

DOI: 10.15825/1995-1191-2025-3-204-215

SURGICAL ASPECTS OF TUNNELED CENTRAL VENOUS CATHETER IMPLANTATION FOR HEMODIALYSIS: A LITERATURE REVIEW

N.L. Shakhov, R.N. Trushkin, V.I. Vtorenko, O.N. Kotenko, N.F. Frolova, M.Yu. Bogodarov, E.S. Kudryavtseva, D.Z. Tazetdinov, A.S. Kiselev, A.A. Evdokimova

City Clinical Hospital No. 52, Moscow, Russian Federation

This review addresses a key issue in establishing vascular access for maintenance hemodialysis: the implantation of tunneled central venous catheters (TCVCs). Advances in catheter design and imaging technologies in recent years have significantly reduced the risk of complications associated with TCVC placement. Nevertheless, certain complex clinical scenarios still require individualized approaches during implantation. This review highlights the indications and contraindications for TCVC placement, examines the various catheter types and potential insertion sites, and discusses patient preparation, intraoperative considerations, and postoperative care. It also reviews early and late complications, along with strategies for their management. The use of additional imaging modalities to facilitate catheter placement is also presented. Currently, a standardized approach to TCVC implantation is employed, encapsulated in a standard operating procedure (SOP), which ensures adherence to aseptic techniques and provides a structured framework for training new clinical staff.

Keywords: tunneled central venous catheter, arteriovenous fistula, synthetic vascular graft, balloon angioplasty.

A joint statement by the American Society of Nephrology, the European Renal Association, and the International Society of Nephrology reported that by 2021, more than 850 million people worldwide had some form of kidney disease. This figure is nearly twice the global prevalence of diabetes (422 million) and about 20 times higher than the prevalence of malignant tumors (42 million) or the number of people living with HIV/AIDS (36.7 million). These estimates were derived from multiple international studies that applied varying definitions of chronic kidney disease (CKD); nevertheless, they remain the most reliable approximation of the global CKD burden [1].

Currently, the number of patients requiring renal replacement therapy (RRT) continues to grow, accompanied by the expansion of hemodialysis (HD) centers worldwide. Advances in dialysis technology and clinical practice have significantly improved the quality of HD, contributing to longer survival among patients with end-stage renal disease (ESRD). However, establishing and maintaining reliable vascular access remains a major clinical challenge. The three principal types of vascular access used in chronic HD are: native arteriovenous fistula (AVF), synthetic vascular graft (SVG), and tunneled (cuffed) central venous catheters [2].

According to the KDOQI (Kidney Disease Outcomes Quality Initiative) guidelines, arteriovenous access (AVF or SVG) is considered the preferred option for patients

requiring HD, provided it aligns with the individual's life plan for ESRD and overall treatment goals. Nonetheless, under specific and justified clinical circumstances, KDOQI guidelines recognize the appropriateness of using tunneled central venous catheters (CVCs) as a long-term vascular access option in select patients [2].

Despite ongoing initiatives aimed at increasing the number of patients starting HD with AVF, data from the US Renal Data System (USRDS) show a persistent reliance on catheters. Between 2018 and 2022, the proportion of patients initiating HD with a catheter increased by 3.9%, reaching 84.7%, underscoring the challenges in achieving widespread early AVF placement [3].

INDICATIONS FOR TUNNELED CENTRAL VENOUS CATHETER IMPLANTATION

- 1 Failure of the fistula to mature sufficiently by the time HD is required, often due to delayed referral to a vascular surgeon or other specialists, resulting in late preventive AVF formation.
- 2 Inability to form an AVF or SVG due to the vascular anatomy (excessive vein depth (>6 mm), which does not allow for adequate puncture, or a scattered type).
- 3 Absence of superficial and deep veins of the required diameter for AVF or SVG formation.
- 4 Severe heart failure with significantly reduced left ventricular ejection fraction, where AVF creation

- would impose additional myocardial stress and decompensation of chronic heart failure.
- 5 Patients undergoing peritoneal dialysis are temporarily implanted with tunneled CVCs for HD in the event of catheter-associated infection.
 - 6 Limited life expectancy (<1 year), where short-term palliative dialysis is indicated.
 - 7 Living-donor kidney transplantation planned within a relatively short period of time.
 - 8 Uncertainty regarding renal function recovery in cases of acute kidney injury (AKI) [4].
 - 9 Patient declines AVF or SVG formation [2].

CONTRAINDICATIONS TO TUNNELLED CENTRAL VENOUS CATHETER IMPLANTATION:

- 1 AKI requiring emergency HD.
- 2 Active infection involving an existing tunneled CVC (as bridge therapy/replacement).
- 3 Short-term bridge therapy (<2 weeks) during AVF reconstruction that does not require prolonged maturation.
- 4 Persistent bloodstream infection and the need for urgent HD treatment [4].

Elderly patients are a special group when it comes to choosing vascular access for HD. With advancing age, progression of kidney disease to an end stage influences multiple therapeutic decisions, including the choice of renal replacement therapy and individualized recommendations for dialysis access [5, 6]. In older individuals with significant comorbidities, such as severe heart failure, peritoneal dialysis or hemodialysis via tunneled CVCs are often considered the most practical and safest options [2, 7].

Currently used tunneled catheters vary in catheter tip design and insertion method [8].

THE THREE MAIN TYPES OF TUNNELED CATHETERS USED FOR HEMODIALYSIS ARE:

1. Retrograde catheters – inserted first into the central vein and then passed through a subcutaneous tunnel.
2. Antegrade catheters – passed initially through a subcutaneous tunnel and then inserted into a central vein.
3. Retroantegrade catheters – may be inserted using either approach, depending on the surgeon's preference.

Polyurethane double-lumen catheters are available in various lengths (tip-to-cuff: 24, 28, 32, 36, and 55 cm) and diameters (10, 12.5, 14.5, and 15 Fr). Their configuration can also differ, being either straight or pre-shaped (curved into a loop or set at a 90° angle).

LUMEN AND TIP DESIGN OF DIALYSIS CATHETERS

Five tip designs are commonly used in tunneled CVCs for hemodialysis: stepped, symmetrical, split, self-centering, and Y-shaped (Fig. 1) [9].

