REVIEW

Dialysis catheters in the ICU: selection, insertion and maintenance

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Purpose of review

Choosing the best catheter for renal replacement therapy (RRT) is not an easy task. Beyond catheter length, many of its properties can influence effectiveness of the RRT session. Maintenance between sessions, particularly the locking solution, also impacts catheter lifespan and infection rates.

Recent findings

Many innovations in dialysis catheters have been proposed by the industry over the past decade, including the material used, the shape of the lumens and the position of the inflow and outflow holes. Impregnated catheters have also been developed to prevent catheter-related infections. Many locking solutions are available, either for maintaining catheter patency or for preventing infections.

Summary

Although studies conducted in the specific context of the ICU are still scarce, some conclusions can be drawn. Catheter length must be adapted to the insertion site to reach an area of high blood flow. Kidney-shape lumens appear to be less thrombogenic and seem to prevent catheter dysfunction. Catheter tip and lumen holes also affect catheter function. For catheter locking, 4% citrate appears nowadays as one of the best options, but taurolidine-based solutions are also interesting.

Keywords

citrate lock, dialysis catheter, ICU, renal replacement therapy

INTRODUCTION

Approximately 13.5% of ICU patients require renal replacement therapy (RRT) and many of these have a temporary dialysis catheter inserted for this purpose [1]. Catheter choice and maintenance are of major importance since RRT efficiency depends on these aspects. Furthermore, dialysis catheters may lead to medical complications such as venous thrombosis or catheter-related bloodstream infection (CRBSI).

In this review, we aim to summarize how to choose and insert a dialysis catheter as well as how to maintain catheter patency and reduce catheter-associated complications. First, we will review the different characteristics that must be considered for dialysis catheter selection and how to insert it for best effectiveness and safety. Second, we will discuss how to maintain it, especially the different locking solutions that may be used to improve its lifespan and patency.

CATHETER CHOICE

Choosing the optimal catheter design is of critical importance to allow a high blood flow rate inside the catheter (>300 ml/min). This is mandatory for an effective RRT session and to reduce the risk of catheter thrombosis. To optimize blood flow inside the lumens, different shapes and lengths have been developed. This review will focus on nontunneled and dual-lumen catheters because they are the most widely used temporary catheters in the ICU, as recommended by the KDIGO guidelines [2]. In accordance with the *nomenclature standardization initiative,* lumens are designated as the in-flow lumen (with a negative pressure) and the out-flow lumen (with a positive pressure) [3]. According to Poiseuille law, blood flow inside the catheter will increase with lumen diameter and decrease with its

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KEY POINTS

- Catheter length, diameter, tip conformation and lumens holes directly affect the effectiveness of a RRT session.
- The optimal lumens shape developed to date is the cycle-C (or kidney-shape).
- Insufficient data are available to recommend the use of coated dialysis catheter in the ICU so far.
- 4% citrate seems to be the preferable locking solution for dialysis catheters.
- Taurolidine-based locks could be an interesting alternative.

length [4]. Fluid dynamics, and therefore blood flow, will be impaired if there are turbulences at the catheter tip or a high contact surface between blood and catheter wall [5]. Therefore, the surface-to-volume ratio must be as high as possible, and an angular conformation of the lumens must be avoided to reduce shear stress and hydraulic resistances. In a recent study, Bellomo *et al.* [6] showed that using a larger gauge catheter (13.5 Fr) was independently associated with the ability to deliver a higher treatment dose. The catheter external diameter is also of importance since a larger diameter is associated with a greater risk of venous thrombosis on the catheter's external surface. A compromise must be found between blood flow inside the catheter and thrombosis risk, with an optimization of the inner-to-outer diameter ratio.

Considering these parameters, different lumen shapes have been developed and studied almost exclusively in mechanistic models (Fig. 1) [7,8▪]. The coaxial catheter offers large blood contact surfaces, and there are acute angles; this catheter is therefore no longer recommended. The double-O catheter combines two cylindrical lumens, side by side in an oval catheter; its main disadvantage is its large external diameter. The double-D is a widely used catheter, but as its internal surface is divided in two symmetrical D-shape lumens, there are acute angles. The cycle-C or kidney shape combines the advantages of the two previous shapes; large lumens (inflow lumen is larger than outflow) with no acute angle, both associated in a smaller outer diameter catheter.

