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REVIEW

Central vascular access in kidney and cancer care: devices, biomaterial strategies, and prevention of complications

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Ivana Campia[1], Cécile Oury[2,3], Patrizio Lancellotti[2,4], Marco Straccia[1]

[1]FRESCI, SCIENCE&STRATEGY SL, Terrassa, Catalonia, 08233, Spain
[2]GIGA Research Institute, University of Liège, Liège, Walloon Region, Belgium
[3]CM4Cure SA, Liège, Walloon Region, Belgium
[4]Cardiology Department, CHU de Liège - Hopital du Sart Tilman Cardiologie, Liège, Walloon Region, Belgium

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Abstract

Chronic kidney disease (CKD) and cancer are among the most prevalent chronic conditions that increasingly demand reliable long-term central venous access devices (CVADs), including central venous catheters (CVCs), peripherally inserted central catheters (PICCs), and implantable ports (PORTs). Despite their essential role, CVAD-related complications, primarily infections and thrombosis, continue to compromise patient safety and burden healthcare systems, remaining a major challenge. Beyond patient- and procedure-related factors, device-intrinsic characteristics such as material composition, surface properties, and design features critically determine thrombogenicity, infection risk, and overall performance. This review provides recent advances in CVAD biomaterials, emphasizing surface engineering strategies aimed at antimicrobial activity, antithrombogenicity, and multifunctional performance. Antimicrobial coatings, antithrombogenic surfaces, and novel polymeric designs demonstrate promising potential to mitigate infection and thrombotic events. However, most innovations are currently unfunctional or lack long-term clinical validation, and their translation into practice is constrained by challenges in standardization, durability, and multifunctional integration. CKD and cancer populations are presented as case studies to illustrate how targeted biomaterial design and engineering can optimize device outcomes. Finally, we discuss future perspectives, emphasizing the need for interdisciplinary biomaterials research combining materials science, engineering, and clinical expertise to develop durable, multifunctional CVAD surfaces that enhance safety, extend device longevity, and reduce the healthcare burden associated with long-term vascular access in high-

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risk patients.

Keywords
Central venous access devices, Biomaterials, Surface modification, Catheter-related infections, Catheter-related thrombosis.



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Corresponding author: Marco Straccia (marco.straccia@fre-sci.com)

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Statement of significance

Central venous access devices are indispensable in dialysis and cancer care, yet their long-term performance remains limited by infection and thrombosis. This review highlights that these complications are critically shaped by biomaterial composition and surface properties at the blood–device interface. By integrating evidence from nephrology and oncology settings, this review shows how material selection, surface engineering, and multifunctional coating strategies can improve hemocompatibility, limit microbial colonization, and enhance device durability. It also underscores a key translational challenge: many promising technologies remain uni-functional or insufficiently validated clinically. These insights provide a biomaterials-focused framework for the design of safer and longer-lasting vascular access devices.

1. Introduction

Central venous access devices (CVADs), including central venous catheters (CVCs), peripherally inserted central catheters (PICCs), and implantable ports (PORTs), are widely used across diverse clinical settings, as life-threatening conditions for patients in intensive care, parenteral nutrition, or long-term intravenous therapies.[1,2] CVADs serve as key vascular access for patients with chronic kidney disease (CKD) and cancer, enabling effective delivery of hemodialysis and systemic anticancer therapy (SACT). CKD affects more than 800 million people globally,[3] with prevalence increasing by more than 30% over the last three decades.[4] New cases more than doubled between 1990 and 2019, reaching 18.99 million in 2019,[5] while CKD-related deaths are projected to rise from 1.2 million in 2017 to over 1.8 million by 2030.[6] In 2010, more than 2.6 million people with CKD progressed to end-stage renal disease (ESRD), undergoing dialysis or receiving a renal transplant, and this number is expected to reach 5.4 million by 2030.[4,7] In nephrology, reliance on central vascular access has increased over the past decade: between 2018 and 2022, the proportion of patients initiating hemodialysis with a catheter rose by 3.9%, reaching 84.7% in 2022.[8]

Globally, cancer incidence is also rising. According to recent estimates by the International Agency for Research on Cancer (IARC) and the American Cancer Society (ACS), 20 million new cancer cases and 9.7 million deaths occurred in 2022,[9] with projections suggesting approximately 35 million new cases and 18.5 million deaths annually by 2050.[9,10] The number of patients requiring SACT as first-line therapy is expected to increase from 9.8 million in 2018 to 15 million annually by 2040.[11] These trends highlight CKD and cancer populations as relevant case studies to examine the challenges and optimization strategies for CVAD use. While CVADs improve patient comfort, minimize repeated procedures, and support consistent treatment delivery, their use is frequently accompanied by adverse events (AEs) that can compromise outcomes. Due to direct and prolonged blood contact, they introduce significant risks that must be carefully considered, including thrombosis, infection, and hemolysis. These complications are influenced not only by procedural and patient-specific factors but critically by device design and material properties. Understanding how CVADs materials affect blood compatibility, thrombogenicity, and infection risk is crucial not only for preventing AEs, but also for optimizing therapy, improving patient outcomes, and guiding the development of safer vascular access technologies.[12] This review focuses on recent advances in CVAD biomaterials, emphasizing surface modification strategies, durability, and multifunctional design aimed at mitigating device-related complications, with CKD and cancer used as case studies to demonstrate how targeted material selection and engineering can optimize device performance in high-risk populations, while also identifying current challenges, knowledge gaps, and opportunities for future innovation.

2. Landscape of vascular access in kidney failure and cancer CVADs: type of devices and uses

According to the CVAA Occlusion Management Guideline for Central Venous Access Devices (CVAA),[13] there are four main types of CVADs: peripherally inserted central catheters (PICCs), non-tunnelled central venous catheters (CVCs), tunnelled CVCs, and implantable venous access devices, also known as PORTs, port-a-cath or totally implantable venous access ports (TIVAPs). CVADs are routinely used in patients with ESRD and cancer to perform hemodialysis and SACT, particularly when urgent dialysis is needed, or creation of a permanent access (arteriovenous fistula or graft) is not feasible due to comorbid conditions.[14–16] While fistulas and grafts generally carry lower risks, they have important limitations, non-maturation, thrombosis, and infection, although these risks are lower than with catheters.[17] Across all CVAD types, thrombosis and infections remain the most frequent complications.[18] In nephrology, CVCs are the intervention used to initiate hemodialysis in approximately 80% of ESRD patients in the USA[14] and nearly 60% in France,[19] with similar trends reported in the United Kingdom (UK), where patients begin hemodialysis with either temporary (i.e., non-tunnelled) or tunnelled CVCs.[20] The start of dialysis with the two types of hemodialysis catheters was evaluated using survey-based data from the International Society of Nephrology Global Kidney Health Atlas (ISN-GKHA), reflecting differences between regions across the world. For example, tunnelled catheters were frequently used to start dialysis in North America, whereas non-tunnelled catheters were more commonly used in Latin America and Africa.[21] In oncology, PICCs and PORTs are the most commonly employed CVADs. Studies have documented the widespread use of PICCs, or PICC lines,[22–25] which are often preferred for ease of insertion, management, and lower costs.[26] However, TIVAPs offer significant advantages for intravenous SACT, supporting prolonged treatment while enhancing patients' quality of life (QoL)[27] and providing a safer and more comfortable access route compared to PICCs.[28] Estimates indicate that by 2012,

Table 1. Central venous access devices: types and uses.

Device type	Description		Duration of use	Applications
CVC	Tunneled	Catheter is inserted subcutaneously (tunneled) under the skin for a tract before exiting the skin	Prolonged access, long-term therapy	Drug administration, hemodialysis, nutritional support
	Non tunneled	Catheter is inserted percutaneously via direct puncture and insertion into the vein	Temporary access, short-term therapy	Emergency dialysis (e.g., acute kidney injury) when immediate vascular access is required
PORT	Small self-sealing reservoir that is subcutaneously implanted under the skin and a tunneled connects the reservoir with central venous system through a deep vein of the chest		Prolonged, intermittent access, long-term therapy	Fluid or nutrition administration, drug administration (cancer treatment)
PICC	Catheter is inserted into a peripheral vein and advanced to the superior or inferior vena cava		Mid-term access, short-intermediate therapy	Nutrition administration, drug administration (cancer treatment)

CVADs are described with reference to their types and features, clinical use timeframe, and applications.[32,33] CVC, Central venous catheter; PORTs, Implantable port; PICC, Peripherally inserted central catheter.

over 400.000 TIVAPs were implanted annually in the USA,[29] with similarly high numbers reported in Germany.[30] Since then, the use of PORTs has continued to grow globally, reflecting their clinical utility.[31] Table 1 summarizes the different types of CVADs and their respective clinical uses. This overview sets the stage for discussing how device choice, materials, and surface engineering strategies can influence complications and optimize outcomes in high-risk populations.

3. Challenges in kidney and cancer care: Device-related infections and thrombosis

All types of devices used in hemodialysis and oncology tunnelled and non-tunnelled CVCs, PORTs, and PICCs – are susceptible to device-related complications. Procedure-related events may occur shortly after hemodialysis catheter placement[34] or surgical implantation of a venous port,[35,36] and can include pneumothorax, embolism, arrhythmias, catheter misplacement, or dislodgement. Device-related infection and thrombosis remain the most common late and long-term complications associated with CVADs use, particularly in patients requiring CVCs and PORTs.[32,34,37] These complications are tightly linked to the blood–device interface, where protein adsorption, biofilm formation, and endothelial trauma initiate inflammatory and coagulation pathways, creating a nidus for thrombosis and infection. Thus, the intrinsic interplay between blood components and catheter materials acts as a critical driver of both thrombogenicity and infective risk, particularly during prolonged indwelling times.[38,39] These AEs are typically related to prolonged catheterization and correlate with increased morbidity and mortality risk.[19] It should also be acknowledged that infections and thrombosis may occur with peripherally inserted devices, such as midlines, generally used for short dwelling time,[40] or when surgical accesses like arteriovenous fistula or grafts are created.[18,41]

3.1 Local and bloodstream infections

Catheter-related infections (CRIs) can present as either local or bloodstream infections.[37,42,43] Local infections typically occur at the catheter exit site, along the tunnel tract, or at the pocket/reservoir. Patients experiencing a local infection typically exhibit inflammatory signs such as erythema, warmth, and pus formation. As reported by Cobo-Sanchez et al, the incidence of exit site infections for hemodialysis catheters varies, partly due to inconsistent definitions in the literature. For tunnelled catheters, exit site infections range from 0.35 to 8.3/1,000 catheter-days, while for non-tunneled catheters they span from 8.2 to 16.75/1,000 catheter-days.[44] In totally implanted PORTs, local infection signs are reported in only 7-12% of bloodstream infection cases.[45]

Catheter-related bloodstream infections (CRBSIs) are defined by the presence of clinical symptoms combined with at least one positive blood culture, in the absence of another identifiable infection source, alongside a matching positive culture at the catheter tip.[19,46] Bloodstream infections are frequent in patients on haemodialysis[47] and constitute a major concern for cancer patients with implanted port systems.[37] Microorganisms can colonize indwelling catheters within 24 hours of insertion, forming biofilms on the catheter surface. These biofilms act as reservoirs for pathogens, which may subsequently enter the bloodstream, leading to infection. Common causative microorganisms include Staphylococcus

aureus, coagulase-negative Staphylococcus, Enterococcus, Pseudomonas, or Candida.[37,47–49] Infections spreading can cause severe complications such as infective endocarditis, septic arthritis, and septic shock,[14,50] requiring catheter removal when antibiotic therapy is not effective.[34,51] Reported infection rates for hemodialysis catheters and PORTs are highly variable. In hemodialysis patients, reviews indicate CRBSI rates between 0.6 and 6.5 per 1,000 catheter-days,[14] and between 0.4 and 32.4 per 100 patients-months.[47] One study reported up to 16.5% of patients developing CRBSIs within one year of catheter placement.[34] Tunnelled hemodialysis catheters are consistently associated with lower infection rates than non-tunnelled devices: a 2006 systematic review reported device- related bloodstream infection rates of 1.6 per 1.000 intravenous device days for long-term, tunnelled, cuffed hemodialysis catheters, compared to 4.8 per 1.000 intravenous device days for temporary, non-cuffed catheters,[52] and such a trend aligns with more recent studies.[53] In oncology, infections associated with implanted ports range between 3 and 10%,[54] consistent with global estimates.[55,56] In Taiwan, a study of 586 ports in oncological population described a 5.6% infection rate and 0.15 infections per 1,000 device-days.[57] An Indian retrospective study (2020 to 2023) registered 7.5% infections (9 out of 119 patients),[58] while a pediatric oncology center in Saudi Arabia documented a lower infection rate of 3.13%, aligning with contemporary rates of 3–4%, markedly lower than earlier reports of up to 16%.[59,60] A retrospective comparison of PORTs and PICCs in patients with solid or hematological tumors highlighted infection rates of 6.4% for ports (158 out of 2475 enrolled patients), and 11.9% for PICCs (106 out of 809 enrolled patients).[61] As pointed out by Rieger et al, such findings were somewhat contrasting with other studies, such as the CAVA trial[62] and the PICCPORT trial.[63] The observed infection patterns emphasize the pivotal role of the blood–device interface, where rapid biofilm development and complex host–material interactions sustain pathogen reservoirs, driving CRIs and reinforcing the imperative for improved catheter materials and targeted preventive strategies.