Catheters with a stepped tip have a narrowed arterial lumen facing the mediastinum (Fig. 1, a). Split-tip catheters

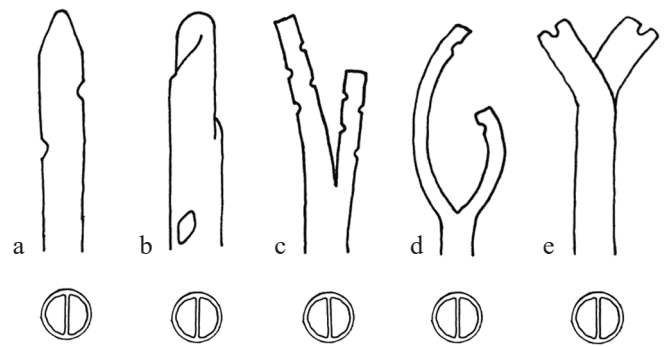


Fig. 1. Modern hemodialysis catheter designs: (a) step-tip catheter; (b) symmetrical-tip catheter; (c) split-tip catheter; (d) self-centering split-tip catheter; (e) Y-shaped catheter. Illustration by Yuri Bassuner [9]

have split lumens at their ends, designed primarily to reduce recirculation (Fig. 1, c). To further address this issue, manufacturers developed the symmetrical tip, in which the venous and arterial lumens terminate at the same level. This design incorporates an inclined spiral notch that diverts venous outflow away from arterial inflow (Fig. 1, b) [10]. The recirculation rate for symmetrical-tip catheters is approximately 1%, the lowest among available designs. In comparison, stepped and split-tip catheters demonstrate recirculation rates of about 7% during direct flow and 10–30% during reverse flow [11]. Although split-tip catheters tend to maintain patency longer than stepped-tip catheters, both designs provide comparable blood flow rates [10]. In comparison, symmetrical-tip catheters have demonstrated higher blood flow rates than stepped-tip catheters, while showing similar outcomes with respect to primary patency, infection, and thrombosis [12].

A prospective randomized trial further reported that symmetrical-tip catheters not only maintain patency for a longer duration but also exhibit lower rates of dysfunction and reverse blood flow compared to stepped-tip designs [13]. Supporting these findings, a 4-year multicenter study in Australia involving 4,722 patients found that both symmetrical-tip and split-tip catheters were associated with a reduced risk of catheter dysfunction requiring removal when compared with stepped-tip catheters [14].

There is another symmetrical catheter tip design that places the distal lumens at an angle on opposite sides of the catheter. This configuration deflects blood exiting the venous port away from blood entering the arterial port, thereby reducing recirculation. In addition, the design generates a spiral laminar flow, which decreases platelet activation during dialysis and consequently prolongs catheter life [15]. A recent multicenter randomized study showed that both symmetrical tip catheters and spiral laminar flow catheters exhibit the same 90-day primary patency; however, Kt/V values were significantly higher in the spiral laminar flow group [16].

The self-centering catheter represents an improved modification of the bifurcated design. Its side ports are oriented inward, preventing contact with the vessel wall and thereby reducing the risk of fibrin sheath formation and port occlusion (Fig. 1, d). In a prospective multicenter study, self-centering catheters maintained a high blood flow rate (>300 ml/min) in 87% of patients during 26 weeks of follow-up. Throughout the study, no reduction in average dialysis flow rate or significant changes in hydraulic resistance of the arterial and venous lumens were observed [17].

Catheters with a Y-shaped tip have slits but no side ports (Fig. 1, e). This design is reported to prolong initial patency and decrease the incidence of catheter-related thrombosis and infections. Preliminary clinical data confirm good patency rates and a low incidence of complications [18].

Various coatings have been developed to enhance the efficiency of HD catheters. Heparin is commonly employed as an anti-adhesive coating to prevent the formation of blood clots and fibrin coats [19], while silver is utilized for its antimicrobial properties. An emerging and promising area of research involves microstructuring, which mimics natural surfaces such as shark skin (Sharklet) or lotus leaves. Through microstructuring technologies, catheter surfaces can be modified to inhibit the adhesion of bacteria and platelets, thereby reducing the risk of colonization and fibrin sheath formation [20]. Another innovative approach, the water infused surface protection (WISP) technology, provides protection for the inner surface of the catheter. This coating reduces protein adsorption, reducing protein adsorption and effectively (up to 96%) degrading adsorbed protein structures on the inner surface, compared to uncoated catheters [21].

According to KDOQI guidelines, the strategies for implanting tunneled CVCs and the choice of catheter insertion sites should be guided by the patient's life plan. This plan outlines the long-term strategy for providing vascular access for dialysis in individuals with chronic kidney disease and is developed jointly with the patient and a multidisciplinary team of specialists. The team typically includes a nephrologist, a surgeon, a radiologist, a nurse, and members of the patient's family.

The choice of catheter location is determined by several factors, including the patient's age, expected duration of tunneled CVC use (short-term, up to 3 months, or long-term, more than 3 months), the presence of an AVF or plans for AVF creation on the same side, as well as waiting for a kidney transplant, where preservation of the iliac vessels is necessary. Based on these criteria, the preferred order of sites for tunneled CVC placement is as follows:

1. Internal jugular vein.
2. External jugular vein.
3. Femoral vein.

4. Subclavian vein.

5. Iliac vein.

Whenever possible, tunneled CVCs should be implanted on the right side rather than the left, as the anatomy of the right-sided veins provides a more direct course to the right atrium. Exceptions include cases where pre-existing pathology (e.g., central venous stenosis) or prior interventions (e.g., pacemaker implantation) preclude right-sided access. In situations where pathology on one side prevents the creation of arteriovenous access but still permits catheter placement, tunneled CVCs should be placed on that side in order to preserve the other side for future arteriovenous access [2].

A recent meta-analysis, however, found no association between unilateral placement of tunneled CVCs and AVFs with regard to fistula maturation time or dysfunction rates [22]. Despite this, dysfunction of tunneled CVCs implanted in the right internal jugular vein is consistently reported to be less frequent than in the left internal jugular vein. Left-sided placement is associated with a higher risk of intraoperative complications due to the longer and more tortuous venous course. Moreover, studies have shown higher rates of infection and dysfunction with left-sided catheters. For adequate performance of left-sided catheters, precise tip positioning within the right atrium is considered essential [9, 23].

If implantation in the jugular veins is not feasible, the femoral vein is recommended as the next option. However, this site is considered less favorable due to a higher incidence of infectious complications, attributable to its anatomical location, and thrombotic complications, particularly catheter lumen thrombosis.

Placement of tunneled CVCs in the right or left subclavian vein is generally not recommended, as it is frequently associated with vascular stenosis [2]. Nevertheless, in some patients, identifying a suitable site for tunneled CVC placement can be extremely challenging or even impossible. In such cases, alternative approaches have been reported in the literature, including tunneled CVC implantation in the external jugular vein [24, 25], placement in the inferior vena cava (IVC) at the confluence of the iliac veins in patients with exhausted vascular access [26], and transhepatic catheterization of the IVC in patients with both exhausted vascular access and a preexisting cava filter [9, 27].