Catheter tip shape also plays a crucial role to reach treatment objectives, as the recirculation rate directly depends on it. Different tips have been developed over the past decade but there is a lack of comparative studies concerning temporary catheters. In a mechanical model, low recirculation rates have been obtained with the split tip, step tip (or shotgun) and symmetric tip, but recirculation increased with lines connected in reverse configuration, mainly with nonsymmetric tips [9].

Size and position of the lumen holes may also generate blood turbulences at the catheter extremity and may decrease blood flow and generate blood clotting. Blood turbulences can be prevented by using two wide entrance holes and avoiding multiple small lateral holes. Aspiration through side holes may induce a suction of the vascular wall, leading to the impossibility to maintain the desired blood flow rate. This phenomenon of wall suction may also induce endothelial damage and vascular thrombosis [10]. Moreover, a comparative study of tunneled catheters with side holes versus without side holes indicates a reduced infection rate with catheters that do not have side holes; these may generate microthrombi, therefore increasing infectious complications [11]. It could thus be recommended to avoid tips with side holes, although the evidence does not come from high-quality studies.

Various materials for dialysis catheters have been developed and each present advantages and pitfalls. Therefore, catheter material must be chosen carefully. The ideal material is biocompatible, rigid at room temperature to make insertion easier, and softer at body temperature to adapt to vessel conformity and avoid vascular damage. The most used materials are polyurethane and silicone. Polyurethane catheters have thinner walls, improving the inner-to-outer diameter ratio. Silicon catheters are more biocompatible and appear to be less thrombogenic; in general, they are also softer and more kink-resistant [12].

To reduce thrombogenicity, heparin-coated catheters have been tested, mainly in chronic dialysis patients, and with tunneled catheters. In a retrospective case–control study, heparin coating did not improve catheter lifespan [13]. Another retrospective study confirmed that heparin coating does not reduce malfunction rate, but that it decreases the incidence of CRBSI [14]. Other coatings specifically aiming at preventing catheter infections have also been studied. Silver coating failed to reduce the infectious risk associated with central venous catheters but also with tunneled hemodialysis catheters [15,16]. A randomized study including patients requiring hemodialysis for acute kidney injury concluded that the use of polyurethane hemodialysis catheters impregnated with minocycline and rifampicin decreased the risk of CRBSI [17]. However, as for central venous catheters, these conclusions must be considered very carefully as it is uncertain whether or not such results would persist in units with low CRBSI rates [18]. Regarding the paucity of