3.2 Catheter-related thrombosis

Multiple processes contribute to the pathogenesis of thrombi associated with CVADs/catheters.[64] Catheter placement can cause endothelial trauma, which, combined with increased catheter-induced blood flow, activates the coagulation cascade and promotes thrombus formation (blood clots), potentially leading to lumen occlusion.[34] Thrombosis may occur within the catheter lumen (intraluminal), resulting in lumen obstruction, or around the catheter (mural), causing partial vein occlusion and increasing the consequent risk of deep vein thrombosis.[65] Related complications include the formation of a fibrin sheath or sleeve along the catheter surface, where fibrotic material accumulates.[36] Catheter-related thrombosis is typically defined as a mural thrombus extending from the catheter into the vessel lumen, as outlined in the CVAA[13] and Gavecelt[66] guidelines. It most commonly involves the deep venous system of the upper extremities, although other districts may be affected depending on the catheter placement.[65] Thrombi migration to the right atrium or superior vena cava can result in serious complications, such as pulmonary embolism and superior vena cava syndrome.[67] Despite its potential severity, catheter-related thrombosis is often asymptomatic, with only about 5% of cases presenting clinical symptoms, which can delay diagnosis. In hemodialysis patients, thrombotic events represent major complications, with highly variable incidence rates reported across studies.[34] A recent review outlined that CVC thrombosis in hemodialysis patients ranges from 12% to as high as 52%, reflecting differences in study design, clinical settings, and patient-related risk factors.[68] In cancer patients, symptomatic catheter-related thrombosis occurs in approximately 2–5% of PORTs, while overall thrombotic complications typically range between 5% and 13%.[29,69] Earlier reports showed rates up to 28%, though advances in catheter materials and insertion techniques have reduced incidence to below 13% in recent years.[29,69,70] Comparing PICCs and PORTs, Rieger et al revealed similar thrombosis rates (3.4% vs 3%),[61] whereas other studies consistently find higher rates associated with PICCs. The CAVA trial reported venous thrombosis rates of 11% for PICCs versus 2% for ports,[62] while the PICCPORT trial found rates of 8% versus 1% for deep vein thrombosis.[63] Overall, the incidence of catheter-related thrombosis and bloodstream infections varies widely across devices and patient populations. Contributing factors include the investigated population (e.g. adults or pediatric), the stage and the type of disease (e.g. dialysis duration, hematological or solid tumors), the patient clinical history (e.g. comorbidities, body mass index), clinical center resources, infrastructures and adherence to aseptic procedures and care guidelines, as well as the specific design type of catheter or the anticipated period of use.[71–73] These patterns highlight the central role of the blood–device interface in thrombus formation, where endothelial trauma, altered flow, and material–blood interactions converge to drive thrombogenicity, reinforcing the need for optimized catheter design and evidence-based preventive strategies.

4. Selection of devices for hemodialysis and cancer treatment: multiple factors guide the choice

The spectrum and frequency of device-related complications are influenced by patient characteristics, disease-specific considerations, device type, and duration of use. Understanding these factors is essential to optimize outcomes and minimize infection and thrombosis in high-risk populations.

Table 2. Patient- and disease-related factors influencing catheter-associated infections and thrombosis, with reported complication rates.

Patient population	Risk factors	Infection risk (CRBSI)	Thrombosis risk	Representative studies
ESRD patients on hemodialysis	Diabetes mellitus, prior CRI, advanced age, female sex, low hemoglobin/albumin, elevated CRP/procalcitonin[77,78,80]	• Moderate–High: 0.6–6.5/1,000 catheter-days; up to 16.5% within 1 year[14]	• High: 12–52% (varies by study, comorbidities, catheter type)[68]	64,65,67,76–78,80,81
Cancer patients undergoing SACT	Immunosuppression, neutropenia, tumor type/location, histology, stage[82]	• Moderate: 3–10% (PORTs), pediatric 3–4%,[54] PORT vs PICC 6.4% vs 11.9%[61]	• Moderate: 2–5% symptomatic PORTs, overall 5–13%; PICCs generally higher (CAVA, PICCPORT)[29,62,63,69]	36,82–84

CRBSI: catheter-related bloodstream infection; PORT: totally implantable venous port; PICC: peripherally inserted central catheter; • = risk level indication (qualitative overview based on reported incidence); Infection and thrombosis rates reflect ranges reported in adult and pediatric populations, as cited in the "Representative studies" column.

4.1 Patient-related factors

Patient characteristics critically shape both device selection and the risk of catheter-related complications, particularly in high-risk populations such as patients with CKD/ESRD or cancer (Table 2). These factors interact closely with the blood–device interface, where endothelial trauma, altered flow, and biofilm formation drive thrombogenicity and infection, as described in the preceding sections. Disease-induced alterations in coagulation and immune function further amplify susceptibility to both thrombosis and CRBSIs.[74,75] Comorbidities are major determinants of risk. In ESRD, diabetes mellitus is frequently associated with higher CRI incidence.[64,67,76,77] A history of prior CRI[64,78] and nasal colonization with Staphylococcus aureus[79] further elevates infection susceptibility. Advanced age and female sex are additional well-documented risk factors for CRBSIs in hemodialysis patients, while laboratory markers, including low serum haemoglobin and albumin levels, and elevated levels of procalcitonin and C-reactive protein (CRP), also correlate with increased complication rates.[80] In hemodialysis, cardiovascular comorbidity, age, obesity, hypertension, and body mass index (BMI) influence the likelihood of catheter-related thrombosis.[65,68,81] A study by Mohazzab et al[76] investigated tunnelled hemodialysis catheters, and identified hypertensive, female and obese individuals as those with higher predisposition for catheter thrombosis. Notably, the development of an infective status in patients may represent a risk factor for catheter-related thrombosis, and the inflammation response triggered by infection can promote the development of the disorder.[68]

In oncology, catheter-related thrombosis and infection are often driven by the prothrombotic and immunosuppressive nature of malignancy, while the immunocompromised state induced by both the disease and SACT further increases the risk of infection. Moreover, cancer patients exhibit higher risk of thrombosis,[36] primarily due to a hypercoagulability status influenced by tumor biology, cancer treatment and tumor effects on procoagulant factors release, vascular endothelial cells and platelets.[83] Specific anticancer drugs can influence the risk of thrombosis,[84] while additional contributing factors include tumor type (solid tumor vs hematologic), tumor location, histology features, and disease stage of cancer.[82] Patient-related variables such as age, lifestyle, body mass, and comorbid conditions further modulate the overall risk profile. These findings underscore the intricate interplay between patient-specific vulnerabilities, disease-driven alterations, and the blood–device interface in shaping thrombosis and infection outcomes. Integrating this knowledge into device choice, insertion protocols, and preventive care can markedly improve safety in vulnerable patients.

4.2 Catheter-related factors

Catheter-related factors broadly include device materials and design features, such as length, tip configuration, and number of lumens, as well as the placement technique and choice of access site (Table 3). These factors play a critical role in catheter performance, durability, and risk of infection and thrombosis. In the following subsections, we examine how biomaterial composition, device design, and clinical context influence clinical outcomes in patients undergoing prolonged hemodialysis or chemotherapy.

4.2.1 Biomaterial composition

Hemodialysis catheters are primarily made of polyurethane, silicone, or carbothane (a polyurethane/polycarbonate blend),[90,91] while PICCs typically use silicone or polyurethane, with a tendency towards polyurethane due to its handling

Table 3. Catheter-related and procedure-related factors in hemodialysis and cancer treatment.

	Type of CVADs used in hemodialysis and SACT			Key considerations and impact
	CVCs (Tunnelled/non tunneled)	**PORTs**	**PICCs**	
Material[34]	Tunneled: silicone, polyurethane, carbothane (copolymer) Non tunneled: silicone, polyurethane	Implantable port: titanium, polymers (Port bodies) Silicone, polyurethane (catheter)	silicone, polyurethane	▪ Material properties such as rigidity and flexibility can influence insertion and risk of infections
Catheter design (e.g. tip, lumen, diameter)[14,32,85]	▪ Tip shapes: symmetrical, step-tip, split-tip, Y-tip or self-centering (tunneled) ▪ Number of lumens: single, double, triple (tunneled/ non tunneled) ▪ Catheter size diameter: 12-16 Fr (hemodialysis tunneled catheters)[86]	▪ Presence of valves: valved or open-ended catheters ▪ Number of lumens: single or double port ▪ Catheter size diameter:5-9 Fr	▪ Presence of valves: valved or open-ended catheters ▪ Number of lumens: single, double, triple ▪ Catheter size diameter:3-5 Fr	▪ Further studies on impact of tip design on device performance and functionality, to consider with other contributing factors ▪ No significant correlation to the presence of valves ▪ Multiple lumens may represent a risk factor for complications such as bloodstream infections ▪ Evaluation of catheter size and catheter-to-vein ratio for adequate blood flow, but avoid risk of thrombotic-related catheter occlusions
Access/ placement site[14,33,87]	▪ Insertion into internal jugular vein mainly, if not accessible use of femoral vein and lastly subclavian vein ▪ Right-side of internal jugular vein preferred to left-side ▪ Catheter tip positioning: into superior vena cava vs pericavoatrial junction or right atrium	▪ Insertion into peripheral veins – e.g. brachial, cephalic, balisic- and advanced to superior or inferior vena ▪ Right-side arm for catheter insertion	▪ Subcutaneous placement of reservoir connected to catheter ▪ Right-side of internal jugular vein for favorable catheter insertion	▪ Internal jugular vein as preferred access route associated to fewer infections, catheter dysfunction/device removal and number of catheterization ▪ Lateralization and preference for right-side insertion for fewer infection and dysfunction complications ▪ Evaluate catheter tip positioning
Insertion procedure[88,89]	▪ Various placement methods (surgical procedures or not) ▪ Use of ultrasound guidance versus landmark anatomical procedures ▪ Clinical use of techniques fluoroscopy, ECG or radiography			▪ Education and training of clinical staff ▪ Key imaging support to guide insertion and minimize complications related to procedure such as pneumothorax, embolism

CVC, Central venous catheter; PORTs, Implantable ports; PICC, Peripherally inserted central catheters; ECG, Electrocardiogram.

characteristics and performance.[33,92] PORT reservoirs combine titanium, stainless steel, or polycarbonate with silicone or polyurethane catheters.[69,93] Silicone's softness and flexibility are favourable to minimize endothelial damage during insertion, but it can make the insertion procedure more challenging.[34] Conversely, polyurethane is characterised by

rigidity during insertion, facilitating the placement, but it softens at body temperature. Carbothane, a polyurethane/polycarbonate copolymer, combines strength and softness to enhance durability and flexibility.[94] Polyurethane and carbothane are frequently used for hemodialysis catheters,[90] especially for tunnelled long-term use catheters.[94] Recent evidence highlights the increasing utilization of hemodialysis catheters, associated complications, and the role of optimized catheter designs and functional coatings in reducing adverse outcomes and improving patient management.[95] Although studies have not conclusively established a link between silicone and increased infection risk,[90,96] one investigation on tunnelled hemodialysis catheters reported a higher incidence of kinking in silicone-based catheters compared to those made of polyurethane.[91] In cancer patients, prevention of catheter-related bloodstream infections remains a priority: systematic reviews have assessed non-drug interventions, including coated CVCs, highlighting limited but promising evidence for efficacy in hematological malignancy patients.[97] Similarly, recent reviews summarize strategies to prevent catheter-related infections, emphasizing antimicrobial-coated catheters and insertion/maintenance bundles.[98] Cochrane studies have examined the impact of different materials and designs on PICC-related complications, highlighting the need for additional high-quality trials to strengthen the evidence and guide clinical decision-making.[92,99] In cancer patients using implantable venous-access ports, some studies have found that silicone catheters are more prone to mechanical instability and breakdowns, while polyurethane catheters are more frequently associated to infections and thrombotic complications.[100–102] In paediatric oncology, studies evaluating long-term venous port use have suggested that polyurethane catheters may be more susceptible to breakage and can be more difficult to remove.[103,104]

4.2.2 Device design features

Catheter architecture can differ by its manufacturing design, including catheter tip shape, lumen number, and diameter size. The type and design of catheters usually depend on clinicians' choice, as reported in the current 2019 Kidney Disease Outcomes Quality Initiative guidelines on vascular access.[46] Tunnelled catheters used for long-lasting hemodialysis in patients with ESRD are typically cuffed, with a polyester cuff (i.e. Dacron) that promotes growth of tissue around it, prevents catheter displacement, and potentially reduces infection risk.[14,34,105] Over the years, different types of shapes have been developed for the tip of hemodialysis catheters,[34,105] particularly to prevent backflow.[96] Common tip configurations—referring to the distal end of the catheter placed within the bloodstream—include symmetrical, step-tip, split-tip, Y-tip, and self-centering.[34,105] Recent studies have investigated interactions between catheter materials and vessel walls, highlighting the importance of mechanical and surface considerations to reduce thrombosis and endothelial damage: interactions between catheter surfaces and vascular tissue can induce localized stress and protein adhesion, which are mitigated by hydrophilic or anti-adhesive coatings.[106] Hydrophilic-coated intermittent catheters (HCICs) have been shown to improve QoL, reduce urinary tract infections, and may be cost-effective compared with uncoated catheters.[107] An Australian cohort study by Lazarus et al.[108] evaluated tunnelled hemodialysis catheter performance, focusing on tip design and blood flow adequacy.[109] Step-tip catheters showed shorter functional lifespans compared to symmetrical tips, while split-tip catheters performed well, albeit in limited numbers.[108] Overall, as noted by Prasad & Vachharajani,[109] catheter tip design influences dysfunction and performance, but further studies are needed to clarify additional contributing factors. Valved catheters, with a closed tip to prevent blood reflux and allow heparin flushing,[32] and not valved/open-end catheters,[110] show similar complication profiles. Early and later studies indicate no significant differences in infection, thrombosis, or catheter removal between valved and non-valved central venous ports,[111,112] and comparable findings have been reported for PICCs in cancer patients.[86] Conversely, it has been demonstrated that PICCs with proximal valves were associated with a higher incidence of unplanned removal compared to open-ended devices, a difference particularly marked in patients without malignancy.[113] Other key design features include the diameter size and the number of lumens. CVADs are available in a wide variety of sizes, typically measured using the French (Fr) scale. As summarised by Kehagias et al,[32] Hickman (tunneled) catheters usually range from 7 to 9 Fr, PICCs from 3 to 6 Fr, and IPs from 5 to 9 Fr. Hemodialysis tunneled catheters are generally larger, with external diameters ranging from 12 to 16 Fr.[14,85] Diameter size is a critical factor in ensuring adequate blood flow[85] and must be taken into consideration within the catheter caliber-to-vein ratio.[64] Indeed, catheter size can affect the development of catheter-related thrombotic occlusions, as observed in TIVAD used in breast cancer patients.[114] CVADs are available in various lumen configurations: single, double, and triple lumens are used in tunnelled catheters and PICCs, whereas implantable venous access systems can have a single or double port.[13] Multi-lumen designs can contribute to optimizing blood flow during dialysis and allow simultaneous administrations; however, they may also increase the risk of complications such as catheter-related bloodstream infections, as highlighted in a recent meta-analysis.[115] Specifically, for CVCs, multiple lumens may slightly increase the risk of infections.[116] In hemodialysis patients, no differences in complications due to the presence of multiple lumens are known,[117] while in cancer patients, double-ports have been observed to be associated with an increased risk of complications such as bloodstream infections[118] and catheter malfunction or related thrombosis.[119] Overall, the 2024 Infusion Therapy Standards of Practice recommend, for general patients, an optimal assessment of catheter-to-vein ratio, and the use of the smallest catheter diameter and the fewest number of lumens during infusion therapy.[120]

4.2.3 Clinical context and biomaterial performance

While patient-specific factors shape the baseline risk for complications, biomaterial properties and catheter design determine how these risks translate into clinical outcomes, particularly in prolonged hemodialysis or chemotherapy. Biomaterial and design choices must align with patient condition and therapy type. In prolonged hemodialysis, durability, thrombotic resistance, and flow optimization are critical, whereas in chemotherapy, device stability, infection resistance, and compatibility with cytotoxic drugs are critical.[91,100–104,121] The blood–device interface, governed by material surface properties, protein adsorption, and flow dynamics, dictates thrombogenic and infective potential.[34,115–120,122] Integrating patient-specific risk factors, careful insertion, maintenance, and monitoring enables clinicians to maximize CVADs performance, minimize complications, and optimize treatment outcomes. Specifically, material and design considerations should be tailored to the clinical context: ensuring durability and thrombotic resistance in prolonged hemodialysis, while prioritizing stability, infection prevention, and drug compatibility in oncology patients. While biomaterial properties and catheter design establish baseline performance and influence thrombosis and infection risk, the overall success of CVADs use in high-risk populations also critically depends on procedural factors.