TUNNELED CVC IMPLANTATION TECHNIQUE

Tunneled CVCs are inserted following a standard algorithm and are typically performed without systemic antibiotic prophylaxis. The rationale for not using prophylactic antibiotics routinely lies in the fact that the procedure is conducted under aseptic conditions. Routine administration of antibiotics may introduce unnecessary risks, such as allergic reactions or drug toxicity, and may contribute to the emergence of antibiotic-resistant microbial strains [28].

Retrograde tunneling catheter placement procedure begins with puncture of the vein using an 18 G needle under ultrasound guidance, followed by insertion of a metal guidewire advanced to the level of the right atrium (visualized in real time in the X-ray operating room). In the absence of intraoperative fluoroscopic control, correct guidewire placement can be verified by observing its characteristic reverse movement (rebound with cardiac contractions), performing Doppler ultrasound of the right subclavian vein (RSV) and left subclavian veins (LSV) and the left internal jugular vein (LIJV) to exclude misplacement, or by echocardiography to directly visualize the guidewire and subsequently the catheter tip in the right atrium (ensuring the catheter does not contact the tricuspid valve) [2, 29–31].

Next, a 1.0–1.5 cm skin incision is made at the guidewire entry site down to the platysma muscle. The vein is dilated sequentially along the guidewire, and a 16 Fr breakaway introducer with reverse-flow valve is advanced (Fig. 2). The chosen catheter is then inserted, after which the guidewire and introducer are removed. The catheter is checked for patency and temporarily clamped with a soft clamp. Since blood often leaks paracatheterically (sometimes significantly), a single suture is placed around the catheter through the platysma muscle using an atraumatic absorbable thread. This helps prevent complications such as hematoma formation in the catheter area or bleeding from postoperative wounds.

Next, the right supraclavicular region is anesthetized, a 0.5 cm skin incision is made, and a metal tunneling guide is passed through the subcutaneous tunnel. After dilation, the catheter is pulled through the tunnel and exteriorized, leaving approximately 2 cm of distance from the cuff to the exit site. A replaceable port block is then attached to the external end of the catheter (Fig. 3). Finally, the catheter is filled with heparin solution, and the skin is closed with sutures followed by an aseptic dressing [4, 32].

For antegrade tunneling catheter placement into the right internal jugular vein (RIJV), the procedure begins with ultrasound-guided puncture of the vein using an 18 G needle, followed by insertion of a metal guidewire advanced to the level of the right atrium. A 1.0–1.5 cm skin incision is then made at the guidewire entry site down to the platysma muscle.

Next, a 5–7 mm incision is created in the right shoulder region at the planned exit site, corresponding to the intended subcutaneous position of the catheter cuff (2–3 cm from the cuff location). Using a tunneler, the catheter is advanced subcutaneously toward the venous puncture site and brought out through the skin incision where the guidewire is located.

The vein is then dilated sequentially along the guidewire, and a 15 Fr breakaway introducer with valve is inserted. After removal of the guidewire, the selected catheter is introduced through the introducer (Fig. 4). The catheter is checked for patency, filled with heparin



Fig. 2. 16 Fr Peel-away introducer with integrated blood backflow valve



Fig. 3. Removable unit with ports



Fig. 4. Non-removable unit with ports

solution, and secured. The skin incisions are closed with sutures, and an aseptic dressing is applied.

The diagram illustrating tunneled CVC placement through the right internal jugular vein, along with the external appearance of the catheter, is presented in Fig. 5.

Advantages of retrograde tunneling technology compared to the traditional antegrade insertion technique:

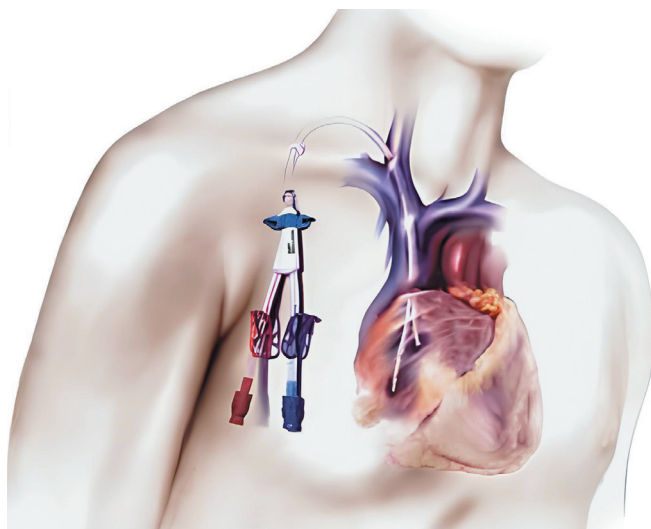


Fig. 5. Final positioning of the tunneled CVC following insertion into the right atrium via the right internal jugular vein

1. Retrograde tunneling allows the catheter tip to be accurately positioned before creating the subcutaneous tunnel, ensuring that the cuff is placed in the optimal location.
2. This technique eliminates the need to advance the catheter tips through the subcutaneous channel prior to venous insertion, thereby reducing the risk of infection.
3. The split V-shaped catheter tip minimizes the risk of occlusion and lowers the level of dialyzed blood recirculation to less than 5%.
4. The presence of a replaceable port block enables continued vascular access in cases where the external portion of the catheter is damaged, thereby extending its functional lifespan.
5. The density of the catheter's material allows it to maintain its bend angle after insertion, preventing breakage at physiological curves and ensuring stable HD flow compared with other catheters [32].

When using the antegrade technique, the catheter is first advanced subcutaneously to the puncture site of the central vein and then positioned in the right atrium. Even a slight deviation from the tunnel trajectory can significantly alter the final position of the catheter tip [33]. Accurate placement of the tip within the right atrium (RA) is a critical determinant of catheter longevity [34, 35]. However, mechanical irritation of the heart tissue by the guidewire or catheter can provoke clinically significant arrhythmias. For this reason, continuous electrocardiographic (ECG) monitoring during tunneled CVC placement is recommended [36].

ADDITIONAL DEVICES USED FOR TUNNELED CVC IMPLANTATION

The revised 2019 KDOQI vascular access guidelines recommend the use of radiographic imaging during tunneled CVC placement to improve procedural success

and enhance patient safety [2]. Ultrasound-guided puncture of the jugular vein significantly reduces the risk of failed cannulation and associated complications [37]. Direct visualization of the guidewire in the IVC and fluoroscopic confirmation of catheter tip placement are considered the gold standard for tunneled CVC insertion. **Fluoroscopy** also enables early detection and timely management of procedural complications [38]. However, its use is limited by high costs and patient exposure to X-rays [39]. In addition, radiological landmarks such as the junction of the superior vena cava (SVC) with the RA or thoracic vertebrae are not always reliable, and extravascular catheter placement may be missed on frontal X-ray images. In uncertain cases, administration of a radiopaque contrast agent is required for precise tip localization. Transesophageal echocardiography can also be used to determine the exact location of the SVC/RA junction [40–42].

