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Central Venous Catheter Insertion: Advanced Clinical Techniques, Complication Prevention, and Evidence-Based Critical Care Practice

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Abstract

Background: Central Venous Catheters (CVCs) are indispensable devices in critical care, enabling advanced hemodynamic monitoring, administration of critical therapies, and provision of renal replacement. Their insertion, however, carries significant risks of mechanical, infectious, and thrombotic complications.

Aim: This article provides a comprehensive review of modern CVC insertion, focusing on advanced techniques, complication prevention, and evidence-based best practices to optimize patient safety and procedural success in critical care settings.

Methods: A detailed narrative synthesis of current literature and clinical guidelines was conducted. The review examines anatomical considerations for common access sites (internal jugular, subclavian, femoral), evaluates the evidence for ultrasound-guided insertion, and analyzes strategies for preventing immediate and delayed complications.

Results: Real-time ultrasound guidance is established as the standard of care, significantly improving first-attempt success and reducing mechanical complications like arterial puncture and pneumothorax. Site selection involves balancing risks: the internal jugular vein offers ease of ultrasound visualization; the subclavian vein has a lower infection risk but a higher pneumothorax risk; the femoral vein is useful in emergencies but carries higher thrombosis and infection risks. Strict adherence to maximal sterile barrier precautions and daily catheter care bundles are paramount for preventing catheter-related bloodstream infections.

Conclusion: Safe and effective CVC management requires a structured, multidisciplinary approach. Mastery of ultrasound-guided technique, meticulous aseptic practice, and vigilant post-procedural care by an interprofessional team are essential to minimize complications and maximize the therapeutic benefits of central venous access.

Keywords: Central venous catheter, ultrasound guidance, Seldinger technique, catheter-related bloodstream infection, internal jugular vein, complication prevention..

Introduction

A central venous catheter (CVC) is an intravascular device designed for placement within one of the major central veins, most frequently the internal jugular, subclavian, or femoral veins, with its distal tip positioned in the superior vena cava, inferior vena cava, or within the right atrium. In contemporary clinical practice, these devices are interchangeably referred to as “central lines,” “central venous lines” (CVLs), or “central venous access” and represent a cornerstone of advanced vascular access. The first description of central venous catheter placement dates back to 1929, marking the beginning of a transformative era in both experimental and clinical medicine [1]. Over subsequent decades, central venous access evolved from an innovative experimental technique into a fundamental tool in the investigation of cardiac physiology and the management of critically ill and medically complex patients [2]. The development and refinement of CVC technology and insertion techniques have expanded the range of clinical indications substantially. Central venous catheters now play a vital role in delivering total parenteral nutrition in patients unable to tolerate enteral feeding, providing reliable venous access for the administration of vasoactive agents, chemotherapeutic drugs, and other medications that require central delivery, and serving

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as access points for intermittent or continuous renal replacement therapies such as hemodialysis and plasmapheresis [1][3][4][5]. Additionally, CVCs are integral to advanced monitoring strategies, including central venous pressure measurement and mixed venous oxygen saturation assessment, thereby informing hemodynamic optimization in critically ill patients. They also facilitate complex interventions such as transvenous pacemaker insertion and serve as conduits for specialized devices in interventional cardiology and critical care [6][7].

Despite the expanding scope of their clinical applications, the fundamental procedural principles underpinning CVC insertion have remained remarkably stable for several decades. The widespread adoption of the Seldinger technique in the 1960s established a systematic, wire-guided method of vascular access that continues to underpin virtually all modern central venous catheterization strategies [8]. The Seldinger approach, involving percutaneous vessel puncture followed by guidewire insertion, tract dilation, and catheter advancement, has proven robust, versatile, and adaptable across multiple access sites and device types. While catheter materials, designs, and adjunctive technologies have undergone continuous innovation, the core methodology of central venous cannulation has changed relatively little since that time. One major advancement that has significantly altered practice patterns, however, is the incorporation of real-time ultrasound guidance. Initially introduced as an adjunct to improve landmark-based techniques, ultrasound has now become the standard of care for internal jugular vein cannulation and is increasingly employed for other central venous sites. Multiple studies have demonstrated that ultrasound guidance enhances first-attempt success rates, reduces the number of needle passes, diminishes the risk of arterial puncture, hematoma, and other mechanical complications, and improves overall procedural safety and efficiency [5][9][10][11][12][13]. As a result, international guidelines and professional societies widely endorse ultrasound-guided central venous access, particularly in anatomically challenging patients or in high-risk settings such as the intensive care unit and emergency department.