4.3 Procedure-related factors

Procedure-related factors play a pivotal role in the performance of CVADs and in the risk of associated complications (Table 3). Numerous studies highlight that both the choice of access vein and the final catheter tip position significantly influence device performance and safety.[87,123] Non-Tunneled Central Venous Catheters (NTCVCs), typically used for short-term (<14 days) and urgent hemodialysis, are most commonly inserted percutaneously via the right internal jugular vein (IJV), with the terminal catheter tip reaching the superior vena cava.[14,33] Tunneled Central Venous Catheters (TCVCs), employed for long-term vascular access and ongoing haemodialysis, also rely on the IJV as the preferred entry site.[14] PICCs are introduced through peripheral veins, such as the basilic, brachial, or cephalic vein, finally reaching the superior or inferior vena cava.[32,33] PORTs consist of a surgically placed reservoir, typically located in a tissue pocket in the arm or chest of patients, and a catheter, connected to the port, usually advanced until the superior or inferior vena cava.[33] The choice of access route is a critical step, since the access type may correlate with complication risks.[124] For instance, in NTCVCs, the skin exit site lies in proximity to the venous entry point, and this position can heighten the risk of catheter-related infections. In contrast, the tunnelling procedure, which involves the subcutaneous passage of the catheter beneath the skin, can be a challenging phase for clinicians[91]; however, by creating spatial separation between the skin entry site and the venous insertion point, it significantly reduces the risk of infection.[33] When the jugular vein is unavailable in hemodialysis patients, due to occlusions or other catheterizations, alternative access sites such as the femoral or subclavian veins might be considered. Nevertheless, these routes are often associated with higher complication risks, as reported by Sohail et al.[14] The lateralization represents another factor in clinical decision-making: the right side of the IJV is often recognised as preferable access,[14] and left-sided access has been linked to increased infection, catheter dysfunction, and need for repeat catheterizations in hemodialysis patients.[87,125,126] Similar findings have been reported in oncology, where right-sided PORT insertion showed lower rates of both early and late complications,[127] and right-arm PICC placement was associated with fewer AEs.[128] Following insertion, a crucial factor is the optimal position of the catheter tip within the vascular system, with current evidence supporting placement into the superior vena cava,[129,130] compared to other options as the pericavoatrial junction or right atrium. However, case studies point out contrasting findings, suggesting the necessity of a case-by-case evaluation of vein accessibility. CVAD placement techniques range from minimally invasive procedures under local anesthesia to complex surgical interventions requiring specialized personnel and equipment.[33,131,132] Procedural success is contingent on clinician expertise, training, and access to appropriate technological support, to avoid repeated venepuncture attempts or risk complications such as pneumothorax, embolism, arterial puncture, or hematoma. The introduction of ultrasound guidance into clinical practice has significantly improved placement outcomes, and it is now recommended by major vascular access guidelines.[33,88] A Cochrane systematic review demonstrated that 2D ultrasound guidance increases placement success rate and reduces hematoma formation compared with anatomical landmark techniques.[133] Beyond facilitating catheter insertion, ultrasound is also valuable for pre-procedural assessment of vascular access in hemodialysis patients[88] and in the placement of totally implantable venous ports.[89] Clinical practice is oriented to further advancements in placement procedures techniques and to increase the success rate of CVADs placement, with literature also highlighting the role of fluoroscopic, radiological, and electrographic guidance methods.[134–136]

5. Surface modification strategies to improve CVADs use in kidney and cancer care

Materials engineering and surface modification are pivotal to ensuring the safe and effective use of CVADs in high-risk populations. Surface modifications are broadly classified as passive or active, employing physical, chemical, or combined approaches to impart antimicrobial/antibacterial, anti-thrombogenic, anti-fouling, and anti-adhesive properties, thereby minimizing device-related infections and thrombotic complications.[137–139]

5.1 Functional goals of surface modification in CVADs

Blood-contacting surfaces of CVADs rapidly interact with proteins and cells, triggering thrombotic cascades, clot formation, and providing a substrate for bacterial adhesion and biofilm formation.[137] Optimally engineered surfaces must therefore be biocompatible, hemocompatible, durable, safe, and functionally optimized. Key surface characteristics, including wettability, charge, roughness, and chemical composition, strongly influence protein adsorption, cellular interactions, bacterial adhesion, and bio- and hemocompatibility, directly affecting the risk of device-related infections.[140]

5.2 Surface-engineering strategies: the biomaterials toolbox against complications

From a biomaterials engineering perspective, CVAD surface modifications can be organized into complementary strategies that address the mechanistic pathways leading to infection, thrombosis, and device failure. Together, these surface-engineering approaches constitute a biomaterials toolbox to mitigate CVAD-related complications. These modifications yield direct clinical outcomes in hemodialysis and oncology, such as reduced heparin needs and prolonged patency in hemodialysis trials, and lower CRBSI in cancer cohorts.[141] Table 4 summarizes the main surface modification strategies investigated for CVADs, highlighting their key features, intended functional goals, and the principal limitations associated with each approach.

Passive Physicochemical Modifications- tuning surface properties such as wettability, roughness, charge, or elemental composition to influence protein adsorption, cellular interactions, bacterial adhesion, and hemocompatibility.[137,140] Recent studies on fluorinated polyphosphazene coatings have demonstrated improved mechanical stability while maintaining antithrombogenic performance, making them promising passive surface modifications for CVCs.[153] In oncology, hydrophilic and PEG-based surface modifications have been investigated to reduce catheter occlusion and improve short-term patency, although robust clinical evidence in CVAD-specific settings is still emerging.[154]

Table 4. Overview of main types of surface modification strategies.

Type of surface modification	Features	Main concerns
Antiseptics impregnation/ coatings[142,143]	• Use of Chlorhexidine, Chlorhexidine + silver sulfadiazine (C-SS) • Use of minocycline and rifampin • Infection prevention	• Limited durability of agents • Cost- benefit • Resistance development
Silver-based[144–146]	• Studies on silver-based nanoparticles or ions • Infection prevention	• Long-term stability • Preparation process and design
Heparin-bonded coatings[90,147,148]	• Studies on use of heparin or in combination Against blood clots and help reduce biofilm formation	• Heparin -side effects especially on long term use • More studies on efficacy and e.g. on design and efficacy testing of combined approaches
Hydrophilic polymers[137,149,150]	• Studies on use PEG, zwitterionic polymers • Anti adhesive/adsorption properties, to prevent fouling and thrombosis	• Long term use durability and efficacy
Surface pattern modifications[137,151]	• Studies on micro, nanopatterning, bioinspired surface changes • Mimicking natural surface properties against bacterial colonization and platelet adhesion	• Applicability in clinical settings • Safety and efficacy, design strategy
NO-releasing surfaces[152]	• Studies on addition of nitric oxide releasing surface • Antibacterial and antiplatelet aggregation	• Long term use and efficacy
SLIPS[137,149]	• Introduction of liquid on surface porous material Potential anti-thrombosis and anti-infection, with self-cleaning properties	• Safety and efficacy, design strategies

PEG, polyethylene glycol; NO, Nitric-oxide; SLIPS, Slippery Liquid-Infused Porous Surfaces.

Covalent Immobilization of Biomolecules or Polymers– permanent attachment of functional agents to confer biofunctional properties such as anticoagulation or antifouling behavior.[149,155] Bioinspired zwitterionic NO-generating coatings have been shown to provide long-term antimicrobial and antithrombogenic activity through covalent attachment of functional polymers and catalytic components on CVC surfaces.[156] Similarly, chitosan-based coatings have demonstrated biocompatible and bactericidal properties when immobilized on catheter surfaces, representing a "green" biofunctional approach.[157] Additionally, dual-functional coatings integrating lysine and Cu2+ with zwitterionic polymers have shown both antibacterial and antithrombotic effects, providing a multifunctional covalent approach for improving long-term CVC performance.[158] Clinically, covalent immobilization strategies such as heparinized surfaces have demonstrated improved hemocompatibility in hemodialysis applications by reducing protein adsorption, platelet adhesion, and clot formation. Advances in plasma activation, polymer grafting, and nanotechnology enhance coating stability, although long-term clinical validation remains limited.[159]

Drug- and Ion-Releasing Coatings– controlled local release of antimicrobial or antithrombotic agents, including antibiotics (e.g., minocycline/rifampin) and silver-based coatings. These strategies address infection prevention and thrombosis. Polymer-drug coatings specifically designed to reduce thrombogenicity and improve hemocompatibility represent an advanced approach to locally deliver antithrombotic agents while preserving systemic safety.[160] In addition, phyto-assisted ZnO nanoparticles provide non-antibiotic antibiofilm activity via slow ion release, representing a promising drug-free antimicrobial strategy.[161] In clinical studies, surfaces engineered to release drugs or ions have demonstrated improved hemocompatibility and reduced thrombogenicity in hemodialysis-related applications; although these results come from stent-based devices, they highlight the potential of similar surface chemistries for CVADs.[162]

Topographical and Nano-Structured Surfaces – micro- and nanoscale features (e.g., micropatterning, SLIPS, nitric oxide-releasing surfaces) that modulate bacterial adhesion, platelet activation, and host–material interactions.[137,149,152–163] Water-infused surface protection (WISP) has been proposed to prevent fibrin sheath formation by creating a dynamic blood-free interface, representing an innovative surface-driven approach to reduce thrombosis and biofilm-related failures.[164] Clinically, pilot RCTs (CASCADE, 2025), testing CVAD securement and dressing strategies including sutureless devices and tissue adhesive, demonstrate feasibility and reduced device failure, highlighting how interface optimization complements surface-engineering approaches.[165]

5.3 Antimicrobial surface strategies

Antimicrobial surface modifications leverage antibiotics (e.g. minocycline/rifampin), antiseptics (e.g. chlorhexidine), and other metal ions (e.g., silver) to inhibit microbial colonization and biofilm formation. Commercially available catheters include chlorhexidine/silver sulfadiazine-coated devices (C-SS) (e.g., Arrowg+ard® Blue Plus CVC, Teleflex), and antibiotic-impregnated catheters with minocycline/rifampin (Spectrum®, Cook Medical). According to CDC's 2011 guidelines, these strategies have proven efficacy against CRBSIs in multiple clinical settings[166]:

- Minocycline/rifampin-impregnated CVADs reduce infection rates in hemodialysis[142] and cancer patients.[143]
- First-generation chlorhexidine/silver sulfadiazine–coated catheters (CHSS) reduce CRBSIs compared to non-coated devices[167,168]; CHSS may provide better protection against central line–associated bloodstream infections (CLABSIs) than silver iontophoretic (SI) catheters.[169]
- Second-generation CHSS catheters show reduced colonization, but randomized controlled trials (RCTs) were underpowered to show significant CRBSI reduction.[170–173]
- Systematic reviews and meta-analyses support antiseptic/antibiotic coatings as generally more effective than standard catheters[174]; however, inconsistencies exist for hemodialysis catheters.[171]

A Cochrane review further concluded that impregnated catheters reduce CRBSI and colonization, particularly for critically patients in intensive care, though benefits may not extend to all care settings.[138] CDC's 2011 and DGHO/AGIHO 2020 guidelines note that the higher cost and risk of microbial resistance should be considered, with priority given to high-risk patients or situations where standard preventive measures, such as strict adherence to antiseptic skin protocols, have failed.[166,175] Owing to silver's biocidal properties, catheters have been developed using silver-impregnated materials or compounds, including silver nanoparticles.[144] Silver-based approaches are being explored across various clinical settings, including hemodialysis.[144,176] Temporary hemodialysis catheters coated with silver nanoparticles demonstrate antibacterial activity without cytotoxic effects, though higher concentrations may induce bacterial activity and cytotoxicity.[145,177] Clinical evidence is controversial: some studies show reduced catheter- and port-related infections, while others report no significant benefit. No significant reduction of infection was observed in a

retrospective study evaluating silver-coated and uncoated catheters in hemodialysis and apheresis.[178] Similarly, a meta-analysis observed that silver-impregnated CVCs did not correlate with lower rates of catheter-related bloodstream infections.[179] Overall, silver-based surface modifications are emphasized due to their broad-spectrum antimicrobial activity, clinical evidence, and increasing use in vascular access devices. Consistent with this, silver-coated central venous catheters and silver-mixed ports have been shown to reduce catheter- and port-related infections, supporting both the clinical effectiveness and the growing focus on silver-based surface strategies.[56,174] Additional biofunctional coatings, including enzymatic surfaces, have shown promise in preclinical studies. Surface-bound enzymatic coatings have demonstrated in vivo efficacy against Pseudomonas biofilms, providing a drug-free antibiofilm strategy,[180] while chlorhexidine-silver coatings, although widely used, exhibit limited long-term efficacy and underscore the need for alternative topographical or chemical modifications.[181] These innovations highlight the ongoing exploration of multi-functional antimicrobial strategies beyond conventional drug or silver-based coatings. Challenges remain in long-term use of silver-based and other antimicrobial coatings, including risk of promoting antibiotic resistance, potential loss of antimicrobial efficacy over time, limitations in coating durability and retention of active agents, and the need for more data on biocompatibility and inflammatory responses, particularly for patients requiring prolonged catheter use, such as those on dialysis or receiving chemotherapy.[182]