ECG monitoring is widely used during tunneled CVC implantation to verify correct catheter tip positioning. When the catheter is inserted from the upper shoulder girdle, a marked increase in P-wave amplitude is recorded on the ECG if the tip is located at the cavo-atrial junction [36]. A study using transesophageal echocardiography confirmed that the maximum P-wave amplitude corresponds precisely to this anatomical location [43]. When the catheter is introduced via the femoral vein, the sequence of ECG changes differs significantly [44]. ECG-assisted tip localization can also be applied in patients with atrial fibrillation [45].

Echocardiography (ECHO). ECHO-guided catheter placement provides direct visualization of the catheter tip in relation to key anatomical structures. This approach helps to avoid malpositioning in the IVC or near the tricuspid valve. Even in cases of low atrial filling, the optimal position within the right atrium can be confirmed by injecting saline into the catheter lumen [29, 30].

Although evidence on the use of ultrasound alone for tunneled CVC positioning remains limited, recent studies have reported promising results. In one series, the authors confirmed correct tip location by visualizing the guidewire within the RA or IVC [46, 47]. More recently, a prospective study of 134 patients undergoing sequential tunneled CVC implantation using an ultrasound-based technique demonstrated its feasibility and safety. The J-shaped tip of the guidewire, located directly at the distal end of the catheter, served as a reliable landmark for safe placement. In this cohort, ultrasound guidance alone was sufficient in 97% of cases; in the remaining 3%, inadequate visualization necessitated supplementary ECG monitoring and saline injection into the catheter lumen, ensuring accurate catheter tip positioning [31].

THE MOST COMMON COMPLICATIONS OF TUNNELED CVCs

The main complications associated with tunneled CVCs include infection, catheter lumen thrombosis, stenosis, and central vein occlusion. Despite advances in catheter design and biomaterials, infectious complications and consequences of central vein stenosis remain significant challenges.

Infectious complications may present as infection of the external catheter exit site, tunnel infection, or catheter-associated bloodstream infection (CABSI). Strategies to reduce infection rates include strict adherence to aseptic technique when connecting tunneled CVCs, education of both patients and dialysis staff, and implementation of local epidemiological surveillance programs [48].

When infection develops at the external catheter exit site, antiseptic dressings (most commonly with chlorhexidine) are applied, which has been shown to reduce the incidence of CABSI [49, 50]. The risk of bacteremia increases proportionally with catheter dwell time. In one study, 16.4% of patients developed CABSI within the first year after catheter insertion, with skin flora microorganisms such as *Staphylococcus aureus* and *Staphylococcus epidermidis* being the most frequently isolated pathogens. Importantly, hematogenous dissemination of these organisms can result in severe complications, including endocarditis, osteomyelitis, septic arthritis, epidural abscess, septic shock, and even death [51].

To reduce CABSI incidence, antimicrobial blocking solutions that inhibit colonization and biofilm formation, often in combination with anticoagulants, are widely used. A common formulation is gentamicin with 4% citrate [52]. Evidence indicates that antimicrobial–citrate combinations are more effective in preventing CABSI than antimicrobial–heparin formulations [53].

Non-antibiotic antimicrobial agents such as taurolidine have also shown benefit. When combined with 4% citrate – or with 4% citrate and weekly urokinase (25,000 units) – taurolidine improves catheter function and significantly reduces CABSI rates [54].

More recently, antimicrobial barrier caps have been introduced. These devices contain a rod impregnated with chlorhexidine acetate, which is inserted into the catheter hub. Chlorhexidine is gradually released into the locking solution, providing continuous antimicrobial activity. Clinical studies have demonstrated that such caps are superior to standard protective caps in reducing CABSI incidence [55, 56].

Catheter lumen thrombosis is among the most frequent complications of tunneled CVCs. It may be classified as internal (thrombus within the catheter lumen, thrombus at the catheter tip, or fibrin sheath formation) and external (thrombosis involving the vessel wall, such as the brachiocephalic trunk, internal jugular vein, subclavian vein; thrombosis of the central veins, including the SVC; or atrial thrombosis) [9].

The pathogenesis is linked to vascular endothelial trauma during catheter insertion and to turbulent blood flow around the catheter. Heparin locks remain the standard method of prevention. In the event of thrombosis, first-line management is local fibrinolytic therapy, most commonly with alteplase, to restore adequate blood flow. Thrombolytic agents have also been evaluated prophylactically as alternatives to heparin locks [57].

A randomized controlled trial demonstrated that a regimen combining taurolidine with heparin (twice weekly) and taurolidine with urokinase (once weekly) significantly reduced both infection and thrombosis compared with 4% citrate locking solution. The use of taurolidine was also associated with improved pharmacoeconomic outcomes, reducing total annual costs per patient [58].

The most serious manifestation is a catheter-related right atrial thrombus (CRAT). In HD patients, CRAT may present with fever, sepsis, or pulmonary embolism, though it is asymptomatic in more than 20% of cases. Optimal management remains debated. Options include catheter removal, anticoagulation, thrombolysis, and surgical thrombectomy [59]. Because premature catheter removal can precipitate pulmonary embolism, removal is generally performed only after initiation of therapeutic anticoagulation. A tailored approach has been proposed: for thrombi <6 cm, catheter removal combined with anticoagulation; for thrombi ≥6 cm, surgical thrombectomy is preferred. Thrombolysis is rarely successful, though it remains an option in cases of hemodynamically unstable thromboembolism [60, 61].

Recent clinical evidence supports these strategies. A prospective study of 178 patients with CRAT confirmed the role of anticoagulation with delayed catheter removal [62]. Similarly, a retrospective study of 20 patients suggested that catheter removal combined with anticoagulant/antiplatelet therapy is effective in HD patients with CRAT [63]. For patients with exhausted vascular access in whom catheter removal is not feasible, combining thrombolytic solution with systemic anticoagulation while retaining the catheter may be considered [64].

There is currently no strong evidence to support treatment of asymptomatic pulmonary embolism. Anticoagulant therapy is recommended only for patients with thromboembolism of the main, lobar, or segmental pulmonary arteries, in those with concomitant deep vein thrombosis, or in patients with cancer [65]. Despite available therapeutic options, mortality remains high: in chronic HD patients, CRAT-related mortality is approximately 18% [59], while pulmonary embolism leads to death within 3 months in approximately 15% of patients [65].

The formation of a fibrinous membrane, composed of smooth muscle cells within a collagen matrix and covered by endothelial cells, plays an important role in the development of venous stenosis. Within a few days, this

structure forms a cuff around the catheter at the vascular entry site and may function as a one-way valve [66, 67].

