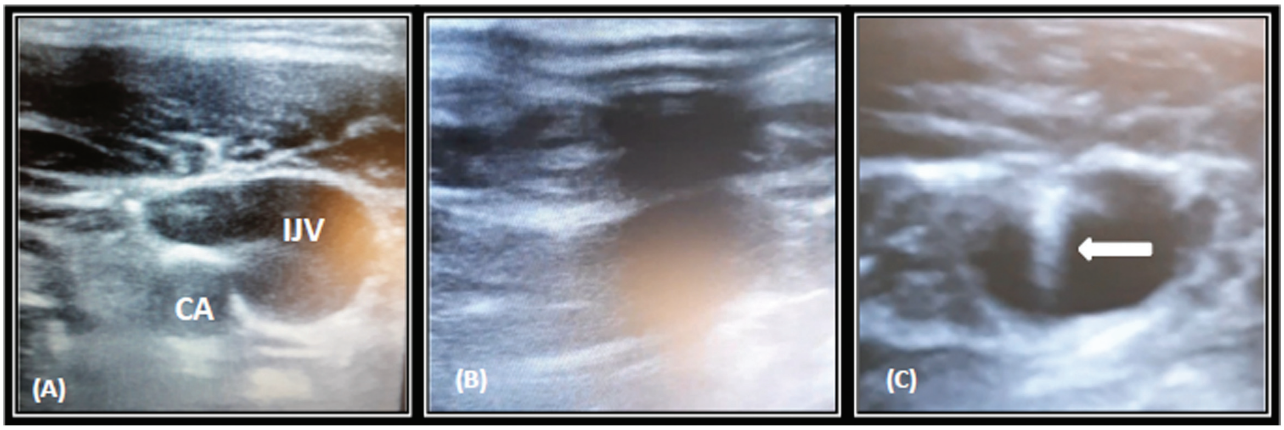
Ultrasound probe preparation and orientation. (a) Sterile gel to maintain a sterile field. (b) Covering the probe by a sterile sheath. (c) Proper orientation of the probe and the screen image. (d) Measuring the depth and caliber of the vein and exclusion of venous thrombi.

Figure 2



Ultrasound guidance during hemodialysis catheters insertion. (a) Short-axis probe orientation. (b) The plane containing the needle appears on the screen as a point. (c) Long-axis probe orientation. (d) The needle plane containing the needle appears on the screen as an echogenic line.

Figure 3



Technique of short-axis imaging ultrasound-guided right internal jugular vein cannulation. (a) Short-axis imaging of right internal jugular vein and common carotid artery. (b) Internal jugular needle puncture by ultrasound-guided short-axis imaging. (c) The needle is seen puncturing the venous wall; the needle is causing a visible ring-down artifact in the anechoic intravenous blood.

according to the time of onset: periprocedural (if it occurs during the first 24 h after the procedure), early (after 24 h and before 30 days), or late complications if occurs after 30 days [17]. The follow-up in the current study was directed toward the detection of periprocedural and early complications up to 1 month after any procedure. Late complications such as catheter thrombosis or infection are out of the scope of this study. Moreover, any complication that required hospitalization of more than 48 h or blood transfusion of more than or equal to 2 units of blood is considered a major complication.

Results

A total of 40 hemodialysis catheters were inserted in 40 patients by dynamic short-axis US guidance. The study was conducted on 40 hemodialysis patients, comprising 22 (55%) females and 18 (45%) males. Their age ranged between 50 and 64 years, with a mean age of 57 years. The baseline characteristics of the study patients are shown in Table 1.

Overall, 28 (70%) catheters were tunneled permanent, whereas 12 (30%) were temporary. Moreover, 22 (55%) catheters were inserted through the right IJV, six (15%) were inserted through the left IJV, and 12 (30%) were inserted through the FVs (nine in the right side and three in the left side). More details regarding insertion sites and types of the inserted catheters are shown in Table 2.

The first-attempt success rate was 85% (catheters were inserted at first attempt in 34 patients), the second-attempt success rate was 5% (in two cases), and the third-attempt success rate was also 5%. Catheters were inserted after more than three attempts in 5% of cases (Table 3).