5.4 Approaches for anti-thrombogenic surface modifications

In addition to infection prevention, strategies against the development of device-related thrombosis are under investigation.[183] Heparin-bonded catheters, featuring covalently attached heparin, inhibit thrombin formation and clotting, and may reduce biofilm nidus.[90] A clinical study showed that heparin-coated tunnelled dialysis catheters maintain similar patency to standard catheters, resulting in significantly fewer catheter-related bacterial infections.[147] Commercially available products include i) Palindrome precision H (heparin bonded, Mozarc Medical), ii) BioFloDuraMax (with proprietary technology, Angiodynamics), indicated to prevent blood clotting and for use in hemodialysis; iii) Palindrome™ Precision SI Chronic Catheter (Silver Ion, Mozarc Medical), combining heparin coating with a silver ion subcutaneous sleeve for hemodialysis. Heparin use carries risks, including bleeding, allergic reactions, and thrombocytopenia. Innovative dual-function coating combining heparin sodium with organosilicon quaternary ammonium surfactant has demonstrated in vitro and in vivo stability under extreme conditions, 60% thrombus adhesion reduction, and >97% broad-spectrum antibacterial activity.[148] However, other studies found no significant difference in infection or mechanical complication rates between heparin-coated and uncoated catheters.[184] Literature reflects variability in heparin coatings efficacy,[149] highlighting the need for further studies across clinical settings and patient groups.[138,185] Passive anti-thrombogenic strategies also employ hydrophilic and antifouling materials, such as hydrogels or hydrophilic polymers, like polyethylene glycol (PEG) and zwitterionic polymers, that prevent protein and cell adsorption, reducing catheter thrombogenicity.[137,149] As reviewed by Balikci et al,[176] there are studies exploring the use of PEG coating in hemodialysis catheters[155] and totally implantable venous port systems.[150] However, clinical data on long-term efficacy of these anti-thrombogenic coatings in CVADs remain limited, particularly in high-risk populations. Key concerns surrounding these approaches involve their long-term durability, particularly due to the potential for desorption, hydrolysis and oxidation.[149]

5.5 Novel approaches for surface modifications

Micropatterning modifies the surface topography to inhibit bacterial adhesion without the use of pharmacological agents. Inspired by natural surfaces such as shark skin and lotus leaves,[137] these microtextures have been shown to reduce both bacterial colonization and platelet adhesion, as demonstrated in shark-skin-inspired micropattern CVCs.[151] Micropatterning approaches suggest promising implications for the prevention of CRIs and thrombosis without drug-eluting agents. Further research is needed to optimize the manufacturing process, assess compatibility across various catheter types, and ensure comprehensive safety and efficacy in clinical use. Additional strategies include the use of nitric oxide (NO)-releasing materials and antimicrobial peptides, or Slippery Liquid-Infused Porous Surfaces (SLIPS). NO-based approaches exploit its properties as an antimicrobial agent and inhibitor of platelet aggregation, by mimicking the physiological release of NO from vascular endothelium.[149] Experimental studies are oriented to identify NO-releasing donors that could be effective in the long term, and there are examples of investigations on charging catheter surfaces.[152] SLIPS are based on creating porous surfaces able to hold introduced liquids with specific properties,[137] and research is advancing through studies on slippery liquid-infused fluoropolymer in commercial central venous devices, such as PICCs, with potential antithrombogenic and infection-resistant properties.[163] Ongoing research is increasingly focused on developing more effective technologies and solutions to prevent catheter-related bloodstream infections and thrombosis, both individually and in combination, given their mechanistic interplay and frequent clinical co-occurrence. Collectively, these approaches highlight the breadth of surface-engineering strategies under investigation. Table 4 summarizes those that have reached a sufficient level of technological maturity for clinical consideration, together with their key features and main limitations.

6. Optimizing central venous access in kidney and cancer care: Best practices and the role of surface-modified devices

Several clinical guidelines address the use of CVADs in hemodialysis and oncology, with shared goals of minimizing infectious and thrombotic complications, preserving vascular access, and ensuring continuity of care (Table 5). Proper device management throughout the lifecycle, combined with adherence to recommended protocols, improves clinical outcomes, maintains vascular access, and reduces mortality. Additionally, preventing complications can significantly lower healthcare costs associated with therapies such as hemodialysis and SACT.

6.1 Device selection and clinical considerations

A primary focus of guidance documents is device selection, which requires careful assessment of patient- and catheter-related factors. Clinicians can rely on tools such as checklists, algorithms, and stepwise protocols to guide decision-making.[33] Selection depends on clinical urgency,[46] healthcare setting,[189] and expected type of therapy and duration, as for non-tunneled versus tunneled hemodialysis catheters.[14] Fully implantable venous ports are preferred to allow long-term, intermittent vascular access (>3–4 months duration, access every 2–3 weeks).[189] Although catheter material and design (e.g. polyurethane versus silicone) have been widely studied, there is currently no consensus regarding their influence on infection or thrombosis risk.[191,192] For instance, the Spanish Multidisciplinary Group on Vascular Access reported insufficient evidence to recommend any preferable catheter material.[186] Device placement is equally critical: insertion site selection (e.g., internal jugular, subclavian, femoral veins) should consider patient anatomy, therapy duration, and clinical context, with the tip positioning ideally at the junction of the superior vena cava and right atrium to minimize arrhythmias and thrombosis.[190] Imaging guidance, including ultrasound or fluoroscopy, is broadly recommended for all CVADs placements.[43,46,189] Kidney Foundation guidelines[46] suggest vascular access via arteriovenous fistulas and grafts over hemodialysis- central vascular catheters, due to a lower risk of catheter-related bloodstream infections.[14,34,42] Nonetheless, CVCs remain common, as highlighted from an Italian study reporting a 61.8% prevalence among dialysis patients.[193] In oncology, fully implantable catheters are recognised as associated with a lower risk of infections, as emerged from ESMO Clinical Practice Guidelines.[43] A meta-analysis comparing PICCs with PORTs found PORTs to be safe and effective vascular access for SACT[26]; however, PICCs remain widely used due to their lower cost and ease of placement.

Following placement, maintenance and prophylactic care of CVADs are essential to prevent complications.[194] Strategies include strict hand hygiene, maximal sterile barriers, and adherence to aseptic techniques such as the Aseptic Non-Touch Technique.[195] Additional measures involve skin antisepsis with agents as 2% chlorhexidine, alcohol solutions, catheter hub decontamination, and the use of sterile dressings for exit sites and catheter securement.[14,33,43] Regular flushing with 0.9% saline is recommended to maintain CVAD patency and prevent fibrin-related occlusion. Flushing intervals vary by device type and usage: while tunneled catheters and PICCs typically require weekly flushing when not in use, PORTs may only need flushing every four weeks or longer.[43,46] Locking solutions, instilled into the catheter lumen and including anticoagulants, thrombolytics, or antibiotic/antiseptics, are applied based on patient risk and device type.[46] Prophylactic use of antimicrobials is not recommended in cancer[43] or hemodialysis patients,[14,46] primarily due to concerns over antimicrobial resistance. Use of antimicrobial locks is generally reserved for patients with recurrent catheter-related bloodstream infections. Recent advances include the 2024 approval of a novel lock solution combining an antimicrobial agent and coagulant -taurolidine-heparin (Defencath), designed to reduce infection risk in hemodialysis patients with central venous catheters.[196] The prophylaxis to prevent catheter-related thrombosis remains crucial. In cancer patients, anticoagulants prophylaxis is not routinely recommended as a standard approach, but is subject to case-by-case evaluation.[43] A Cochrane review assessing anticoagulant agents such as unfractionated heparin, low-molecular-weight heparin, and vitamin K antagonists emphasized the need to balance thromboembolic risk reduction against potential AEs.[197] Similarly, in the Kidney Disease Foundation guidelines, there is strong advice against routine use of prophylactic systemic anticoagulants for maintaining or improving patency of tunnelled hemodialysis catheters, considering limited evidence in support of to benefit and potential side effects.[46] Intermittent heparin flushing is common practice, but evidence comparing it to saline is inconclusive. A Cochrane review by López-Briz et al. found no clear difference in occlusion prevention between heparin and 0.9% saline locking.[198] Advances include the FDA-approved taurolidine-heparin lock solution Defencath, shown to significantly reduce catheter-related bloodstream infections in hemodialysis patients compared to heparin alone, though risks such as heparin-induced thrombocytopenia and sensitivity reactions must be considered.[199,200] Use of thrombolytic-based prophylaxis with agents such as urokinase, streptokinase, and alteplase is also not routinely recommended in cancer care.[43] However, selective use, such as weekly thrombolytic agent (recombinant TPA) locks in high-infection-rate units, is supported in nephrology guidelines.[46]

6.2 Implementation strategies and multidisciplinary care

Guidelines are most effective when combined with structured implementation strategies. Evidence shows that multi-disciplinary teams, standardized care bundles, and continuous performance feedback are key to improving outcomes and

Table 5. Clinical guidance practices for CVADs management.

Applications	Title	Provider	Year	Main indications	Reference
Hemodialysis	KDOQI vascular access guidelines	KDOQI	2019	• ESKD Life-Plan supports an individualized approach to vascular access choice and location; Indications for use of hemodialysis CVC • CVC Care to Prevent Infection: aseptic measures and hygiene, flushing protocols e.g. 0.9% normal saline	(Lok et al., 2020)[46]
	Spanish Clinical Guidelines on Vascular Access for Haemodialysis	GEMAV	2017	• Recommended a non-tunnelled CVC in situations in which the catheter has to remain in place for under two weeks. For longer periods tunnelled CVC can be used • No specific tunnelled CVC model is preferred over others for haemodialysis. • CVC handling have to be performed under strict aseptic conditions • Assess the CVC exit site dressing at each haemodialysis session. Change it if wet, stained, detached or presents signs of infection; otherwise, change weekly. • Initial treatment of thrombosed or dysfunctional tunnelled CVCs should include vigorous saline flushing, guidewire-based mechanical intervention, or intraluminal fibrinolytic infusion; systemic fibrinolytics or catheter replacement. • Between haemodialysis sessions, tunnelled CVCs should be locked with heparin, citrate, or tPA, alternating with heparin as needed. • Catheter-related infections: routine antibiotic prophylaxis is not recommended before insertion or handling of CVC • Catheter-related infections: infection-treatment protocol after assessment of complicated/uncomplicated infections. Immediate withdrawal e.g. non tunnelled catheters, signs of septic shock	(Ibeas et al., 2019)[186]
	Editor's Choice - Vascular Access: 2018 Clinical Practice Guidelines of the ESVS	ESVS	2018	• Tunnelled cuffed CVCs as a long standing haemodialysis modality should be considered when the creation of arteriovenous fistulas or grafts is impossible or in patients with limited life expectancy. • Skin preparation for insertion of all type of access/ cannulization • All vascular access late infections should be treated with antibiotics to cover both gram positive and gram negative organisms.	(ESVS Guidelines) (Schmidli et al., 2018)[187]

Table 5. *Continued*

Applications	Title	Provider	Year	Main indications	Reference
	Guidelines for the Prevention of Intravascular Catheter-Related Infections	CDC	2011	• Avoid the subclavian site in hemodialysis patients and patients with advanced kidney disease, to escape subclavian vein stenosis • Antibiotic/Antiseptic Ointments: apply at the catheter exit site after insertion and post-dialysis only if compatible with catheter material per manufacturer guidelines. • Antibiotic Lock/Flux Prophylaxis: use in long-term catheter patients with recurrent CRBSIs despite strict aseptic practices. • Anticoagulants: do not routinely use anticoagulant therapy to reduce the risk of catheter-related infection in general patient populations	(Guidelines for the Prevention of Intravascular Catheter-Related Infections, 2011)[166]
	Hemodialysis clinical practice guidelines	CSN	2006	• Catheter position should be confirmed using radiography, and the catheter tip should be readjusted as necessary to ensure proper position. • Change catheter exit site dressings at each hemodialysis treatment (Grade D, opinion) • Treat dysfunctional tunneled hemodialysis catheters with instillation/infusion of tPA using a protocol (Grade D, opinion) • Treat central venous catheter-related bacteremia with systemic antibiotics and catheter exchange over a wire (Grade D) • Treat catheter tunnel infections without bacteremia with parenteral antibiotics and appropriate local measures. • Catheter removal is indicated if the infection fails to respond to 2 wk of therapy.	(Culleton, 2006)[188]
Cancer	International experts consensus on optimal central vascular access device selection and management for patients with cancer	Panel of oncologists and healthcare professionals	2024	• Totally implantable ports are preferred for infrequent long-term vascular access (>3–4 months duration, access every 2–3 weeks) • Patient lifestyle patients assessment and use of ports • Equipment for port placement and healthcare staff specialised in venous access procedures • Ports should be flushed at intervals ranging from 4 to 12 weeks according to specific local protocol • For all types of CVADs, use of ultrasound guided venipuncture for lower attempts and minimized risk (mechanical, thrombotic, and infectious complications)	(Jahanzeb et al., 2024)[189]