Central vein stenosis and occlusion are common and severe complications in patients receiving long-term HD, with a reported incidence of 20–50% [2]. In patients with a functioning AVF or SVG on the ipsilateral side, the condition is often associated with more pronounced symptoms than in the general population with this pathology [19].

According to KDOQI guidelines, the preferred first-line treatment is percutaneous transluminal angioplasty (PTA) with or without stent placement [2]. Technical success rates for PTA range from 70% to 90%. However, angioplasty alone can result in intimal rupture, predisposing to restenosis [68].

Stents correct vessel tortuosity, prevent elastic recoil following balloon dilation, eliminate dissections that impede blood flow, and help maintain long-term venous patency [2]. The use of high-pressure balloons coated with antiproliferative agents (paclitaxel) has further improved outcomes. Clinical studies demonstrate superior secondary patency at 6 and 12 months compared with conventional balloon angioplasty [69, 70].

In patients with central vein occlusion, a complex hybrid device, the HD Reliable Outflow (HeRo) graft, has been developed as an alternative. The device consists of a venous outflow component – a radiopaque silicone tube reinforced with braided nitinol (6.3 mm in diameter, 40 cm in length) – and an arterial component, a polytetrafluoroethylene (PTFE) vascular prosthesis

(7.3 mm in diameter, 53 cm in length), connected via a titanium adapter. This design enables long-term HD access by bypassing the stenosed or occluded central venous segment [71].

REPLACEMENT OF TUNNELED CVCs

Catheter dysfunction is defined by KDOQI guidelines as the inability to sustain adequate blood flow for HD without significantly prolonging treatment duration. Causes of catheter dysfunction include mechanical problems such as kinking, fracture, twisting, migration, or malposition of the catheter tip. In such cases, catheter removal or replacement is indicated [2]. Replacement may be performed in two ways: creating a new tunnel and exit site or inserting a guidewire through the existing catheter with or without a new tunnel [72, 73].

STANDARDIZED APPROACH

To ensure the effective and safe implantation and maintenance of tunneled CVCs, adherence to a comprehensive set of measures is essential. Every step of the catheter placement and post-procedural care must follow a unified standard, typically outlined in a standard operating procedure (SOP). Such an SOP not only provides a framework for training new staff but also facilitates consistent monitoring of safety and quality indicators. Presented below is an example of a standardized protocol adapted in our practice to optimize both the implantation and long-term use of tunneled CVCs (Tables 1 and 2) [74].

Table 1

Key steps in the implantation of a tunneled central venous catheter

S/N	Implantation of a tunneled central venous catheter
1	Surgical asepsis: a) surgical hand disinfection b) use of sterile gloves, gown, and face mask c) establishment of a limited sterile surgical field
2	Use of a two-component aseptic solution consisting of alcohol and a residual antimicrobial agent (e.g., chlorhexidine, octenidine dihydrochloride)
3	Preferred site for catheter placement: right internal jugular vein a) catheter placement in the subclavian and femoral veins should be reserved for cases where access to the internal jugular veins is not possible due to occlusion
4	Central vein puncture only under ultrasound guidance
5	The correct catheter tip position (ideally located in the mid-right atrium) should be confirmed by: a) a second (additional) control method, such as ECG, echocardiography, or fluoroscopy b) an aspiration test using a 20 ml syringe prior to final catheter placement
6	Use of sterile dressings for catheter site care, preferably semi-permeable transparent dressings)
7	Teaching patients the basics of asepsis: a) Hand hygiene b) Understanding the potential risks associated with catheter use c) Recognizing early signs of catheter infection d) Receiving clear instructions on how patients should behave with a catheter outside the dialysis unit e) Catheter site care f) Instructions on keeping the area around the catheter dry and clean, no showering for 3 days after catheter placement g) When resuming showering, always use a waterproof dressing

Table 2

Guidelines for the care and removal of a tunneled central venous catheter

S/N	Catheter care
1	Always follow strict aseptic technique when handling the catheter, including the use of sterile gloves and a gown a) Clean the catheter exit site using a chlorhexidine-based antiseptic solution
2	Dressing guidelines: a) Should protect against environmental contamination b) To further minimize infection risk, consider using a chlorhexidine-impregnated dressing c) Change the dressing regularly – at least once per week
3	Apply an antimicrobial locking solution (e.g., based on citrate or taurine)
4	If the patient is diagnosed with intranasal colonization by <i>S. aureus</i> , include mupirocin nasal ointment in the treatment protocol
5	Patient education
	Catheter removal
1	The tunneled catheter should be removed as planned no later than 2 weeks after its last use
2	In the event of thrombosis, the catheter must be promptly replaced with a new one
3	If catheter-associated bloodstream infection (CAIK) or sepsis is suspected, catheter removal should be strongly considered
4	Routine catheter exchange over a guidewire is not recommended

CONCLUSION

Tunneled CVCs have become an indispensable component in the management of patients receiving maintenance HD. Standardized implantation techniques are now well established and enable reliable vascular access in most cases. However, in complex scenarios such as patients with exhausted vascular access, an individualized approach is essential, often requiring the development of new surgical strategies [75].

The authors declare no conflict of interest.