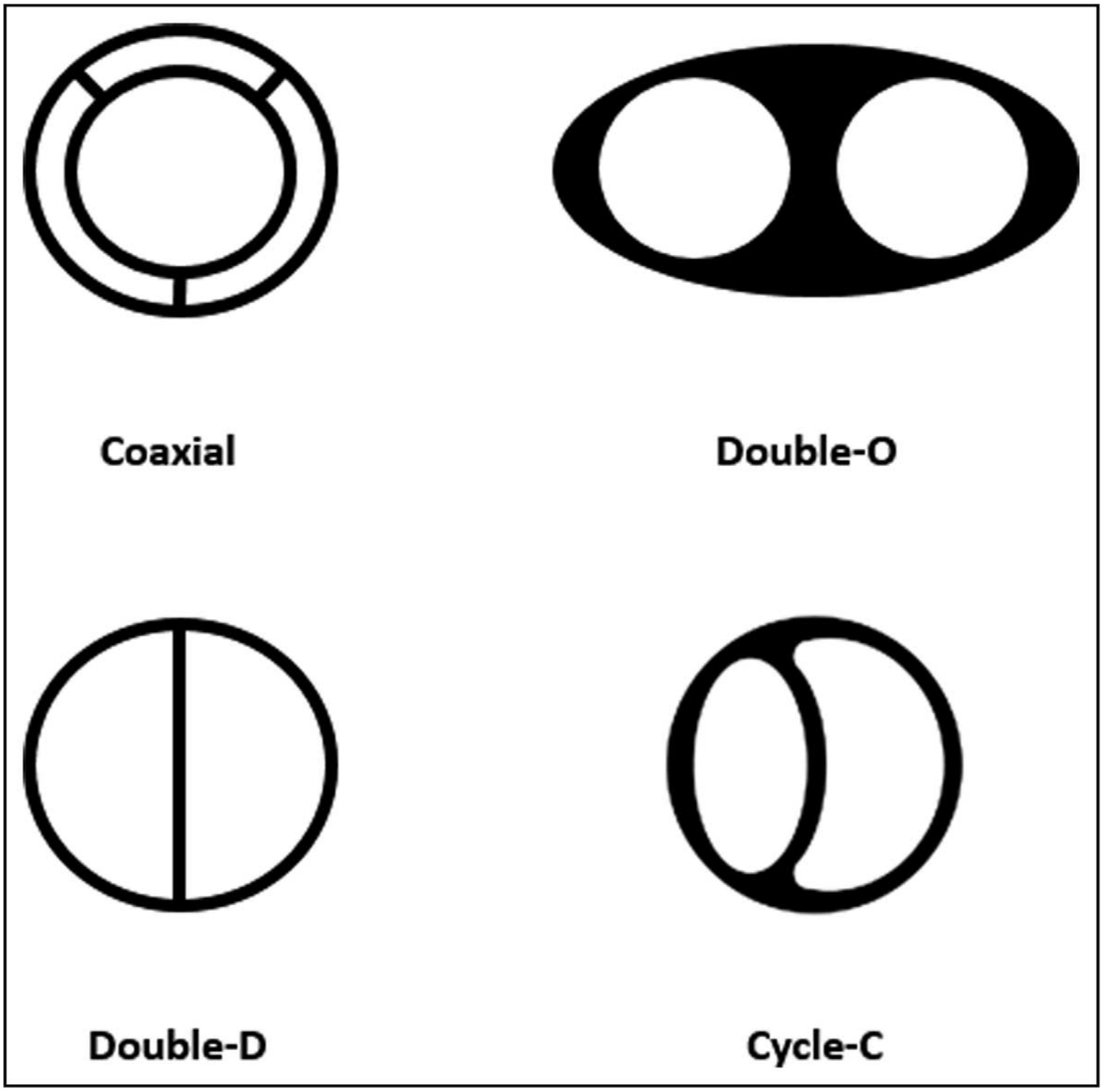

FIGURE 1. Different catheter lumen shapes.

studies evaluating surface-coated nontunneled catheters in the ICU and their increased cost, it seems difficult to recommend their use.

CATHETER INSERTION

After choosing the most appropriate catheter for the particular clinical situation, the physician must proceed to catheter insertion. Numerous studies have compared the different sites in terms of RRT performance and occurrence of complications. Catheter dysfunction should be defined as 'the inability to complete a single dialysis session without triggering recurrent pressure alarms or reproducibly deliver a mean dialysis blood flow at least 300 ml/min or provide a Kt/V more than 1.2 in 4 h or less' [19▪▪]. In contrast with older studies, recent large trials suggested that internal jugular and femoral sites are similar in terms of catheter dysfunctions and patient safety [20–23]. One study suggested that the femoral site improved RRT circuit lifespan, as compared with jugular site [23]. However, when the side of insertion was taken into account, the right internal jugular site was associated with less catheter dysfunctions [21]. Concerning infection risk, jugular access does not appear to reduce the risk compared with femoral access, except among adults with a high BMI (>28 kg/m^2) [20,24,25]. Taking these results together, and according to the KDIGO guidelines, the right jugular vein must be the first-line choice [2]. As second-line, the femoral access, right or left is recommended, and as a last resort the left jugular vein is recommended. The subclavian veins should be avoided because of a high risk of dysfunction and venous thrombosis or stenosis, which would compromise arterio-venous fistula creation in case of end-stage renal disease.

Catheter length must be long enough to ensure the tip is placed in a high blood flow area. Such tip positioning will allow for high blood flow rate inside the catheter and reduce the risks of recirculation and thrombosis [26]. The optimal tip position when the catheter is inserted in a jugular vein is still debated, and it is not clear whether the distal tip must be in the atrium or in the inferior portion of the superior vena cava [27,28]. The cavo-atrial junction is therefore often recommended. The tip must be in the inferior vena cava for catheters inserted through the femoral vein. To optimize tip position, the following lengths are recommended (for standard anatomical conditions) regarding the insertion site: 25 cm for the femoral vein, 20 cm for the left jugular vein, and 15 cm for the right jugular vein [2].