Table 5. *Continued*

Applications	Title	Provider	Year	Main indications	Reference
	Clinical practice guidelines for breast cancer implantable intravenous infusion ports: Chinese Society of Breast Surgery practice guidelines 2021	CSBrS	2021	• Selection of vein insertion place • Catheter tip position in infusion port	(Ma et al., 2021)[190]
	Central venous access in oncology: ESMO clinical practice guidelines.	ESMO	2015	• Attention to the placement of tip of the central venous catheter • Antimicrobial prophylaxis is not recommended as well as extensive routine prophylaxis with anticoagulants, or thrombolytic agents • No strong recommendation for use of antibiotic coated catheters, except than in clinical settings with high rates of bloodstream infections • Recommended neutral pressure mechanical valve connectors against risk of infections • Routine replacement of central venous catheters is not a preventive measure against infections • Routine maintenance and flushing protocols to prevent occlusions and aseptic practice (skin preparation) as Infection prevention strategies. • Implementation of bundle strategies including procedural guidelines for hygiene, dressing changes, and access as well as specific timeframes • Education and training of health care personnel, education of patients	(Sousa et al., 2015)[43]
	Central venous catheter–related infections in hematology and oncology: 2020 updated guidelines on diagnosis, management, and prevention by the Infectious Diseases Working Party (AGIHO) of the German Society of Hematology and Medical Oncology (DGHO)	AGIHO of DGHO	2020	• Infection Prevention: ensure strict hygiene and aseptic technique during catheter insertion and handling. Use chlorhexidine-based antiseptics, antimicrobial dressings (preferably transparent gel types), and consider antimicrobial-impregnated CVCs for long-term use if high CRI rates persist despite training efforts. • Implement education programs and bundles for nurses and physicians including continuous surveillance and feedback to reduce the incidence of CRIs	(Böll et al., 2021)[175]

CVC, Central venous catheter; IPs, Implantable port; PICC, Peripherally inserted central catheter: KDOQI, National Kidney Foundation Disease Outcomes Quality Initiatives; GEMAV, Spanish Multidisciplinary Group on Vascular Access; ESKD, End-Stage Kidney Disease; tPA, tissue plasminogen activator; ESVS, European Society for Vascular Surgery; CDC, Centers for Disease Control and Prevention; CSN, Canadian Society of Nephrology; CRBSIs, Chinese Society of Breast Surgery of the Chinese Medical Association; Catheter-Related Bloodstream Infection; ESMO, European Society for Medical Oncology; AGIHO, Infectious Diseases Working Party; DGHO, German Society for Hematology and Medical Oncology; CRI, Catheter-Related Infection

ensuring safe vascular access management.[46] Effective teams often include nephrologists or oncologists, nurses, pharmacists, vascular access specialists, and infection-prevention experts, enabling shared decision-making and timely interventions. Education is a key pillar: structured programs for healthcare providers, patients, and caregivers improve safe CVAD use and early recognition of complications.[43,46] Although guidelines can provide a useful framework for clinicians when using CVADs, their implementation can be challenging and not straightforward. Patient-specific conditions, clinical judgement, cost considerations, clinical ease of management, resource availability, and staff expertise are factors that can limit the guidelines' implementation. Effective implementation of best practices for central CVAD management requires a coordinated, system-level approach. Evidence shows that multidisciplinary teams, the adoption of standardized care bundles, and continuous performance feedback are associated with reduced complication rates and improved patient outcomes. Beyond nursing and medical staff, the involvement of pharmacists, infectious disease specialists, infection-prevention teams, and vascular access experts ensures rigorous monitoring and timely, shared decision-making.[201] Education remains a fundamental pillar of implementation strategies. Both nephrology and oncology guidelines emphasize the need for structured educational programs targeting not only healthcare professionals but also patients and families, intending to promote safe and informed CVAD use. Despite the benefits of guidelines as a framework for clinical decision-making, translating recommendations into daily practice remains challenging. Patient-specific conditions, clinical judgment, cost considerations, availability of technology and supplies, and varying levels of staff expertise can influence and sometimes limit the application of recommended practices. Organizational barriers, such as high workload, staff turnover, and differences in local care models, may further hinder full adoption. Consequently, many institutions have implemented phased or adaptive strategies, incorporating strong clinical leadership, ongoing quality-indicator monitoring, and continuous review cycles to tailor guideline implementation to the needs and constraints of the local context.[202] Within this framework, surface-modified CVADs offer a strategic advantage for high-risk populations. By reducing thrombosis and infection risk, these devices complement guideline-based care and support improved vascular access outcomes. While surface-engineered catheters often involve higher initial costs, potential long-term savings arise from fewer complications, reduced device replacements, and lower hospitalization rates. Their successful integration requires alignment with multidisciplinary care bundles, staff training, careful patient selection, and adherence to maintenance protocols. Thus, surface-modified CVADs should be viewed not only as a biomaterial innovation but also as a practical tool for implementing best practices, bridging technology, clinical protocols, and patient-centered care. Long-term clinical validation, cost-effectiveness assessments, and real-world implementation studies remain essential to guide widespread adoption and maximize patient benefit.[203]

7. Challenges and perspectives

CVADs remain essential for life-saving therapies such as hemodialysis and chemotherapy. Despite decades of technological evolution, CVADs are not exempt from complications, and bloodstream infections and thrombosis continue to represent the most frequent complications in kidney and cancer patients, driving morbidity and imposing significant burdens on healthcare systems.[204] Outcomes are influenced by both patient-specific factors and device-intrinsic properties, including material composition, surface characteristics, and design features, highlighting the need for an integrated, biomaterials-focused approach to improve vascular access safety. While clinical guidelines provide evidence-based recommendations for device selection, placement, maintenance, and complication prevention, persistent high rates of infection and thrombosis indicate that adherence to best practice alone is insufficient. While evidence on surface modification strategies is constrained by small, single-center studies, emphasizing the need for large multicenter trials, their challenging implementation underscores the importance of technological improvement in device design and materials, and highlights biomaterial innovation as a key strategy to bridge the gap between guidelines and real-world outcomes. Current technological approaches in surface modification represent a step forward, with some promising options already available in clinical practice, although most remain limited to addressing either infection or thrombosis. Most current solutions are limited in scope, applying only to certain types of catheters, and are often hampered by concerns regarding durability, cost-effectiveness, microbial resistance, and limited safety or efficacy data.[205] More research is therefore necessary to optimise the technological development of CVADs and to find effective solutions that could help minimise the risk of device-related infections and thrombosis. Future biomaterials research should focus on developing multifunctional, durable, and clinically validated surface technologies that can be applied to both external and internal CVAD surfaces to improve long-term outcomes for patients requiring vascular access.

7.1 Limitations

This review has several limitations. As a narrative synthesis, it may be subject to selection bias, while heterogeneity in study design, populations, and outcome definitions limits comparability across trials. Most evidence on surface modification strategies comes from small, single-center studies with short follow-up, reducing the strength of clinical inferences. Moreover, guideline implementation across healthcare systems was not systematically assessed, potentially affecting the generalizability of some recommendations.

8. Conclusions

CVADs are indispensable for life-saving therapies but continue to be challenged by complications, primarily infection and thrombosis. While clinical guidelines help mitigate these risks, technological innovation, particularly in biomaterials and surface modification, remains critical to overcoming current limitations. Most existing strategies are uni-functional or lack long-term clinical validation, emphasizing the need for durable, multifunctional, and clinically tested surface technologies. Interdisciplinary biomaterials research integrating engineering, chemistry, and clinical science will be key to advancing the safety, efficacy, and long-term performance of CVADs, ultimately improving patient outcomes.

Ethics and consent

Ethical approval and consent were not required.

Declaration of AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT by OpenAI to support language refinement. After using this tool/service, the authors critically reviewed and edited the content as needed and take full responsibility for the content of the publication.

Data availability

This paper does not include original data, since it is a review on the available evidence on the topic.

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References

1. Martincich I, Cini K, Lapkin S, *et al.*: **Central Venous Access Device Complications in Patients Receiving Parenteral Nutrition in General Ward Settings: A Retrospective Analysis.** *JPEN J. Parenter. Enteral Nutr.* 2020; **44**: 1104–1111.
Publisher Full Text

2. Baldauf B, Cemin R, Hummel J, *et al.*: **Central Vascular Access Devices: Current Standards and Future Implications.** *J. Vasc. Dis.* 2025; **4**: 3.
Publisher Full Text

3. Kovesdy CP: **Epidemiology of chronic kidney disease: an update 2022.** *Kidney Int.***Suppl. 12**(2022): 7–11.
Publisher Full Text

4. Francis A, Harhay MN, Ong ACM, *et al.*: **Chronic kidney disease and the global public health agenda: an international consensus.** *Nat. Rev. Nephrol.* 2024; **20**: 473–485.
Publisher Full Text

5. Ying M, Shao X, Qin H, *et al.*: **Disease Burden and Epidemiological Trends of Chronic Kidney Disease at the Global, Regional, National Levels from 1990 to 2019.** *Nephron.***148**(2024): 113–123.
Publisher Full Text

6. Shahbazi F, Doosti-Irani A, Soltanian A, *et al.*: **Global forecasting of chronic kidney disease mortality rates and numbers with the generalized additive model.** *BMC Nephrol.* 2024; **25**: 286.
Publisher Full Text

7. Liyanage T, Ninomiya T, Jha V, *et al.*: **Worldwide access to treatment for end-stage kidney disease: a systematic review.** *Lancet.* 2015; **385**: 1975–1982.
Publisher Full Text

8. US Renal Data System: **2024 USRDS Annual Data Report: Epidemiology of Kidney Disease in the United States.** 2024.
Reference Source

9. Bray F, Laversanne M, Sung H, *et al.*: **GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries.** *CA Cancer J. Clin.* 2022; **74** (2024). 229–263.
Publisher Full Text

10. Bizuayehu HM, Ahmed KY, Kibret GD, *et al.*: **Global Disparities of Cancer and Its Projected Burden in 2050.** *JAMA Netw. Open.* 2024; **7**: e2443198.
Publisher Full Text

11. Wilson BE, Jacob S, Yap ML, *et al.*: **Estimates of global chemotherapy demands and corresponding physician workforce requirements for 2018 and 2040: a population-based study.** *Lancet Oncol.* 2019; **20**: 769–780.
Publisher Full Text

12. Mermel LA: **Short-term Peripheral Venous Catheter–Related Bloodstream Infections: A Systematic Review.** *Clin. Infect. Dis.* 2017; **65**: 1757–1762.
Publisher Full Text

13. Daphne Broadhurst AR, Cernusca C, Cook C, *et al.*; **CVAA Occlusion Management Guideline for Central Venous Access Devices (CVADs).**
Reference Source

14. Sohail MA, Vachharajani TJ, Anvari E: **Central Venous Catheters for Hemodialysis—the Myth and the Evidence.** *Kidney Int. Reports.* 2021; **6**: 2958–2968.
Publisher Full Text

15. Wang Z, Wang K, Xu Y: **Friction injury of the central vein caused by catheter for hemodialysis: an in vitro study.** *Sci. Rep.* 2024; **14**: 5836.
Publisher Full Text

16. Lok CE, Yuo T, Lee T: **Hemodialysis Vascular Access: Core Curriculum 2025.** *Am. J. Kidney Dis.* 2025; **85**: 236–252.
Publisher Full Text

17. MacRae JM, Dipchand C, Oliver M, *et al.*: **Arteriovenous Access Failure, Stenosis, and Thrombosis.** *Can. J. Kidney Health Dis.* 2016; **3**.
Publisher Full Text

18. Lubitz A, Woo K: **Choice of dialysis access: Catheter, peritoneal, or hemodialysis.** *Semin. Vasc. Surg.* 2024; **37**: 369–374.
Publisher Full Text

19. Hajji M, Neji M, Agrebi S, *et al.*: **Incidence and challenges in management of hemodialysis catheter-related infections.** *Sci. Rep.* 2022; **12**: 20536.
Publisher Full Text

20. Stevenson T, White S, Ahmed S, *et al.*: **WCN25-153 A NATIONAL SURVEY OF HAEMODIALYSIS CENTRAL VENOUS CATHETER PROTOCOLS AND PRACTICE.** *Kidney Int. Reports.* 2025; **10**: S368.
Publisher Full Text

21. Ghimire A, Shah S, Chauhan U, *et al.*: **Global variations in funding and use of hemodialysis accesses: an international report using the ISN Global Kidney Health Atlas.** *BMC Nephrol.* 2024; **25**: 159.
Publisher Full Text

22. Barrigah-Benissan K, Ory J, Simon C, *et al.*: **Clinical factors associated with peripherally inserted central catheters (PICC) related bloodstream infections: a single centre retrospective cohort.** *Antimicrob. Resist. Infect. Control.* 2023; **12**: 5.
Publisher Full Text

23. Sapkota S, Sannur R, Naik R: **Analysis of Peripherally Inserted Central Catheter Line in Cancer Patients: A Single-Center Experience, South Asian.** *J. Cancer.* 2020; **09**: 253–256.
Publisher Full Text

24. Larcher R, Barrigah-Benissan K, Ory J, *et al.*: **Peripherally Inserted Central Venous Catheter (PICC) Related Bloodstream Infection in Cancer Patients Treated with Chemotherapy Compared with Noncancer Patients: A Propensity-Score-Matched Analysis.** *Cancers (Basel).* 2023; **15**: 3253.
Publisher Full Text

25. Piredda A, Radice D, Zencovich C, *et al.*: **Safe use of Peripherally Inserted Central Catheters for chemotherapy of solid malignancies in adult patients: A 1-year monocentric, prospectively-assessed, unselected cohort of 482 patients.** *J. Vasc. Access.* 2021; **22**: 873–881.
Publisher Full Text

26. Lin L, Li W, Chen C, *et al.*: **Peripherally inserted central catheters versus implantable port catheters for cancer patients: a meta-analysis.** *Front. Oncol.* 2023; **13**.
Publisher Full Text

27. Janatolmakan M, Awys L, Khatony A: **Cancer patients' experience with implanted venous ports: A qualitative descriptive study.** *J. Vasc. Nurs.* 2024; **42**: 74–79.
Publisher Full Text

28. Qiu J, Huang S, Wen P, *et al.*: **Implantable Port Catheters versus Peripherally Inserted Central Catheters for Cancer Patients Requiring Chemotherapy: An RCT-Based Meta-Analysis.** *J. Cancer.* 2025; **16**: 1127–1136.
Publisher Full Text

29. Jiang M, Li C, Pan C, *et al.*: **Risk of venous thromboembolism associated with totally implantable venous access ports in cancer patients: A systematic review and meta-analysis.** *J. Thromb. Haemost.* 2020; **18**: 2253–2273.
Publisher Full Text

30. Klaiber U, Grummich K, Jensen K, *et al.*: **Closed cannulation of subclavian vein vs open cut-down of cephalic vein for totally implantable venous access port (TIVAP) implantation: protocol for a systematic review and proportional meta-analysis of perioperative and postoperative complications.** *Syst. Rev.* 2015; **4**: 53.
Publisher Full Text