Debate persists regarding the optimal choice of venous access site for CVC placement. The internal jugular, subclavian, and femoral veins each have distinct advantages and risk profiles, including differing rates of pneumothorax, catheter-related bloodstream infection, thrombosis, and patient comfort or mobility limitations. Comparative studies and meta-analyses have yielded nuanced and sometimes conflicting data regarding which site should be preferred under specific clinical circumstances. For example, subclavian access may be associated with a lower risk of infection but a higher risk of pneumothorax relative to the internal jugular vein, whereas femoral access may be more convenient in emergent situations but carries a higher risk of infection and thrombosis. Consequently, site selection is often individualized, considering patient anatomy, coagulation status, infection risk, urgency of access, and operator expertise. Nonetheless, these ongoing discussions about site-specific risk do not diminish the central role of CVCs in contemporary critical care [5][9][10][11][12][13]. In modern practice, proficiency in both the placement and management of central venous catheters is viewed as a core competency for physicians and advanced practitioners caring for acutely and critically ill patients, including those in emergency medicine, anesthesiology, intensive care, surgery, and hospital medicine. Beyond technical insertion skills, clinicians must be adept at recognizing indications and contraindications, minimizing and managing complications, and applying evidence-based strategies to reduce catheter-related infections and thrombosis. Accordingly, this article aims to provide a comprehensive review of central venous catheterization, encompassing its indications, contraindications, procedural techniques, potential complications, and best practices for ongoing management, with particular emphasis on the integration of modern imaging guidance and safety-focused protocols.

Anatomy and Physiology

Central venous catheterization relies on precise understanding of the venous anatomy and its relationship to adjacent structures, as well as the physiological implications of accessing different central veins. Multiple venous sites can be used for central venous catheter (CVC) placement, but in routine clinical practice, three short-term access points are most commonly employed: the internal jugular, subclavian, and common femoral veins. These sites are typically used for temporary access, ranging from days to weeks, in critically ill or perioperative patients. By contrast, more peripheral upper-extremity veins such as the basilic and brachial veins serve as entry points for peripherally inserted central catheters (PICCs), which are often chosen for mid- to long-term venous access when more durable or outpatient-compatible solutions are needed. Tunneled catheters, implantable ports, and other forms of long-term central access placed using complex interventional radiology techniques follow related anatomical principles but fall outside the scope of this discussion, which focuses on short-term central venous access. Selection of an access site is never purely anatomic; it is a clinical decision informed by the patient's condition, anticipated duration and purpose of access, coagulation status, infection risk, prior surgeries or devices, and operator expertise. Each site confers specific advantages and disadvantages, meaning that optimal choice is highly individualized. A comprehensive appreciation of local vascular anatomy and the spatial relationship of veins to arteries, pleura, nerves, and musculoskeletal

structures is essential to perform the procedure safely and to minimize potentially serious complications such as arterial puncture, pneumothorax, hemothorax, nerve injury, and catheter malposition [9].

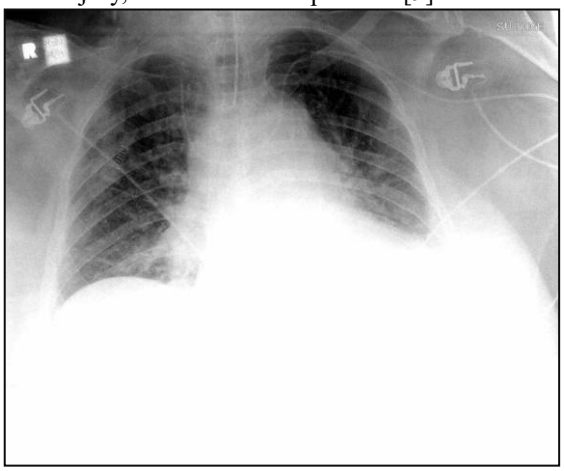

Fig. 1: Malpositioned Central Line, Chest Radiograph.