No major complications occurred during the study. Only minor periprocedural complications occurred in five (12.5%) patients. Carotid puncture was performed in two (5%) patients and femoral artery puncture in one (2.5%) patient. A small neck hematoma occurred in one patient, and moderate hemothorax occurred in one patient after insertion of a left internal jugular tunneled permanent catheter, which was managed by insertion of intercostal chest tube without blood transfusion (Table 4).

Table 1 The characters of the study patients

Items	*n* (%)
Number of patients	40
Number of interventions	40
Age (years) (mean±SD)	57±7
Female sex	22 (55)
Male sex	18 (45)
Hypertension	32 (80)
Diabetes mellitus	28 (70)
Heart disease	8 (20)
Chronic hemodialysis	36 (90)
Acute hemodialysis	4 (10)
Past history of hemodialysis catheter	26 (65)

Table 2 The insertion sites and types of inserted catheters

Catheter types	*n* (%)
Tunneled permanent catheter	28 catheters (70)
	20 catheters in right IJV (50)
	4 catheters in left IJV (10)
	3 right femoral vein (7.5)
	1 left femoral vein (2.5)
Temporary catheter	12 catheters (30)
	2 catheters in right IJV (5)
	2 catheters in left IJV (5)
	6 right femoral vein (15)
	2 left femoral vein (5)
Catheter insertion sites	
Right internal jugular vein	22 cases (55)
Left internal jugular vein	6 cases (15)
Right femoral vein	9 cases (22.5)
Left femoral vein	3 cases (7.5)

IJV, internal jugular vein.

Discussion

Hemodialysis catheters were previously inserted using anatomic landmarks techniques based on palpation of arterial pulsations besides the veins. These landmark techniques cannot account for anatomic variations at the CVC insertion site [18]. The described anatomic variations and the possible presence of venous thrombosis can hardly be identified using the landmarks technique. In addition, the operator's expertise is extremely important in using landmark techniques [19].

Previous literature has reported a 35% failure rate using anatomic landmarks alone without US for central vein catheterization, with reported complications rates between 5 and 40% [20].

Recently, image-guided placement of CVCs by both fluoroscopic and US imaging has been used routinely to confirm patency of the vein and decrease unintended arterial puncture or unsuccessful cannulation [21]. Routine use of DUS is a cost-effective approach because it is available in most centers. This led to

Table 3 The number of attempts for venous cannulation

Number of attempts	*n* (%)
1	34 (85)
2	2 (5)
3	2 (5)
>3	2 (5)

Table 4 Reported periprocedural complications

Complication	*N* (%)
Carotid puncture	2 (5)
Femoral artery puncture	1 (2.5)
Neck hematoma	1 (2.5)
Moderate hemothorax	1 (2.5)

the endorsement of standard routine US guidance for catheter placement to maximize patient care [22].

Several studies have demonstrated increased clinical and technical success, with fewer technical complications, with routine use of US during central venous catheterization [10,22,23]. In a recent study by Screva *et al.* [24] comparing USG central venous catheterization with landmark technique, the overall success was reported to be higher in USG technique (98 vs 90%), and the first-attempt success rate was higher (80 vs 60%). The complication rate was also lower with USG catheterization (arterial puncture, 1 vs 8%; pneumothorax, 0 vs 4%; and neck hematoma, 4 vs 10%).

Our results are comparable to these results as the first-attempt success rate in the current study was 85%. In the current study, no major complications occurred, but minor complications occurred in five (12.5%) patients. Carotid puncture was performed in two (5%) patients and femoral artery puncture in one (2.5%) patient. A small neck hematoma occurred in one patient, and moderate hemothorax occurred in one patient during placement of a left internal jugular catheter.Many randomized studies reported higher incidence of arterial puncture (5–15%) during the anatomical landmarks technique in contrast to USG catheter placement (0–1%) in both the IJV [8,25,26], as well as in the FV [27–29].

Although US guidance is a noninvasive and effective procedure in decreasing complications during CVC insertion, there are some limitations and disadvantages of US guidance. Use of US without following a strict aseptic technique increases the incidence of catheter-related infections. Moreover routine US use will result in a lack of skills in the use of landmark techniques in case of unavailability of US [30].

Conclusion

The use of dynamic US guidance for hemodialysis catheter insertion makes the procedure faster and safer. It is important to be familiar with ultrasound techniques, which have become the current standard of care and should be used routinely in all cases.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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