31. Madabhavi I, Patel A, Sarkar M, *et al.*: **A Study of Use of "PORT" Catheter in Patients with Cancer: A Single-Center Experience.** *Clin. Med. Insights Oncol.* 2017; **11**.
Publisher Full Text

32. Kehagias E, Galanakis N, Tsetis D: **Central venous catheters: Which, when and how.** *Br. J. Radiol.* 2023; **96**.
Publisher Full Text

33. Moureau NL: *Vessel Health and Preservation: The Right Approach for Vascular Access.* Cham: Springer International Publishing; 2019.
Publisher Full Text

34. El Khudari H, Ozen M, Kowalczyk B, *et al.*: **Hemodialysis Catheters: Update on Types, Outcomes, Designs and Complications.** *Semin. Intervent. Radiol.* 2022; **39**: 090–102.
Publisher Full Text

35. Machat S, Eisenhuber E, Pfarl G, *et al.*: **Complications of central venous port systems: a pictorial review.** *Insights Imaging.* 2019; **10**: 86.
Publisher Full Text

36. Vescia S, Baumgärtner AK, Jacobs VR, *et al.*: **Management of venous port systems in oncology: a review of current evidence.** *Ann. Oncol.* 2008; **19**: 9–15.
Publisher Full Text

37. Huang X-M, Li X, Deng J, *et al.*: **Clinical applications and research progress of totally implantable venous access ports: a literature review.** *Front. Oncol.* 2025; **14**.
Publisher Full Text

38. LeRoy K, Donahue D: **In Vitro Venous Catheter Material Comparison: Microbial Adhesion in a Thrombotic Blood Flow Model.** *J. Infus. Nurs.* 2025; **48**: 386–394.
Publisher Full Text

39. Bouhrour N, Nibbering PH, Bendali F: **Medical Device-Associated Biofilm Infections and Multidrug-Resistant Pathogens.** *Pathogens.* 2024; **13**: 393.
Publisher Full Text

40. Abdulelah M, Haider O, Abdulelah H, *et al.*: **Venous access devices (Review).** *Med. Int.* 2025; **5**: 42.
Publisher Full Text

41. Vajdič Trampuž B, Arnol M, Gubenšek J, *et al.*: **A national cohort study on hemodialysis arteriovenous fistulas after kidney transplantation - long-term patency, use and complications.** *BMC Nephrol.* 2021; **22**: 344.
Publisher Full Text

42. Shahar S, Mustafar R, Kamaruzaman L, *et al.*: **Catheter-Related Bloodstream Infections and Catheter Colonization among Haemodialysis Patients: Prevalence, Risk Factors, and Outcomes.** *Int. J. Nephrol.* 2021; **2021**: 1–9.
Publisher Full Text

43. Sousa B, Furlanetto J, Hutka M, *et al.*: **Central venous access in oncology: ESMO Clinical Practice Guidelines.** *Ann. Oncol.* 2015; **26**: v152–v168.
Publisher Full Text

44. Cobo-Sánchez JL, Blanco-Mavillard I, Mancebo-Salas N, *et al.*: **Early identification of local infections in central venous catheters for hemodialysis: A systematic review.** *J. Infect. Public Health.* 2023; **16**: 1023–1032.
Publisher Full Text

45. Lebeaux D, Fernández-Hidalgo N, Chauhan A, *et al.*: **Management of infections related to totally implantable venous-access ports: challenges and perspectives.** *Lancet Infect. Dis.* 2014; **14**: 146–159.
Publisher Full Text

46. Lok CE, Huber TS, Lee T, *et al.*: **KDOQI Clinical Practice Guideline for Vascular Access: 2019 Update.** *Am. J. Kidney Dis.***75**(2020): S1–S164.
Publisher Full Text

47. Bello AK, Okpechi IG, Osman MA, *et al.*: **Epidemiology of haemodialysis outcomes.** *Nat. Rev. Nephrol.* 2022; **18**: 378–395.
Publisher Full Text

48. Wang T-Y, Lee K-D, Chen P-T, *et al.*: **Incidence and risk factors for central venous access port-related infection in Chinese cancer patients.** *J. Formos. Med. Assoc.* 2015; **114**: 1055–1060.
Publisher Full Text

49. Gowin E, Świątek-Kościelna B, Mańkowski P, *et al.*: **The Profile of Microorganisms Responsible for Port-Related Bacteremia in Pediatric Hemato-Oncological Patients.** *Cancer Control.* 2020; **27**.
Publisher Full Text

50. Bitunguramye A, Nkundimana G, Aboubasha AM, *et al.*: **Incidence, Risk Factors, Organism Types, and Outcomes of Catheter-Related Bloodstream Infections in Hemodialysis Patients.** *Cureus.* 2024.
Publisher Full Text

51. Hara Y, Sumida Y, Yamazaki S, *et al.*: **Risk factors for infection of totally implantable central venous access ports among patients requiring port removal.** *J. Vasc. Access.* 2025; **26**: 519–524.
Publisher Full Text

52. Maki DG, Kluger DM, Crnich CJ: **The Risk of Bloodstream Infection in Adults With Different Intravascular Devices: A Systematic Review of 200 Published Prospective Studies.** *Mayo Clin. Proc.* 2006; **81**: 1159–1171.
Publisher Full Text

53. Mahapatra HS, Muthukumar B, Krishnan C, *et al.*: **Comparative Outcomes of Tunneled and Non-Tunneled Catheters as Bridge to Arteriovenous Fistula Creation in Incident Hemodialysis Patients.** *Semin. Dial.* 2025; **38**: 187–193.
Publisher Full Text

54. Kim G-M, Song S, Kim DY, *et al.*: **Impact of insertion into the left internal jugular vein in chemoport-associated infections: a retrospective single-center study of 1690 cases.** *Sci. Rep.* 2024; **14**: 8925.
Publisher Full Text

55. Lebeaux D, Larroque B, Gellen-Dautremer J, *et al.*: **Clinical Outcome After a Totally Implantable Venous Access Port-Related Infection in Cancer Patients.** *Medicine (Baltimore).* 2012; **91**: 309–318.
Publisher Full Text

56. Suzuki T, Michimoto K, Hasumi J, *et al.*: **Silver-Mixed Port Reduces Venous Access Port Related Infection Rate Compared to Non-Silver-mixed Port: A Single-center Retrospective Analysis.** *Cardiovasc. Intervent. Radiol.* 2023; **46**: 1696–1702.
Publisher Full Text

57. Chang L, Tsai J-S, Huang S-J, *et al.*: **Evaluation of infectious complications of the implantable venous access system in a general oncologic population.** *Am. J. Infect. Control.* 2003; **31**: 34–39.
Publisher Full Text

58. Sharma V, Pandey A: **A Spectrum of Chemoport-Associated Complications and Their Management in Cancer Patients.** *Cureus.* 2024.
Publisher Full Text

59. Ghmaird AS, Mohammad Alnoaiji MS, Alalawi YS, *et al.*: **Port-a-Cath Insertion in Pediatric Patients With Malignancy in Tabuk.**

Cureus. 2021.
Publisher Full Text

60. Zaghal A, Khalife M, Mukherji D, *et al.*: **Update on totally implantable venous access devices.** *Surg. Oncol.* 2012; **21**: 207–215.
Publisher Full Text

61. Rieger MJ, Schenkel X, Dedic I, *et al.*: **Complication rates of peripherally inserted central catheters vs implanted ports in patients receiving systemic anticancer therapy: A retrospective cohort study.** *Int. J. Cancer.* 2023; **153**: 1397–1405.
Publisher Full Text

62. Moss JG, Wu O, Bodenham AR, *et al.*: **Central venous access devices for the delivery of systemic anticancer therapy (CAVA): a randomised controlled trial.** *Lancet.* 2021; **398**: 403–415.
Publisher Full Text

63. Taxbro K, Hammarskjöld F, Thelin B, *et al.*: **Clinical impact of peripherally inserted central catheters vs implanted port catheters in patients with cancer: an open-label, randomised, two-centre trial.** *Br. J. Anaesth.* 2019; **122**: 734–741.
Publisher Full Text

64. Wang L, Jia L, Jiang A: **Pathology of catheter-related complications: what we need to know and what should be discovered.** *J. Int. Med. Res.* 2022; **50**.
Publisher Full Text

65. Girardi L, Di Nisio M, Candeloro M, *et al.*: **Catheter-related deep vein thrombosis: Where are we at and where are we going? Updates and ongoing unmet clinical needs.** *Eur. J. Clin. Investig.* 2025; **55**.
Publisher Full Text

66. Mauro Pittiruti e Giancarlo Scoppettuolo: **RACCOMANDAZIONI GAVeCeLT 2024 PER LA INDICAZIONE, L'IMPIANTO E LA Gest. DEI Dispos. PER ACCESSO VENOSO.** 2024.
Reference Source | **Reference Source**

67. Wang K, Wang P, Liang X, *et al.*: **Epidemiology of haemodialysis catheter complications: a survey of 865 dialysis patients from 14 haemodialysis centres in Henan province in China.** *BMJ Open.* 2015; **5**: e007136.
Publisher Full Text

68. López-Rubio M, Lago-Rodríguez M-O, Ordieres-Ortega L, *et al.*: **A Comprehensive Review of Catheter-Related Thrombosis.** *J. Clin. Med.* 2024; **13**: 7818.
Publisher Full Text

69. Dridi M, Mejri N, Labidi S, *et al.*: **Implantable port thrombosis in cancer patients: a monocentric experience, Cancer.** *Biol. Med.* 2016; **13**: 384–388.
Publisher Full Text

70. Piran S, Ngo V, McDiarmid S, *et al.*: **Incidence and risk factors of symptomatic venous thromboembolism related to implanted ports in cancer patients.** *Thromb. Res.* 2014; **133**: 30–33.
Publisher Full Text

71. Bailleul A, Fulgencio J-P, Vimont S, *et al.*: **Risk factors and prognostic significance of infection of totally implantable vascular access port in solid tumor patients: A prospective cohort study.** *Infect. Dis. Now.* 2023; **53**: 104766.
Publisher Full Text

72. Morisi N, Montani M, Ehode EN, *et al.*: **Evaluating Short-Term Outcomes of Tunneled and Non-Tunneled Central Venous Catheters in Hemodialysis.** *J. Clin. Med.* 2024; **13**: 3664.
Publisher Full Text

73. Lebeaux D, Zarrouk V, Leflon-Guibout V, *et al.*: **Complications infectieuses liées aux chambres implantables: caractéristiques et prise en charge.** *La Rev. Médecine Interne.* 2010; **31**: 819–827.
Publisher Full Text

74. Saeed Z, Sirolli V, Bonomini M, *et al.*: **Hallmarks for Thrombotic and Hemorrhagic Risks in Chronic Kidney Disease Patients.** *Int. J. Mol. Sci.* 2024; **25**.
Publisher Full Text

75. Cieri IF, Patel S, Rodriguez Alvarez AA, *et al.*: **Variability in Coagulation Profiles in Patients with Chronic Kidney Disease and Peripheral Artery Disease.** *Ann. Vasc. Surg.* 2025; **113**: 267–277.
Publisher Full Text

76. Mohazzab A, Khavanin Zadeh M, Dehesh P, *et al.*: **Investigation of risk factors for tunneled hemodialysis catheters dysfunction: competing risk analysis of a tertiary center data.** *BMC Nephrol.* 2022; **23**: 300.
Publisher Full Text

77. Sahli F, Feidjel R, Laalaoui R: **Hemodialysis catheter-related infection: rates, risk factors and pathogens.** *J. Infect. Public Health.* 2017; **10**: 403–408.
Publisher Full Text

78. Lemaire X, Morena M, Leray-Moragués H, *et al.*: **Analysis of Risk Factors for Catheter-Related Bacteremia in 2000 Permanent Dual Catheters for Hemodialysis.** *Blood Purif.* **28**(2009): 21–28.
Publisher Full Text

79. Katneni R, Hedayati SS: **Central venous catheter-related bacteremia in chronic hemodialysis patients: epidemiology and evidence-based management.** *Nat. Clin. Pract. Nephrol.* 2007; **3**: 256–266.
Publisher Full Text

80. Guo H, Zhang L, He H, *et al.*: **Risk factors for catheter-associated bloodstream infection in hemodialysis patients: A meta-analysis.** *PLoS One.* 2024; **19**: e0299715.
Publisher Full Text

81. Leung A, Heal C, Perera M, *et al.*: **A systematic review of patient-related risk factors for catheter-related thrombosis.** *J. Thromb. Thrombolysis.* 2015; **40**: 363–373.
Publisher Full Text

82. Jiang D, Lee AI: **Thrombotic Risk from Chemotherapy and Other Cancer Therapies., Cancer Treat.** *Demogr. Res.* 2019; **179**: 87–101.
Publisher Full Text

83. Peng Q, Zhu J, Zhang Y, *et al.*: **Blood hypercoagulability and thrombosis mechanisms in cancer patients -A brief review.** *Heliyon.* 2024; **10**: e38831.
Publisher Full Text

84. Decousus H, Bourmaud A, Fournel P, *et al.*: **Cancer-associated thrombosis in patients with implanted ports: a prospective multicenter French cohort study (ONCOCIP).** *Blood.* 2018; **132**: 707–716.
Publisher Full Text

85. Huriaux L, Costille P, Quintard H, *et al.*: **Haemodialysis catheters in the intensive care unit, Anaesth. Crit. Care.** *Pain Med.* 2017; **36**: 313–319.
Publisher Full Text

86. Pittiruti M, Emoli A, Porta P, *et al.*: **Randomized Comparison of three different types of Valved and Non-Valved Peripherally inserted Central Catheters.** *J. Vasc. Access.* 2014; **15**: 519–523.
Publisher Full Text

87. Kanchanasuttirak W, Lekhavat V, Kanchanasuttirak P: **Long-Term Tunneled Hemodialysis Catheters: Achieving Efficiency Through Tip Position Optimization.** *Ann. Vasc. Surg.* 2024; **105**: 158–164.
Publisher Full Text

88. Forneris G, Marciello A, Savio D, *et al.*: **Ultrasound in central venous access for hemodialysis.** *J. Vasc. Access.* 2021; **22**: 97–105.
Publisher Full Text

89. Chelazzi C, Innocenti C, Pelagatti C, *et al.*: **Ultrasound-guided positioning of totally implantable access port systems: a single-center experience.** *Crit. Care.* 2009; **13**: P197.
Publisher Full Text