The internal jugular (IJ) vein has emerged as a preferred route for many temporary CVCs due to its generally predictable anatomy, superficial location, and the ease with which it can be visualized and accessed using real-time ultrasound guidance. These characteristics contribute to lower rates of mechanical complications and higher first-pass success when compared with purely landmark-based approaches [9]. Laterality is not arbitrary; the right internal jugular vein is usually favored in standard patients because it provides the most direct and relatively straight course from the neck to the superior vena cava (SVC) and right atrium. This linearity decreases the risk of catheter kinking and facilitates accurate tip positioning in the lower SVC or cavoatrial junction, which is optimal for hemodynamic monitoring and rapid infusion. Additionally, the right IJ is often larger in caliber and positioned more superficially than the left, making cannulation technically easier and more reliable [14]. Clinical circumstances may, however, dictate alternative choices. History of neck surgery or radiation, head and neck malignancy, unilateral trauma, thrombosis, or the presence of existing vascular devices such as pacemaker leads or previous central lines may require using the contralateral side or an entirely different venous territory.

Anatomically, the internal jugular vein descends within the carotid sheath alongside the common carotid artery and the vagus nerve. At the level of the lower neck, the vein lies anterolateral to the common carotid artery, typically within the apex of the triangle formed by the sternal and clavicular heads of the sternocleidomastoid (SCM) muscle and the clavicle. It ultimately joins the ipsilateral subclavian vein posterior to the sternoclavicular joint to form the brachiocephalic (innominate) vein. The right and left brachiocephalic veins then converge to form the SVC, which drains directly into the right atrium. Historically, landmark-based access to the IJ has been described via anterior, central, and posterior approaches relative to the bifurcation of the SCM. The central approach, entering between the two heads of the SCM, is commonly used due to its balance of accessibility and perceived safety. The posterior approach, which inserts the needle more laterally and posteriorly along the SCM, has been proposed as safer in terms of distance from the carotid artery and lung apex, whereas the anterior approach takes advantage of the easily palpable carotid artery as a reference but places the needle in closer proximity to vital structures. In practice, anatomic variation in the relative position of the vein and artery can be substantial, and head rotation or patient habitus can further distort predictable relationships. For this reason, most contemporary guidelines and experts advocate routine use of ultrasound guidance to identify the internal jugular vein, distinguish it from the carotid artery, and guide real-time needle advancement into the vessel lumen [15][16].

The subclavian (SC) vein represents another major route for central venous access and has several notable advantages. It is associated with relatively low risks of catheter-related bloodstream infection and thrombosis compared with some other sites, properties that are particularly appealing when longer indwelling times are anticipated [17]. Subclavian access is also advantageous in polytrauma patients or those immobilized with rigid cervical collars, situations in which internal jugular access may be technically challenging or contraindicated. However, the subclavian site is anatomically more complex, and attempts at cannulation carry a higher risk of certain complications, most notably pneumothorax or hemothorax, due to the close proximity of the pleural dome and lung parenchyma. The site is also noncompressible, as the vein lies posterior to the clavicle, so uncontrolled bleeding or arterial injury can be difficult to manage. From an anatomical perspective, the subclavian vein is a continuation of the axillary vein, beginning at the lateral border of the first rib and coursing medially beneath the clavicle. As it travels from lateral to medial, it arcs gently, sloping cephalad beneath the mid-clavicle before descending slightly to meet the internal jugular vein posterior to the sternoclavicular joint, where together they form the brachiocephalic vein. At the typical puncture site, the vein lies immediately posterior and inferior to the clavicle. Superimposed in this narrow space are several critical structures. The subclavian artery lies posterior and slightly inferior to the vein; the lung apex and pleura extend superiorly into the thoracic inlet, lying inferomedial to the vessel near the first rib. The brachial plexus and thoracic duct (on the left side, or right thoracic duct variant as described in some texts) also course nearby, and the phrenic nerve descends along the anterior scalene

muscle, passing deep to the brachiocephalic vein at its confluence with the internal jugular vein. These intimate relationships render the subclavian region vulnerable to vascular, neural, and pleural injuries during blind puncture [18].