REFERENCES

- Kidney Disease: Improving Global Outcomes (KDIGO) CKD Work Group. KDIGO 2024 Clinical Practice Guideline for the Evaluation and Management of Chronic Kidney Disease. *Kidney Int.* 2024; 105 (4S): S117–S314.
- Lok CE, Huber TS, Lee T et al. KDOQI Clinical Practice Guideline for Vascular Access: 2019 Update. *Am J Kidney Dis.* 2020. 75 (4): S1–S164. doi: 10.1053/j.ajkd.2019.12.001.
- United States Renal Data System. 2023 USRDS Annual Data Report: Epidemiology of Kidney Disease in the United States. Bethesda, MD: National Institute of Diabetes and Digestive and Kidney Diseases, 2023.
- Bernd Schröppel, Lucas Bettac, Lena Schulte-Kemna et al. Placement of tunnelled haemodialysis catheters – interventional standard. *Nephrol Dial Transplant.* 2025; 40: 264–272. https://doi.org/10.1093/ndt/gfae181.
- O'Hare AM, Choi AI, Bertenthal D et al. Age affects outcomes in chronic kidney disease. *J Am Soc Nephrol.* 2007; 18: 2758–2765. https://doi.org/10.1681/ASN.2007040422.
- Schulte-Kemna L, Künzig M, Dallmeier D et al. [Frailty in renal diseases]. *Z Gerontol Geriatr.* 2021; 54: 708–716. https://doi.org/10.1007/s00391-021-01953-0.
- Lyu B, Chan MR, Yevzlin AS et al. Catheter dependence after arteriovenous fistula or graft placement among elderly patients on hemodialysis. *Am J Kidney Dis.* 2021; 78: 399–408.e1. https://doi.org/10.1053/j.ajkd.2020.12.019.
- Boubes K, Shaikh A, Alsaukas Z et al. New directions in ensuring catheter safety. *Adv Chronic Kidney Dis.* 2020; 27: 228–235. https://doi.org/10.1053/j.ackd.2020.02.004.
- Husameddin El Khudari, Merve Ozen, Bridget Kowalczyk et al. Hemodialysis Catheters: Update on Types, Outcomes, Designs and Complications. *Semin Intervent Radiol.* 2022 Feb 18; 39 (1): 90–102. doi: 10.1055/s-0042-1742346.
- D M, Trerotola SO, Clark T. Clinical and Regulatory Considerations for Central Venous Catheters for Hemodialysis. *Clin J Am Soc Nephrol.* 2018; 13 (12): 1924–1932. doi: 10.2215/CJN.14251217.
- Vesely TM, Ravenscroft A. Hemodialysis catheter tip design: observations on fluid flow and recirculation. *J Vasc Access.* 2016; 17 (01): 29–39. doi: 10.5301/jva.5000463.
- Van Der Meersch H, De Bacquer D et al. Hemodialysis catheter design and catheter performance: a randomized controlled trial [published correction appears in *Am J Kidney Dis.* 2015 May; 65 (5): 810]. doi: 10.1053/j.ajkd.2014.02.017.
- Hwang HS, Kang SH, Choi SR et al. Comparison of the palindrome vs. step-tip tunneled hemodialysis catheter: a prospective randomized trial. *Semin Dial.* 2012; 25 (05): 587–591. doi: 10.1111/j.1525-139X.2012.01054.x.
- Benjamin Lazarus, Kevan R Polkinghorne, Martin Gallagher et al. Tunneled Hemodialysis Catheter Tip Design and Risk of Catheter Dysfunction: An Australian Nationwide Cohort Study. *Am J Kidney Dis.* 2024 Apr; 83 (4): 445–455. doi: 10.1053/j.ajkd.2023.09.021.
- Clark TW, Redmond JW, Mantell MP. Initial Clinical Experience: Symmetric-Tip Dialysis Catheter with Helical Flow Characteristics Improves Patient Outcomes. *J Vasc Interv Radiol.* 2015; 26 (10): 1501–1508. doi: 10.1016/j.jvir.2015.06.033.

16. Nadolski GJ, Redmond J, Shin B. Comparison of Clinical Performance of VectorFlow and Palindrome Symmetric-Tip Dialysis Catheters: A Multicenter, Randomized Trial. *J Vasc Interv Radiol*. 2020; 31 (07): 1148–1155. doi: 10.1016/j.jvir.2020.02.001.
17. Anil K Agarwal, Stephen R Ash. Maintenance of blood flow rate on dialysis with self-centering CentrosFLO catheter: A multicenter prospective study. *Hemodial Int*. 2016 Oct; 20 (4): 501–509. doi: 10.1111/hdi.12443.
18. Tal MG, Peixoto AJ, Crowley ST et al. Comparison of side hole versus non side hole high flow hemodialysis catheters. *Hemodial Int*. 2006; 10 (01): 63–67. doi: 10.1111/j.1542-4758.2006.01176.x.
19. Bulent Arslan, Abdulrahman Masrani. Patency and time to malfunction comparison of BioFlo Duramax to Equistream hemodialysis catheters. *Journal of Vascular and Interventional Radiology*. 2016; 27 (3): S199–S200. https://doi.org/10.1016/j.jvir.2015.12.514.
20. May RM, Magin CM, Mann EE. An engineered micro-pattern to reduce bacterial colonization, platelet adhesion and fibrin sheath formation for improved biocompatibility of central venous catheters. *Clin Transl Med*. 2015; 4: 9. doi: 10.1186/s40169-015-0050-9.
21. David W Sutherland Jr, Zachary D Blanks, Xin Zhang. Relationship Between Central Venous Catheter Protein Adsorption and Water Infused Surface Protection Mechanisms. *Artif Organs*. 2018 Nov; 42 (11): E369–E379. doi: 10.1111/aor.13274.
22. Koudounas G, Giannopoulos S, Volteas P et al. Arteriovenous fistula maturation in patients with ipsilateral versus contralateral tunneled dialysis catheter: a systematic review and metaanalysis. *Ann Vasc Surg*. 2024; 103: 14–21. doi: 10.1016/j.avsg.2023.11.048.
23. Engstrom BI, Horvath JJ, Stewart JK et al. Tunneled internal jugular hemodialysis catheters: impact of laterality and tip position on catheter dysfunction and infection rates. *J Vasc Interv Radiol*. 2013; 24: 1295–302. https://doi.org/10.1016/j.jvir.2013.05.035.
24. Ali Akbar Beigi, Ali Sharifi, Hafez Gaheri et al. Placement of long-term hemodialysis catheter (permcath) in patients with end-stage renal disease through external jugular vein. *Advanced Biomedical Research*. 2014 Dec; 3 (1): 252. doi: 10.4103/2277-9175.146381.
25. Pei Wang, Yufei Wang, Yingjin Qiao et al. Retrospective Study of Preferable Alternative Route to Right Internal Jugular Vein for Placing Tunneled Dialysis Catheters: Right External Jugular Vein versus Left Internal Jugular Vein. *PLoS One*. 2016; 11 (1): e0146411. doi: 10.1371/journal.pone.0146411.
26. Yankovoy AG, Zulkarnaev AB. Surgical implantation of a tunnel dialysis catheter into the inferior vena cava. Case report. *Nephrology and Dialysis*. 2023; 25 (1): 111–115. (In Russ.). doi: 10.28996/2618-9801-2023-1-111-115.
27. Hieu M Vo, Raeaha Syeda, Mohammad Ali. Inferior Vena Cava Placement of a Transhepatic Tunneled Dialysis Catheter in a Patient with Atypical Hepatic Venous Anatomy. *A Case Report*. 2024 Sep 13; 16 (9): e69365. doi: 10.7759/cureus.69365.
28. Buetti N, Souweine B, Mermel L et al. Concurrent systemic antibiotics at catheter insertion and intravascular catheter-related infection in the ICU: a post hoc analysis using individual data from five large RCTs. *Clin Microbiol Infect*. 2021; 27: 1279–1284. https://doi.org/10.1016/j.cmi.2020.10.026.
29. Korsten P, Kuczera T, Wallbach M et al. The rapid atrial swirl sign for ultrasound-guided tip positioning of retrogradetunneled hemodialysis catheters: a cross-sectional study from a single center. *J Clin Med*. 2021; 10: 3999. https://doi.org/10.3390/jcm10173999.
30. Da Hora Passos R, Ribeiro M, da Conceição LFMR et al. Agitated saline bubble – enhanced ultrasound for the positioning of cuffed, tunneled dialysis catheters in patients with end-stage renal disease. *J Vasc Access*. 2019; 20: 362–367. https://doi.org/10.1177/1129729818806121.
31. Kächele M, Bettac L, Hofmann C et al. Feasibility analysis of ultrasound-guided placement of tunneled hemodialysis catheters. *Kidney Int Rep*. 2023; 8: 2001–2007. https://doi.org/10.1016/j.ekir.2023.07.03.
32. Bream PR. Update on insertion and complications of central venous catheters for hemodialysis. *Semin Interv Radiol*. 2016; 33: 31–38. doi: 10.1055/s-0036-1572547.
33. Sharma M, Tong WL, Thompson D et al. Placing an appropriate tunneled dialysis catheter in an appropriate patient including the nonconventional sites. *Cardiovasc Diagn Ther*. 2023; 13: 28190–28290. https://doi.org/10.21037/cdt-22-426.
34. Maggiani-Aguilera P, Chávez-Iñiguez JS, Navarro-Gallardo JG et al. The impact of anatomical variables on haemodialysis tunnelled catheter replacement without fluoroscopy. *Nephrology (Carlton)*. 2021; 26: 824–832. doi: 10.1111/nep.13909.
35. Engstrom BI, Horvath JJ, Stewart JK et al. Tunneled internal jugular hemodialysis catheters: impact of laterality and tip position on catheter dysfunction and infection rates. *J Vasc Interv Radiol*. 2013; 24: 1295–1302. https://doi.org/10.1016/j.jvir.2013.05.035.
36. Practice guidelines for central venous access 2020: an updated report by the American Society of Anesthesiologists Task Force on Central Venous Access. *Anesthesiology*. 2020; 132: 8–43. https://doi.org/10.1097/ALN.0000000000002864.
37. Rabindranath KS, Kumar E, Shail R et al. Use of real-time ultrasound guidance for the placement of hemodialysis catheters: a systematic review and meta-analysis of randomized controlled trials. *Am J Kidney Dis*. 2011; 58: 964–970. https://doi.org/10.1053/j.ajkd.2011.07.025.
38. Prasad P, Vachharajani TJ. Non-fluoroscopic techniques to insert a tunneled hemodialysis catheter. *Kidney Int Rep*. 2023; 8: 2191–2193. https://doi.org/10.1016/j.ekir.2023.09.023.
39. Yevzlin AS, Song GU, Sanchez RJ et al. Fluoroscopically guided vs modified traditional placement of tunneled hemodialysis catheters: clinical outcomes and cost analysis. *J Vasc Access*. 2007; 8: 245–251. https://doi.org/10.1177/112972980700800405.
40. Hsu JH, Wang CK, Chu KS et al. Comparison of radiographic landmarks and the echocardiographic SVC/RA junction in the positioning of long-term central venous catheters. *Acta Anaesthesiol Scand*. 2006; 50: 731–735. https://doi.org/10.1111/j.1399-6576.2006.01025.x.
41. Schuepfer AC, Schuepfer G, Mauch J. Three near fatal or fatal complications during implantation of tunnelled