90. Knuttinen M-G, Bobra S, Hardman J, *et al.*: **A Review of Evolving Dialysis Catheter Technologies.** *Semin. Intervent. Radiol.* 2009; **26**: 106–114.
Publisher Full Text

91. Gołębiowski T, Kusztal M, Letachowicz K, *et al.*: **Difficulties with tunneling of the cuffed catheter: a single-centre experience.** *Sci. Rep.* 2018; **8**: 3314.
Publisher Full Text

92. Schults JA, Kleidon T, Petsky HL, *et al.*: **Peripherally inserted central catheter design and material for reducing catheter failure and complications.** *Cochrane Database Syst. Rev.* 2019.
Publisher Full Text

93. Murray-Taylor S, Schamban N: **Access of Ports and Catheters and Management of Obstruction.** *Pediatr. Emerg. Med.* Elsevier; 2008; pp. 1205–1207.
Publisher Full Text

94. Tal M, Ni N: **Features of chronic hemodialysis catheters and common complications.** *Diálisis y Traspl.* 2010; **31**: 17–20.
Publisher Full Text

95. Chen K, Liu X, Luo Q, *et al.*: **The current status and evolution of hemodialysis catheters.** *Ren. Fail.* 2025; **47**: 2524523.
Publisher Full Text

96. Tal MG, Ni N: **Selecting Optimal Hemodialysis Catheters: Material, Design, Advanced Features, and Preferences.** *Tech. Vasc. Interv. Radiol.* 2008; **11**: 186–191.
Publisher Full Text

97. Muhamad NA, Ma'amor NH, Mustapha N, *et al.*: **Nondrug Intervention for Opportunistic Infections in Individuals With Hematological Malignancy: Systematic Review.** *Interact. J. Med. Res.* 2023; **12**: e43969.
Publisher Full Text

98. Malek AE, Raad II: **Preventing catheter-related infections in cancer patients: a review of current strategies.** *Expert Rev. Anti-Infect. Ther.* 2020; **18**: 531–538.
Publisher Full Text

99. Schults JA, Kleidon T, Charles K, *et al.*: **Peripherally inserted central catheter design and material for reducing catheter failure and complications.** *Cochrane Database Syst. Rev.* 2024; **2024**.
Publisher Full Text

100. Abou-Mrad A, Marano L, Oviedo RJ: **A Monocentric Analysis of Implantable Ports in Cancer Treatment: Five-Year Efficacy and Safety Evaluation.** *Cancers (Basel).* 2024; **16**: 2802.
Publisher Full Text

101. Busch JD, Vens M, Herrmann J, *et al.*: **Material Failure of Silicone Catheter Lines: A Retrospective Review of Partial and Complete Ruptures in 553 Patients.** *Am. J. Roentgenol.* 2017; **208**: 464–469.
Publisher Full Text

102. Wildgruber M, Lueg C, Borgmeyer S, *et al.*: **Polyurethane versus silicone catheters for central venous port devices implanted at the forearm.** *Eur. J. Cancer.* 2016; **59**: 113–124.
Publisher Full Text

103. Alzahrani K, Lejeune J, Lakhal W, *et al.*: **Polyurethane versus silicone port a cath: What's going on at removal?.** *J. Pediatr. Surg.* 2018; **53**: 1417–1419.
Publisher Full Text

104. Crook JL, Lu Z, Wang X, *et al.*: **Why do subcutaneous ports get stuck? A case-control study.** *J. Pediatr. Surg.* 2022; **57**: 229–233.
Publisher Full Text

105. Silverstein DM, Trerotola SO, Clark T, *et al.*: **Clinical and Regulatory Considerations for Central Venous Catheters for Hemodialysis.** *Clin. J. Am. Soc. Nephrol.* 2018; **13**: 1924–1932.
Publisher Full Text

106. Yuan H, Lin C, Wang C: **Research progress of the interaction between blood vessels and intervention catheters and its surface modification.** *Friction.* 2025; **13**: 9441003.
Publisher Full Text

107. Welk B, Isaranuwatchai W, Krassioukov A, *et al.*: **Cost-effectiveness of hydrophilic-coated intermittent catheters compared with uncoated catheters in Canada: a public payer perspective.** *J. Med. Econ.* 2018; **21**: 639–648.
Publisher Full Text

108. Lazarus B, Polkinghorne KR, Gallagher M, *et al.*: **Tunneled Hemodialysis Catheter Tip Design and Risk of Catheter Dysfunction: An Australian Nationwide Cohort Study.** *Am. J. Kidney Dis.* 2024; **83**: 445–455.
Publisher Full Text

109. Prasad P, Vachharajani TJ: **Dialysis Catheter Tip Design and Dysfunction: An Unsolved Challenge.** *Am. J. Kidney Dis.* 2024; **83**: 429–431.
Publisher Full Text

110. South Wales Intravenous Access Advisory Group, Guidelines for the Care and Maintenance of a Peripherally Inserted Central Catheter (PICC): 2014; **32**.
Reference Source

111. Amroun K, Brugel M, Rhaiem R, *et al.*: **Assessing the time-to-removal of totally implantable venous access devices comparing valved-versus open-ended catheters in patients treated with chemotherapy.** *J. Vasc. Access.* 2025; **26**: 447–454.
Publisher Full Text

112. Biffi R, De Braud F, Orsi F, *et al.*: **A randomized, prospective trial of central venous ports connected to standard open-ended or Groshong catheters in adult oncology patients.** *Cancer.* 2001; **92**: 1204–1212.
Publisher Full Text

113. Yu K, Li J, Zhang D, *et al.*: **Types of peripherally inserted central catheters and the risk of unplanned removals in patients: A prospective cohort study.** *Int. J. Nurs. Stud.* 2024; **149**: 104621.
Publisher Full Text

114. Liu L, Liu Z, Wang J, *et al.*: **Exploring risk factors for totally implantable venous access devices (TIVADs)-related thrombotic occlusion in the off-treatment period.** *Sci. Rep.* 2023; **13**: 10767.
Publisher Full Text

115. Lafuente Cabrero E, Terradas Robledo R, Civit Cuñado A, *et al.*: **Risk factors of catheter- associated bloodstream infection: Systematic review and meta-analysis.** *PLoS One.* 2023; **18**: e0282290.
Publisher Full Text

116. Dezfulian C, Lavelle J, Nallamothu BK, *et al.*: **Rates of infection for single-lumen versus multilumen central venous catheters: A meta-analysis.** *Crit. Care Med.* 2003; **31**: 2385–2390.
Publisher Full Text

117. Contreras G, Liu P-Y, Elzinga L, *et al.*: **A multicenter, prospective, randomized, comparative evaluation of dual- versus triple-lumen catheters for hemodialysis and apheresis in 485 patients.** *Am. J. Kidney Dis.* 2003; **42**: 315–324.
Publisher Full Text

118. Kozlowski KM, Jalaeian H, Travis LM, *et al.*: **A comparative analysis of infection and complication rates between single- and double-lumen ports.** *Infect. Control Hosp. Epidemiol.* 2024; **45**: 698–702.
Publisher Full Text

119. She R, Kobayashi K: **Comparison of Infection Rates between Single-Lumen and Double-Lumen Chest Ports among Patients with Cancer: A Propensity Score Matching Analysis.** *J. Vasc. Interv. Radiol.* 2024; **35**: 592–600.e5.
Publisher Full Text

120. Infusion Therapy Standards of Practice: n.d.
Reference Source

121. Ling Q, Tian Y, Lv Z, *et al.*: **Synthetic engineering of central venous catheter based on antibacterial endothelial simulation can effectively antagonize vascular infection and thrombosis.** *Front. Mater.* 2025; **12**.
Publisher Full Text

122. Thorarinsdottir H, Kander T, Johansson D, *et al.*: **Blood compatibility of widely used central venous catheters; an experimental study.** *Sci. Rep.* 2022; **12**: 8600.
Publisher Full Text

123. Flick AI, Winters R: **Vascular Tunneled Central Catheter Access, StatPearls.** 2023.

124. Hamilton H: **Central venous catheters: choosing the most appropriate access route.** *Br. J. Nurs.* 2004; **13**: 862–870.
Publisher Full Text

125. 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.
Publisher Full Text

126. Gharaibeh KA, Abdelhafez MO, Guedze KEB, *et al.*: **Impact of initial jugular vein insertion site selection for central venous catheter placement on hemodialysis catheter complications.** *J. Crit. Care.* 2025; **87**: 155011.
Publisher Full Text

127. Charvát J, Linke Z, Horáèková M, *et al.*: **Implantation of central venous ports with catheter insertion via the right internal jugular vein in oncology patients—single center experience.** *Support Care Cancer.* 2006; **14**: 1162–1165.
Publisher Full Text

128. Paquet F, Boucher L-M, Valenti D, *et al.*: **Impact of Arm Selection on the Incidence of PICC Complications: Results of a Randomized Controlled Trial.** *J. Vasc. Access.* 2017; **18**: 408–414.
Publisher Full Text

129. Premuzic V, Perkov D, Smiljanic R, *et al.*: **The Different Impacts on the Long-Term Survival of Tunneled Internal Jugular Hemodialysis Catheters Based on Tip Position and Laterality.** *Blood Purif.* 2017; **43**: 315–320.
Publisher Full Text

130. Soh NYT, Tan BS, Chan SJM, *et al.*: **Deeper may not be better: relationship between catheter dysfunction and location of the catheter tip in right-sided tunnelled haemodialysis catheters.** *Clin. Radiol.* 2022; **77**: 678–683.
Publisher Full Text

131. Hsu CC-T, Kwan GN, Evans-Barns H, *et al.*: **Venous cutdown versus the Seldinger technique for placement of totally implantable venous access ports.** *Cochrane Database Syst. Rev.* 2016; **2016**.
Publisher Full Text

132. Laguna JC, Cooksley T, Ahn S, *et al.*: **Catheter-related thrombosis (CRT) in patients with solid tumors: a narrative review and clinical guidance for daily care.** *Support Care Cancer.* 2022; **30**: 8577–8588.
Publisher Full Text

133. Brass P, Hellmich M, Kolodziej L, *et al.*: **Ultrasound guidance versus anatomical landmarks for internal jugular vein catheterization.** *Cochrane Database Syst. Rev.* 2015; **2018**.
Publisher Full Text

134. Wang Z-X, Li L, Zhao Y-F: **Fluoroscopically guided repositioning of peripherally inserted central catheter in patients failing ultrasound-guided-only placement: a retrospective five-year study.** *Acta Radiol.* 2023; **64**: 2132–2136.
Publisher Full Text

135. Gianazza S, Valli C, Mangano S, *et al.*: **Positioning of the Central Venous Catheter for Hemodialysis Using Wireless Intracavitary ECG: A Case Series and Narrative Review of the Literature.** *Med. Sci.* 2025; **13**: 39.
Publisher Full Text

136. Tashi S, Tan AB, Chua JME, *et al.*: **Radiologic placement of totally implantable venous access devices: Outcomes and

complications from a large oncology cohort. *Ann. Acad. Med. Singap.* 2025; **54**: 27–35.
Publisher Full Text

137. Wallace A, Albadawi H, Patel N, *et al.*: **Anti-fouling strategies for central venous catheters.** *Cardiovasc. Diagn. Ther.* 2017; **7**: S246–S257.
Publisher Full Text

138. Lai NM, Chaiyakunapruk N, Lai NA, *et al.*: **Catheter impregnation, coating or bonding for reducing central venous catheter-related infections in adults.** *Cochrane Database Syst. Rev.* 2016; **2018**.
Publisher Full Text

139. Coronel-Meneses D, Sánchez-Trasviña C, Ratera I, *et al.*: **Strategies for surface coatings of implantable cardiac medical devices.** *Front. Bioeng. Biotechnol.* 2023; **11**.
Publisher Full Text

140. Sánchez-Bodón J, Diaz-Galbarriatu M, Pérez-Álvarez L, *et al.*: **Strategies to Enhance Biomedical Device Performance and Safety: A Comprehensive Review.** *Coatings.* 2023; **13**: 1981.
Publisher Full Text

141. Bonomini M, Piscitani L, Di Liberato L, *et al.*: **Biocompatibility of Surface-Modified Membranes for Chronic Hemodialysis Therapy.** *Biomedicine.* 2022; **10**: 844.
Publisher Full Text

142. Chatzinikolaou I, Finkel K, Hanna H, *et al.*: **Antibiotic-coated hemodialysis catheters for the prevention of vascular catheter–related infections: a prospective, randomized study.** *Am. J. Med.* 2003; **115**: 352–357.
Publisher Full Text

143. Hanna H, Benjamin R, Chatzinikolaou I, *et al.*: **Long-Term Silicone Central Venous Catheters Impregnated With Minocycline and Rifampin Decrease Rates of Catheter-Related Bloodstream Infection in Cancer Patients: A Prospective Randomized Clinical Trial.** *J. Clin. Oncol.* 2004; **22**: 3163–3171.
Publisher Full Text

144. Sousa C, Henriques M, Oliveira R: **Mini-review: Antimicrobial central venous catheters – recent advances and strategies.** *Biofouling.* 2011; **27**: 609–620.
Publisher Full Text

145. Deng J, Wu K, Yang Y, *et al.*: **Antimicrobial activity and cytocompatibility of silver nanoparticles coated catheters via a biomimetic surface functionalization strategy.** *Int. J. Nanomedicine.* 2015; 7241.
Publisher Full Text

146. Paladini F, Pollini M, Deponti D, *et al.*: **Effect of silver nanocoatings on catheters for haemodialysis in terms of cell viability, proliferation, morphology and antibacterial activity.** *J. Mater. Sci. Mater. Med.* 2013; **24**: 1105–1112.
Publisher Full Text

147. Jain G, Allon M, Saddekni S, *et al.*: **Does Heparin Coating Improve Patency or Reduce Infection of Tunneled Dialysis Catheters?.** *Clin. J. Am. Soc. Nephrol.* 2009; **4**: 1787–1790.
Publisher Full Text

148. Liu L, Yu H, Wang L, *et al.*: **Heparin-network-mediated long-lasting coatings on intravascular catheters for adaptive antithrombosis and antibacterial infection.** *Nat. Commun.* 2024; **15**: 107.
Publisher Full Text

149. Hong JK, Waterhouse A: **Bioinspired Approaches to Engineer Antithrombogenic Medical Devices for Vascular Intervention.** *Arterioscler. Thromb. Vasc. Biol.* 2023; **43**: 797–812.
Publisher Full Text