Although ultrasound guidance has been successfully applied to subclavian cannulation, its routine use is less widespread than for internal jugular access, in part because the clavicle can obstruct the acoustic window and make visualization of the vessel more challenging. Many clinicians continue to rely on landmark-based techniques in this region, particularly for infraclavicular access, drawing on surface anatomy, the contour of the clavicle, and experience [19]. Evidence suggests that ultrasound guidance for subclavian catheterization can reduce mechanical complications such as inadvertent arterial puncture, pneumothorax, and brachial plexus injury, and can increase success rates; however, uptake remains variable, and operator comfort with the landmark technique continues to influence practice patterns [16][20][21][22]. The subclavian vein can be approached either infraclavicularly or supraclavicularly. In clinical practice, the infraclavicular method has traditionally been more commonly used, with the needle advanced just inferior to the clavicle toward the sternal notch. The supraclavicular approach, accessing the vein in the clavisternomastoid angle formed by the clavicle and the posterior border of the SCM, offers distinct anatomic advantages. It provides a relatively well-defined insertion landmark, a shorter and more direct course to the subclavian vein and SVC, and potentially greater distance from the pleura and lung. Moreover, some authors have observed that ultrasound imaging is technically easier in the supraclavicular fossa than beneath the clavicle, and on this basis have argued that it should replace the infraclavicular approach as the preferred technique for subclavian access [22][23]. However, other studies have reported a higher incidence of local hematoma with the supraclavicular route and comparable rates of other complications, leading to ongoing support for continuing the established infraclavicular approach in many settings [24]. Ultimately, choice of approach is guided by operator training, institutional protocols, and patient-specific factors.

The common femoral vein constitutes the third principal site for temporary central venous access. In critically ill patients, the femoral route is often attractive because the groin is usually accessible even when the chest and neck are crowded with monitoring equipment, endotracheal tubes, cervical collars, or surgical dressings. For patients in extremis or undergoing active resuscitation, femoral cannulation can be performed with minimal interference in airway management or chest procedures. A further advantage is that the common femoral vein lies in a location amenable to direct external compression, an important consideration in coagulopathic patients, those receiving thrombolytic therapy, or trauma patients in whom inadvertent arterial puncture or venous bleeding may occur [25]. Unlike internal jugular or subclavian access, femoral cannulation poses no risk of iatrogenic pneumothorax or hemothorax, which may be particularly advantageous in patients with severe pulmonary disease or pre-existing thoracic injury. Additionally, lower-extremity placement leaves the upper limbs and thorax free, which some patients find more comfortable and less restrictive once they stabilize. Nevertheless, femoral CVCs are not without disadvantages. They have been associated with higher rates of catheter-related thrombosis, likely related to lower-extremity venous stasis and local anatomical factors. The groin region is also prone to contamination from skin flora and gastrointestinal sources, raising concern for increased catheter-related bloodstream infection risk. While several studies have suggested that femoral lines may carry higher infection rates, others, particularly those conducted with rigorous sterile technique and standardized line care bundles, have produced conflicting results, calling into question whether femoral access is inherently more prone to infection or whether modifiable procedural and post-procedural factors are more consequential [5][26][27][28]. As a result, some guidelines recommend avoiding femoral lines when feasible, especially in obese patients or those at high risk of infection, whereas others accept femoral access as an appropriate option when meticulous aseptic technique and diligent line maintenance are assured [28].

A unique physiological limitation of femoral lines is their inaccuracy for traditional central venous pressure (CVP) monitoring, particularly in the context of intra-abdominal hypertension, elevated intra-pelvic pressures, or obstructive venous pathology. Whereas CVCs placed in the superior vena cava approximate right atrial pressure and can inform fluid responsiveness and venous return dynamics, femoral catheters—terminating in the inferior vena cava or iliac veins—may not reflect central cardiac filling pressures accurately, especially in conditions with compartmentalized venous pressures. For many modern hemodynamic strategies this is less critical, as dynamic indices and echocardiographic assessments increasingly supplement or replace CVP, but it remains a consideration in specific clinical scenarios. Anatomically, the common femoral vein resides within the femoral triangle, a region bounded superiorly by the inguinal ligament, medially by the adductor longus muscle, and laterally by the sartorius muscle. In contrast to the neck, where the internal jugular vein typically lies lateral to the common carotid artery, in the groin the relationships are reversed: the femoral vein is medial to the femoral artery. This inversion underscores the importance of

site-specific anatomic knowledge. A classic mnemonic—NAVEL—summarizes the lateral-to-medial order of structures encountered just inferior to the inguinal ligament: femoral Nerve, femoral Artery, common femoral Vein, a potential "Empty" space corresponding to the femoral canal, and Lymphatics [29]. This organizational pattern guides both landmark-based palpation (identifying the arterial pulse and inserting the needle just medial to it) and ultrasound interpretation, where the compressible, thin-walled vein lies medial to the pulsatile, thicker-walled artery. In obese patients, those with hypotension, or in challenging anatomical variants, ultrasound guidance is particularly useful to differentiate vessels and avoid inadvertent arterial cannulation, pseudoaneurysm formation, or arteriovenous fistula creation [11].