Recent studies and international guidelines recommend the use of ultrasound guidance during insertion to reduce the risk of CRBSI and immediate complications [29]. The use of CRBSI prevention bundles, including sterile environment, preparation with alcoholic chlorhexidine and hermetic dressings is mandatory to prevent infections [30]. In France, the ICU-associated infections network survey for the year 2016 found a CRBSI rate for hemodialysis catheter of 0.65 for 1000 catheter-days [31].

For catheters inserted in the superior vena cava, post procedural verification of tip position with chest radiography is mandatory before initiating RRT [2]. Per procedural control with intracavitary ECG guidance could be an option, as it is proven to be safe and sensitive to predict the tip position during central venous catheter insertion. However, few trials concerning dialysis catheters have been published so far [32].

CATHETER MAINTENANCE

After insertion, correct daily maintenance is mandatory to keep catheter patency and extend its lifespan. First, it is of primary importance to avoid blood deposits in the catheter lumens before applying the locking solution. Each lumen of the dialysis catheter must be flushed full strength as fast as possible with at least 10 ml of saline immediately after blood contact. Lines must be clamped in a positive pressure manner to limit the aspiration effect of clamping, which can attract blood into the catheter extremity, thus leading to thrombosis. After such rapid flushing, a locking solution can be instilled into the catheter, to avoid catheter thrombosis and infection (Table 1). This lock must be injected slowly (over 10 s), and the volume instilled must match with the internal volume of each lumen.

Unfractionated heparin is still considered as the reference for dialysis catheter locks. However, heparin use is associated with numerous complications. For instance, systemic anticoagulation occurs frequently in critically ill patients after lock with heparin [33■]. This can be due to inadvertent excessive volume instilled, but also to heparin release from the catheter into systemic circulation. Other complications include allergic reactions and heparin-induced thrombocytopenia [34,35]. Moreover, although heparin should prevent thrombosis better than saline solution, it is deprived of antimicrobial effect.

Antimicrobial solutions have thus been proposed to prevent biofilm formation and CRBSI.

Table 1. Advantages and drawbacks of the different available locking solutions for hemodialysis catheters

Lock solution	Advantages	Drawbacks
Heparin	Cheap, easily available	Systemic anticoagulation, heparin-induced thrombocytopenia, no antimicrobial effect
Antibiotic (vancomycin, gentamycin…)	↓ CRBSI rate	Selection of drug-resistant bacteria
Ethanol	Theoretically antiseptic	No difference in CRBSI rate vs. placebo, biocompatibility issues with catheter material
Taurolidine	↓ CRBSI vs. 4% citrate in hemodialysis patients, ↓ rt-PA use	Different associations (heparin, citrate, urokinase), with different properties, expensive (but cost-effective?)
30–46.7% Citrate	↓ CRBSI vs. heparin, ↓ catheter malfunctions vs. saline	Metabolic complications (hypocalcemia), no longer recommended
1–7% Citrate	↓ CRBSI vs. heparin, ↓ catheter exchange vs. heparin, cost-effective vs. heparin	Specific study on ICU patients recently completed, results available soon

CRBSI, catheter-related bloodstream infection.

To be active on the biofilm, a high concentration of the antimicrobial agent is required. This strategy is effective in reducing catheter-related infections in chronic hemodialysis patients [36]. A recent meta-analysis suggested that lock with gentamicin and heparin was associated with the lowest rates of CRBSI, vancomycin and heparin with the lowest cutaneous exit site infections, and gentamicin and citrate with the lowest all-cause mortality [37]. Another meta-analysis concluded that, compared with heparin, antimicrobial locks (antibiotics and nonantibiotics – e.g. ethanol, citrate, taurolidine) probably reduce catheter-related infections, with no difference in thrombosis prevention. The combination of both lock solutions seems to reduce catheter thrombosis rates [38▪]. However, repeated exposure to antibiotics results in selection of drug-resistant bacteria [39,40]. Ethanol could represent an interesting alternative to antibiotic agents, yet it did not reduce the incidence of CRBSI compared with saline in a randomized controlled trial (RCT) involving nearly 1500 ICU patients and 13 000 catheter-days [41]. Moreover, ethanol compatibility with the catheter material must be verified, especially with polyurethane catheters [42,43].