- hemodialysis catheters learning from experts. *Anaesthesiologie*. 2022; 71: 541–545.
42. Rattka M, Rottbauer W, Markovic S. Acute chest pain following parenteral infusion. *Dtsch Arzteblatt Int*. 2021; 118: 841. doi: 10.3238/arztebl.m2021.0094.
 43. Jeon Y, Ryu HG, Yoon SZ et al. Transesophageal echocardiographic evaluation of ECG-guided central venous catheter placement. *Can J Anaesth*. 2006; 53: 978–983. <https://doi.org/10.1007/BF03022525>.
 44. Gibault P, Desruennes E, Bourgain JL. Peroperative electrocardiographic control of catheter tip position during implantation of femoral venous ports. *J Vasc Access*. 2015; 16: 294–298. <https://doi.org/10.5301/jva.5000386>.
 45. Steinhagen F, Kanthak M, Kukuk G et al. Electrocardiography-controlled central venous catheter tip positioning in patients with atrial fibrillation. *J Vasc Access*. 2018; 19: 528–534. <https://doi.org/10.1177/1129729818757976>.
 46. Pereira Junior GM, Souza Alvarenga A, Almeida Felipe CR et al. Use of ultrasound to confirm guidewire position in hemodialysis catheter implantation. *J Nephrol*. 2022; 35: 1515–1519. <https://doi.org/10.1007/s40620-022-01346-5>.
 47. Kairidibo, Pandey AR, Dwivedi V et al. “Rapid Atrial Swirl Sign”: A Better Tool Than the Landmark Technique for Ensuring Correct Depth of Insertion of Central Venous Catheters. *Cureus*. 2024 Jul 23; 16 (7): e65211. doi: 10.7759/cureus.65211.
 48. Fisher M, Golestaneh L, Allon M et al. Prevention of bloodstream infections in patients undergoing hemodialysis. *Clin J Am Soc Nephrol*. 2020; 15: 132–151. <https://doi.org/10.2215/CJN.06820619>.
 49. Apata IW, Hanfelt J, Bailey JL et al. Chlorhexidine-impregnated transparent dressings decrease catheter-related infections in hemodialysis patients: a quality improvement project. *J Vasc Access*. 2017; 18: 103–108. <https://doi.org/10.5301/jva.5000658>.
 50. Hou Y, Griffin L, Bernatchez SF et al. Comparative Effectiveness of 2 Chlorhexidine Gluconate-Containing Dressings in Reducing Central Line-Associated Bloodstream Infections, Hospital Stay, and Costs. *Inquiry*. 2023 Jan-Dec; 60: 469580231214751. doi: 10.1177/00469580231214751.
 51. Gabriele Donati, Alessandra Spazzoli, Anna Laura Croci Chiocchini. Bloodstream infections and patient survival with tunneled-cuffed catheters for hemodialysis: A single-center observational study. *Int J Artif Organs*. 2020 Dec; 43 (12): 767–773. doi: 10.1177/0391398820917148.
 52. Carol L Moore, Anatole Besarab, Marie Ajluni. Comparative effectiveness of two catheter locking solutions to reduce catheter-related bloodstream infection in hemodialysis patients. *Clin J Am Soc Nephrol*. 2014 Jul; 9 (7): 1232–1239. doi: 10.2215/CJN.11291113.
 53. Hongxia Mai, Yuliang Zhao, Stephen Salerno et al. Citrate versus heparin lock for prevention of hemodialysis catheter-related complications: updated systematic review and meta-analysis of randomized controlled trials. *Int Urol Nephrol*. 2019 Jun; 51 (6): 1019–1033. doi: 10.1007/s11255-019-02150-0.
 54. Fadwa Al-Ali, Ahmad F Hamdy, Abdullah Hamad et al. Safety and efficacy of taurolidine/urokinase versus taurolidine/heparin as a tunneled catheter lock solution in hemodialysis patients: a prospective, randomized, controlled study. *Nephrol Dial Transplant*. 2018 Apr 1; 33 (4): 619–626. doi: 10.1093/ndt/gfx187.
 55. Jeffrey L Hymes, Ann Mooney, Carly Van Zandt et al. Dialysis Catheter-Related Bloodstream Infections: A Cluster-Randomized Trial of the ClearGuard HD Antimicrobial Barrier Cap. *Am J Kidney Dis*. 2017 Feb; 69 (2): 220–227. doi: 10.1053/j.ajkd.2016.09.014.
 56. Amy Nau, Troy Richardson, Diana Cardwell et al. Use of ClearGuard HD caps in pediatric hemodialysis patients. *Pediatr Nephrol*. 2024 Jul; 39 (7): 2171–2175. doi: 10.1007/s00467-023-06273-6.
 57. Hemmelgarn BR, Moist LM, Lok CE et al. Prevention of dialysis catheter malfunction with recombinant tissue plasminogen activator. *N Engl J Med*. 2011; 364: 303–312. <https://doi.org/10.1056/NEJMoa1011376>.
 58. Winnicki W, Herkner H, Lorenz M et al. Taurolidine-based catheter lock regimen significantly reduces overall costs, infection, and dysfunction rates of tunneled hemodialysis catheters. *Kidney Int*. 2018; 93: 753–760. <https://doi.org/10.1016/j.kint.2017.06.026>.
 59. Tran MH, Wilco T, Tran PN. Catheter-related right atrial thrombosis. *J Vasc Access*. 2020; 21 (3): 300–307. doi: 10.1177/1129729819873851.
 60. Stavroulopoulos A, Aresti V, Zounis C. Right atrial thrombi complicating haemodialysis catheters. A meta-analysis of reported cases and a proposal of a management algorithm. *Nephrol Dial Transplant*. 2012; 27 (7): 2936–2944. doi: 10.1093/ndt/gfr739.
 61. Chen L, Chen B, Lai Q et al. Management of catheter-related right atrial thrombus in hemodialysis: a systematic review. *BMC Cardiovasc Disord*. 2024 Nov 20; 24 (1): 656. <https://doi.org/10.1186/s12872-024-04330-y>.
 62. Sun J, Liu Y, Chen J et al. Catheter replacement combined with antiplatelet therapy in hemodialysis catheter-related right atrial thrombus: a potential treatment approach. *BMC Cardiovasc Disord*. 2025 Jan 16; 25 (1): 26. <https://doi.org/10.1186/s12872-025-04485-2>.
 63. Yang H, Chen F, Jiao H et al. Management of tunneled-cuffed catheter-related right atrial thrombosis in hemodialysis patients. *J Vasc Surg*. 2018; 68 (5): 1491–1498. doi: 10.1016/j.jvs.2018.02.039.
 64. Rossi L, Libutti P, Casucci F et al. Is the removal of a central venous catheter always necessary in the context of catheter-related right atrial thrombosis? *J Vasc Access*. 2018; 20 (1): 98–101. doi: 10.1177/1129729818774438.
 65. Kruger PC, Eikelboom JW, Douketis JD et al. Pulmonary embolism: update on diagnosis and management. *Med J Aust*. 2019 Jul; 211 (2): 82–87. doi: 10.5694/mja2.50233.
 66. Ahmed R, Chapman SA, Tantrige P et al. TuLIP (Tunneled Line Intraluminal Plasty): An Alternative Technique for Salvaging Haemodialysis Catheter Patency in Fibrin Sheath Formation. *Cardiovasc Intervent Radiol*. 2019; 42: 770–774. <https://doi.org/10.1007/s00270-019-02189-7>.
 67. Lizhu Jin, Hui Wang, Tianlei Cui et al. [Catheter Replacement Methods in Hemodialysis Patients With Dysfunctional Tunneled-Cuffed Catheters With Fibrin Sheaths]. *Sichuan Da Xue Xue Bao Yi Xue Ban*. 2023 Nov 20; 54 (6): 1283–1287. doi: 10.12182/20231160201.