Beyond regional anatomy, an appreciation of venous physiology helps explain why central venous access at these sites is so valuable in critical care. The SVC and IVC collect the majority of systemic venous return and convey it directly to the right atrium, making them ideal locations for rapid administration of high-osmolarity solutions, vasoactive drugs, and large-volume resuscitation, which might cause irritation or thrombophlebitis in smaller peripheral veins. The high-flow, low-resistance environment of the central veins dilutes infusates quickly, reducing local endothelial injury. Accurate positioning of the catheter tip in or near the cavoatrial junction also enables measurement of central venous oxygen saturation and provides a surrogate for right atrial pressure in most circumstances, thereby informing assessment of intravascular volume status and cardiac performance. In summary, the anatomy and physiology relevant to central venous catheterization are foundational to safe and effective practice. The internal jugular, subclavian, and common femoral veins each offer distinct anatomical access corridors, physiological properties, and risk profiles. Understanding their three-dimensional relationships to arteries, nerves, lungs, pleura, and musculoskeletal structures, as well as their role in systemic venous return, allows clinicians to choose the most appropriate site for a given patient, to perform the procedure with minimal complications, and to interpret hemodynamic and clinical data derived from the catheter accurately. As ultrasound guidance becomes increasingly integrated into practice, this detailed anatomical knowledge is complemented—not replaced—by real-time visualization, aligning anatomical theory with bedside procedural reality [9][11][16].

Indications

Central venous catheters are inserted to address a range of critical clinical needs that cannot be adequately met with peripheral venous access. One of the primary indications is the presence of hemodynamic instability requiring vasopressor or inotropic support.

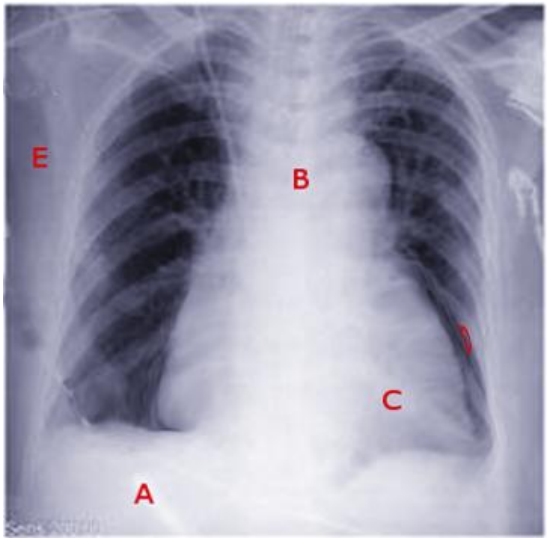

Fig. 2: Central Line, Pericardium.

These agents, which are often highly concentrated and carry a risk of significant local tissue injury if extravasated, must be delivered through a reliable, high-flow central vein to ensure both efficacy and safety. Central venous access is also frequently required for advanced hemodynamic monitoring. Measurement of central venous pressure and, in some cases, central venous oxygen saturation provides valuable information regarding intravascular volume status, right heart function, and overall perfusion, guiding resuscitation and ongoing management in critically ill patients. Another important indication is the need to administer hyperosmolar or irritant solutions that may cause phlebitis or sclerosis of peripheral veins. This includes total parenteral nutrition, certain chemotherapeutic agents, concentrated electrolyte solutions, and other medications with low pH or high osmolarity. In such cases, central veins, with their larger caliber and higher blood flow, facilitate rapid dilution and reduce the risk of local vascular injury. Central venous lines are also crucial when peripheral venous access is unobtainable or inadequate, whether due to patient habitus, vascular depletion from prior cannulations, shock, or the urgency of establishing reliable access for resuscitation. In emergency situations, the inability to secure sufficient peripheral access may necessitate central venous cannulation as a life-saving measure [16][24].