In a recent RCT, taurolidine-based solutions showed promising results. Nearly 100 chronic hemodialysis patients were randomized to receive either locks with 4% citrate three times a week, or with taurolidine–citrate–heparin on the two first sessions and taurolidine–citrate–urokinase on the last session of the week. Over 15 000 catheter-days, patients in the taurolidine group developed fewer CRBSI and required less alteplase rescue therapy for catheter thrombosis; this strategy was cost-effective [44▪▪]. Another RCT compared taurolidine–heparin and taurolidine–citrate–urokinase in 160 chronic hemodialysis patients over a 6-month period. In the taurolidine–citrate–urokinase group, catheter exchange rate (for thrombosis or CRBSI) was significantly lower, and rt-PA rescue therapy was used less often. A trend toward higher blood flow rates was also observed in the taurolidine–citrate–urokinase group [45▪▪].

By chelating calcium, citrate impedes coagulation cascade activation. Citrate solutions can be a seducing alternative to the previously cited locking solutions. Highly concentrated trisodium citrate solutions also present antimicrobial properties. In a RCT involving almost 300 hemodialysis patients, significantly fewer catheters were removed because of any complication in the 30% citrate versus the unfractionated heparin group. No significant difference was observed for thrombosis rate, but there were fewer major bleeding events in the citrate group. The most important effect was the protection against infection. Indeed, this study was even stopped prematurely after the observation of considerably lower rates of CRBSI in the citrate group as compared with that in the heparin group (1.1 vs. 4.4 per 1000 catheter-days, respectively) [46].

Similar incidence of CRBSI (1.6 per 1000 catheter-days) was observed in critically ill patients, for whom catheter was locked with 4 or 30% citrate [47]. In a RCT involving 78 ICU patients, 46.7% citrate doubled catheter lifespan as compared with saline. Catheter malfunctions were five times less frequent in the citrate group. The time to occurrence of infection was also longer in the citrate group [48]. In a propensity score matched cohort of 600 ICU patients, catheter-tip colonization incidence in the 46.7% citrate lock group was half that of the control (heparin or saline) group. Risk of CRBSI was low and not significantly different between groups (1.1 vs. 1.8 per 1000 catheter-days in the citrate and control groups, respectively) [49].

In 2000, after a fatal complication occurred with a 46.7% citrate lock, the FDA discontinued the use of this product in the USA. Concentrated citrate solutions are no longer recommended because of severe metabolic complications such as severe hypocalcemia [50]. To support such decision, a recent meta-analysis in chronic hemodialysis patients found that antimicrobial-containing citrate lock with low (1–4%) to moderate (4.6–7%) citrate concentration, rather than highly concentrated (30–46.7%) citrate solutions, were superior to heparin in lowering the incidence of CRBSI [51]. A before and after study concluded that 4% citrate led to fewer catheter exchanges and need for rt-PA use, as compared with heparin [52]. The cost-effectiveness of citrate versus heparin was confirmed in another before and after study, representing more than 60 000 catheter-days. The incidence of CRBSI was not different between groups, but indeed very low (<1 per 1000 catheter-days) [53]. As citrate is associated with fewer side effects than heparin, it seems to be a better locking agent [54]. Concerning the specific ICU population, data regarding the efficacy of 4% citrate are very scarce. The VERROU-REA study, a RCT involving 400 ICU patients and comparing heparin with 4% trisodium citrate for dialysis catheter locks, has recently been completed [55]. Results should be available soon.

CONCLUSION

The main finding of this review is that we lack studies that have specifically focused on temporary dialysis catheters in ICU patients. Most studies were conducted in chronic hemodialysis patients and used no consensual definition of catheter dysfunction.

Future research should use the recently published definition of catheter dysfunction to address these pitfalls.

Catheter optimization, with enhanced designs and materials, has become a very dynamic area of industrial research. However, clinical and economic studies to guide the choice of a certain catheter are still scarce. Therefore, physicians must choose dialysis catheters according to the type of patients they treat and local specificities (e.g. high CRBSI rate in the unit, use of high blood flow rates).

Locking solutions may maintain dialysis catheter patency and prevent infections. Heparin locks can induce systemic anticoagulation by leakage from the catheter tip. Highly concentrated citrate solutions may generate severe metabolic side effects via leakage in the systemic circulation. Antibiotic-containing locks are generally effective in reducing CRBSI, but may lead to selection of resistant bacteria. Low concentration (4%) citrate seems safe and effective, however it has only been extensively studied in chronic hemodialysis patients and not in the intensive care context. Taurolidine-containing solutions may also represent an interesting alternative.

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Conflicts of interest

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