150. Chauhan A, Bernardin A, Mussard W, *et al.*: **Preventing Biofilm Formation and Associated Occlusion by Biomimetic Glycocalyxlike Polymer in Central Venous Catheters.** *J. Infect. Dis.* 2014; **210**: 1347–1356.
Publisher Full Text

151. May RM, Magin CM, Mann EE, *et al.*: **An engineered micropattern to reduce bacterial colonization, platelet adhesion and fibrin sheath formation for improved biocompatibility of central venous catheters.** *Clin. Transl. Med.* 2015; **4**.
Publisher Full Text

152. Margel D, Mizrahi M, Regev-Shoshani G, *et al.*: **Nitric oxide charged catheters as a potential strategy for prevention of hospital acquired infections.** *PLoS One.* 2017; **12**: e0174443.
Publisher Full Text

153. Gregorits BM, Wu Y, Chen C, *et al.*: **In Vitro and in vivo biocompatibility study of fluorinated polyphosphazene coatings for blood-contacting medical devices.** *Acta Biomater.* 2025; **203**: 346–357.
Publisher Full Text

154. Nazari S, Abdelrasoul A: **Impact of Membrane Modification and Surface Immobilization Techniques on the Hemocompatibility of Hemodialysis Membranes: A Critical Review.** *Membranes (Basel).* 2022; **12**: 1063.
Publisher Full Text

155. Kim S, Feinberg B, Kant R, *et al.*: **Diffusive Silicon Nanopore Membranes for Hemodialysis Applications.** *PLoS One.* 2016; **11**: e0159526.
Publisher Full Text

156. Ma Q, Zhang W, Mou X, *et al.*: **Bioinspired Zwitterionic Block Polymer-Armored Nitric Oxide-Generating Coating Combats Thrombosis and Biofouling.** *Research.* 2024; **7**.
Publisher Full Text

157. Mendoza G, Regiel-Futyra A, Tamayo A, *et al.*: **Chitosan-based coatings in the prevention of intravascular catheter-associated infections.** *J. Biomater. Appl.* 2018; **32**: 725–737.
Publisher Full Text

158. Li K, Peng J, Liu Y, *et al.*: **Surface Engineering of Central Venous Catheters via Combination of Antibacterial Endothelium-Mimicking Function and Fibrinolytic Activity for Combating Blood Stream Infection and Thrombosis.** *Adv. Healthc. Mater.* 2023; **12**.
Publisher Full Text

159. Aryanti PTP, Nugroho FA, Kusmala YY: **Heparin and heparin-like modifications in hemodialysis membranes: Current innovations and future directions.** *Biotechnol. Adv.* 2025; **80**: 108527.
Publisher Full Text

160. Zawidlak-Węgrzyńska B, Rydz J, Musioł M, *et al.*: **Polymer-Drug Anti-Thrombogenic and Hemocompatible Coatings as Surface Modifications.** *Pharmaceutics.* 2024; **16**.
Publisher Full Text

161. Malhotra A, Chauhan SR, Rahaman M, *et al.*: **Phyto-assisted synthesis of zinc oxide nanoparticles for developing antibiofilm surface coatings on central venous catheters.** *Front. Chem.* 2023; **11**.
Publisher Full Text

162. Pinelo A, Loureiro L, Mendes D, *et al.*: **Drug-Eluting Stents vs. Stent-Grafts in Hemodialysis Vascular Access Outflow Interventions.** *J. Endovasc. Ther.* 2025.
Publisher Full Text

163. Bandyopadhyay S, Jones A, McLean A, *et al.*: **Slippery liquid infused fluoropolymer coating for central lines to reduce catheter associated clotting and infections.** *Sci. Rep.* 2020; **10**: 14973.
Publisher Full Text

164. Sutherland DW, Zhang X, Charest JL: **Water Infused Surface Protection as an Active Mechanism for Fibrin Sheath Prevention in Central Venous Catheters.** *Artif. Organs.* 2017; **41**.
Publisher Full Text

165. Ullman AJ, Kleidon T, Gibson V, *et al.*: **Central venous Access device SeCurement And Dressing Effectiveness (CASCADE) in paediatrics: protocol for pilot randomised controlled trials.** *BMJ Open.* 2016; **6**: e011197.
Publisher Full Text

166. **Guidelines for the Prevention of Intravascular Catheter-Related Infections.**2011; **2011**: 80. (n.d.)
Reference Source

167. Mermel LA: **Prevention of Intravascular Catheter–Related Infections.** *Ann. Intern. Med.* 2000; **132**: 391–402.
Publisher Full Text

168. Veenstra DL, Saint S, Saha S, *et al.*: **Efficacy of Antiseptic-Impregnated Central Venous Catheters in Preventing Catheter-Related Bloodstream Infection.** *JAMA.* 1999; **281**: 261.
Publisher Full Text

169. Abouleish YZ, Oldfield EC, Marik PE: **Comparison of central-line–associated bloodstream infections between central venous catheters lined by combined chlorhexidine and silver sulfadiazine versus silver ionotrophes alone: A before–after–before retrospective study.** *Infect. Control Hosp. Epidemiol.* 2021; **42**: 225–227.
Publisher Full Text

170. Brun-Buisson C, Doyon F, Sollet J-P, *et al.*: **Prevention of intravascular catheter-related infection with newer chlorhexidine-silver sulfadiazine-coated catheters: a randomized controlled trial.** *Intensive Care Med.* 2004; **30**: 837–843.
Publisher Full Text

171. Rabindranath KS, Bansal T, Adams J, *et al.*: **Systematic review of antimicrobials for the prevention of haemodialysis catheter-related infections.** *Nephrol. Dial. Transplant.* 2009; **24**: 3763–3774.
Publisher Full Text

172. Rupp ME, Lisco SJ, Lipsett PA, *et al.*: **Effect of a Second-Generation Venous Catheter Impregnated with Chlorhexidine and Silver Sulfadiazine on Central Catheter–Related Infections.** *Ann.*

Intern. Med. 2005; **143**: 570–580.
Publisher Full Text

173. Ostendorf T, Meinhold A, Harter C, *et al.*: **Chlorhexidine and silver-sulfadiazine coated central venous catheters in haematological patients—a double-blind, randomised, prospective, controlled trial.** *Support Care Cancer.* 2005; **13**: 993–1000.
Publisher Full Text

174. Wang H, Tong H, Liu H, *et al.*: **Effectiveness of antimicrobial-coated central venous catheters for preventing catheter-related blood-stream infections with the implementation of bundles: a systematic review and network meta-analysis.** *Ann. Intensive Care.* 2018; **8**: 71.
Publisher Full Text

175. Böll B, Schalk E, Buchheidt D, *et al.*: **Central venous catheter–related infections in hematology and oncology: 2020 updated guidelines on diagnosis, management, and prevention by the Infectious Diseases Working Party (AGIHO) of the German Society of Hematology and Medical Oncology (DGHO).** *Ann. Hematol.***100**(2021): 239–259.
Publisher Full Text

176. Balikci E, Yilmaz B, Tahmasebifar A, *et al.*: **Surface modification strategies for hemodialysis catheters to prevent catheter related infections: A review.** *J. Biomed. Mater. Res. Part B Appl. Biomater.* 2021; **109**: 314–327.
Publisher Full Text

177. Najahi-Missaoui W, Arnold RD, Cummings BS: **Safe Nanoparticles: Are We There Yet?.** *Int. J. Mol. Sci.* 2020; **22**: 385.
Publisher Full Text

178. Bambauer R, Schiel R, Bambauer C, *et al.*: **Surface-Treated versus Untreated Large-Bore Catheters as Vascular Access in Hemodialysis and Apheresis Treatments.** *Int. J. Nephrol.* 2012; **2012**: 1–8.
Publisher Full Text

179. Chen Y-M, Dai A-P, Shi Y, *et al.*: **Effectiveness of silver-impregnated central venous catheters for preventing catheter-related blood stream infections: a meta-analysis.** *Int. J. Infect. Dis.* 2014; **29**: 279–286.
Publisher Full Text

180. Asker D, Awad TS, Raju D, *et al.*: **Preventing Pseudomonas aeruginosa Biofilms on Indwelling Catheters by Surface-Bound Enzymes.** *ACS Appl. Bio Mater.* 2021; **4**: 8248–8258.
Publisher Full Text

181. Choi YJ, Lim JK, Park JJ, *et al.*: **Chlorhexidine and silver sulfadiazine coating on central venous catheters is not sufficient for protection against catheter-related infection: Simulation-based laboratory research with clinical validation.** *J. Int. Med. Res.* 2017; **45**: 1042–1053.
Publisher Full Text

182. Casals E, Gusta MF, Bastus N, *et al.*: **Silver Nanoparticles and Antibiotics: A Promising Synergistic Approach to Multidrug-Resistant Infections.** *Microorganisms.* 2025; **13**: 952.
Publisher Full Text

183. Lavery KS, Rhodes C, Mcgraw A, *et al.*: **Anti-thrombotic technologies for medical devices.** *Adv. Drug Deliv. Rev.* 2017; **112**: 2–11.
Publisher Full Text

184. Özdemir M, Taydaş O, Danışan G, *et al.*: **Comparison of the complications and long-term results of heparin-coated and non-heparin-coated symmetric-tip hemodialysis catheters.** *J. Vasc. Access.* 2025; **26**: 139–143.
Publisher Full Text

185. Lee AYY, Kamphuisen PW: **Epidemiology and prevention of catheter-related thrombosis in patients with cancer.** *J. Thromb. Haemost.* 2012; **10**: 1491–1499.
Publisher Full Text

186. Ibeas J, Roca-Tey R, Vallespín J, *et al.*: **por el Grupo Español Multidisciplinar del Acceso Vascular (GEMAV), Erratum to «Spanish Clinical Guidelines on Vascular Access for Haemodialysis».** *Nefrologia.* 2019; **39**: 1–2.
Publisher Full Text

187. Schmidli J, Widmer MK, Basile C, *et al.*: **Editor's Choice - Vascular Access: 2018 Clinical Practice Guidelines of the European Society for Vascular Surgery (ESVS).** *Eur. J. Vasc. Endovasc. Surg.* 2018; **55**(6): 757–818.
PubMed Abstract | **Publisher Full Text**

188. Culleton BF: **Introduction.** *J. Am. Soc. Nephrol.* 2006; **17**: S1–S3.
Publisher Full Text

189. Jahanzeb M, Wu C-Y, Lim H, *et al.*: **International experts consensus on optimal central vascular access device selection and management for patients with cancer.** *J. Vasc. Access.* 2024.
Publisher Full Text

190. Ma L, Ge Z-C, Xin L, *et al.*: **Clinical practice guidelines for breast cancer implantable intravenous infusion ports: Chinese Society of Breast Surgery practice guidelines 2021.** *Chin. Med. J.* 2021; **134**: 1894–1896.
Publisher Full Text

191. Slaughter E, Kynoch K, Brodribb M, *et al.*: **Evaluating the Impact of Central Venous Catheter Materials and Design on Thrombosis: A Systematic Review and Meta-Analysis.** *Worldviews Evidence-Based Nurs.* 2020; **17**: 376–384.
Publisher Full Text

192. Falcone G, Gallucci F, Aprea P, *et al.*: **Central venous catheters in oncology. comparison of materials for prevention of complications: literature review.** *Ann. Oncol.* 2016; **27**: iv83.
Publisher Full Text

193. Napoli M, Guzzi F, Morale W, *et al.*: **Vascular access for hemodialysis in Italy: What a national survey reveals.** *J. Vasc. Access.* 2025; **26**: 471–476.
Publisher Full Text

194. Central venous access devices, 2023: n.d..
Reference Source

195. The international standard for safe aseptic technique: n.d.
Reference Source

196. Agarwal AK, Roy-Chaudhury P, Mounts P, *et al.*: **Taurolidine/Heparin Lock Solution and Catheter-Related Bloodstream Infection in Hemodialysis.** *Clin. J. Am. Soc. Nephrol.* 2023; **18**: 1446–1455.
Publisher Full Text

197. Kahale LA, Tsolakian IG, Hakoum MB, *et al.*: **Anticoagulation for people with cancer and central venous catheters.** *Cochrane Database Syst. Rev.* 2018; **6**: CD006468.
Publisher Full Text

198. López-Briz E, Ruiz Garcia V, Cabello JB, *et al.*: **Heparin versus 0.9% sodium chloride locking for prevention of occlusion in central venous catheters in adults.** *Cochrane Database Syst. Rev.* 2018; **2018**.
Publisher Full Text

199. Nguyen T, Camins BC, Butler DA: **Taurolidine and Heparin as Catheter Lock Solution for Central Venous Catheters in Hemodialysis.** *Am. J. Ther.* 2024; **31**: e398–e409.
Publisher Full Text

200. Aschenbrenner DS: **New Drug Reduces Catheter-Related Bloodstream Infections in Patients Undergoing Hemodialysis, AJN.** *Am. J. Nurs.* 2024; **124**: 20–20.
Publisher Full Text

201. Jarding EK, Flynn Makic MB: **Central Line Care and Management: Adopting Evidence-Based Nursing Interventions.** *J. PeriAnesthesia Nurs.* 2021; **36**: 328–333.
Publisher Full Text

202. Comber ER, Keogh S, Nguyen LN, *et al.*: **Implementation frameworks, strategies and outcomes in optimizing central venous access device practice in paediatrics: A scoping review.** *J. Adv. Nurs.* 2025; **81**: 7007–7019.
Publisher Full Text

203. Xu J, Zare H, Chiu H-C, *et al.*: **Evaluating the Cost-Effectiveness of Chlorhexidine-Coated vs. Standard Peripheral Insertion Central Catheters in Patients with Hematologic Disease: A Health Economic Analysis.** *Int. J. Environ. Res. Public Health.* 2025; **22**: 373.
Publisher Full Text

204. Teja B, Bosch NA, Diep C, *et al.*: **Complication Rates of Central Venous Catheters.** *JAMA Intern. Med.* 2024; **184**: 474.
Publisher Full Text

205. Luu CH, Nguyen N, Ta HT: **Unravelling Surface Modification Strategies for Preventing Medical Device-Induced Thrombosis.** *Adv. Healthc. Mater.* 2024; **13**.
Publisher Full Text