68. Nayak-Rao S, Ramanna B, Subramanyam K et al. Endovascular intervention for central venous stenosis in hemodialysis patients: A single-center experience. *Indian J Nephrol.* 2020; 0 (0): 0. doi: 10.4103/ijn.IJN_343_19.
69. Kitrou PM, Papadimitos P, Spiliopoulos S et al. Paclitaxel-Coated Balloons for the Treatment of Symptomatic Central Venous Stenosis in Dialysis Access: Results from a Randomized Controlled Trial. *J Vasc Interv Radiol.* 2017 Jun; 28 (6): 811–817. doi: 10.1016/j.jvir.2017.03.007.
70. Panagiotis M Kitrou, Tobias Steinke, Rami El Hage et al. Paclitaxel-Coated Balloons for the Treatment of Symptomatic Central Venous Stenosis in Vascular Access: Results from a European, Multicenter, Single-Arm Retrospective Analysis. *J Endovasc Ther.* 2021 Jun; 28 (3): 442–451. doi: 10.1177/15266028211007471.
71. David M Tabriz, Bulent Arslan. HeRO Graft: Indications, Technique, Outcomes, and Secondary Intervention. *Semin Intervent Radiol.* 2022 Feb 18; 39 (1): 82–89. doi: 10.1055/s-0042-1742391.
72. Leclaire C, Lobbedez T, Henri P et al. A new procedure for guidewire exchange of tunneled hemodialysis catheters in chronic hemodialysis patients: a pilot study. *Blood Purif.* 2023; 52: 91–100. <https://doi.org/10.1159/000525436>.
73. Wang J, Nguyen TA, Chin AI et al. Treatment of tunneled dialysis catheter malfunction: revision versus exchange. *J Vasc Access.* 2016; 17: 328–332. <https://doi.org/10.5301/jva.5000533>.
74. Lazarus B, Kotwal S, Gallagher M et al. Effect of a multifaceted intervention on the incidence of hemodialysis catheter dysfunction in a national stepped-wedge cluster randomized trial. *Kidney Int Rep.* 2023; 8: 1941–1950. <https://doi.org/10.1016/j.ekir.2023.07.013>.
75. Niyyar VD, Beathard G. Interventional nephrology: opportunities and challenges. *Adv Chronic Kidney Dis.* 2020; 27: 344–349.e1. <https://doi.org/10.1053/j.ackd.2020.05.013>.

The article was submitted to the journal on 20.02.2025