Central access is also required to support extracorporeal therapies that demand high-volume or high-flow circuits, such as intermittent hemodialysis, plasmapheresis, and continuous renal replacement therapy. These modalities depend on catheters capable of sustaining adequate flow rates without excessive resistance or collapse, which peripheral lines cannot provide. Similarly, when multiple

infusions must be delivered simultaneously—especially when they are chemically incompatible or require distinct infusion rates—central venous catheters facilitate the use of multi-lumen devices, allowing safe and organized administration of complex regimens, including vasopressors, sedatives, parenteral nutrition, and adjunctive therapies. In the context of massive transfusion protocols, central venous access can provide robust, high-flow channels for rapid administration of blood products when peripheral access is insufficient. Furthermore, CVCs serve as a conduit for a variety of venous interventions and advanced procedures. These include placement of inferior vena cava filters, catheter-directed thrombolytic therapy for venous thrombosis, transvenous cardiac pacing in patients with bradyarrhythmias or conduction block, and deployment of intravascular stents. In all of these situations, central venous catheterization is not merely a convenience but a critical enabling step that underpins both diagnostic and therapeutic strategies in acute and critical care practice [9][11][19].

Contraindications

The decision to place a central venous catheter must balance the urgency of vascular access against the potential risks inherent to the procedure. Contraindications to central venous catheterization are classically divided into absolute and relative categories, and many are specific to the intended access site. In critically ill patients, relative contraindications may be overridden when central access is essential for life-saving interventions, but such decisions require careful clinical judgment, an understanding of the underlying pathology, and an individualized risk–benefit assessment. Absolute contraindications represent conditions in which the risk of harm from attempting cannulation at a particular site clearly outweighs any potential benefit and cannot be mitigated by technique modification or adjuncts. One such absolute contraindication is the presence of active infection of the skin or soft tissue overlying the proposed insertion site. Introducing a catheter through infected tissue greatly increases the risk of catheter-related bloodstream infection and deep extension of the infection. Similarly, significant anatomical distortion at the intended site, whether due to prior surgery, radiation, scarring, or the presence of indwelling hardware such as hemodialysis catheters, pacemaker or defibrillator leads, or vascular grafts, can render the procedure technically hazardous and may predispose to malposition, vascular injury, or device interference. Another absolute contraindication is known or suspected vascular injury proximal or distal to the planned insertion site, as may be seen in penetrating or blunt trauma. Cannulating a vessel that is lacerated, dissected, thrombosed, or otherwise compromised risks exacerbating hemorrhage, embolization, or limb- or organ-threatening ischemia [30].

Relative contraindications, in contrast, identify conditions that increase procedural risk but may be deemed acceptable in emergent situations or when alternative routes are unavailable. Coagulopathy is a prominent example. Although central venous catheterization has historically been approached cautiously in coagulopathic patients, contemporary data suggest that the overall incidence of clinically significant bleeding is relatively low, around 0.8% [30]. Nonetheless, abnormal coagulation parameters can meaningfully increase the risk of hematoma, hemothorax, or retroperitoneal bleeding, particularly at noncompressible sites such as the subclavian vein. Thrombocytopenia similarly correlates with a greater likelihood of bleeding complications, especially when platelet counts fall to very low levels. Patients with an international normalized ratio (INR) greater than 3.0 or platelet counts below 20 × 10^9/L are considered to have severe coagulopathy and a substantially increased bleeding risk [31]. In such cases, it may be appropriate to administer fresh frozen plasma and/or platelet transfusions prior to, or shortly after, catheter placement, depending on the clinical urgency and the feasibility of correction. Other relative contraindications include an uncooperative or agitated patient who is awake and unable to remain still during the procedure, which can increase the risk of inadvertent arterial puncture, misplacement, or needle-related injury. Sedation, physical restraint, or deferral of the procedure until adequate control is achievable may be necessary in such cases, provided the clinical situation allows. Distortion of anatomical landmarks, whether from congenital anomalies, trauma, tumor, or prior surgery, can similarly complicate landmark-based approaches and increase the risk of complications; here, ultrasound guidance is particularly valuable in mitigating risk. Morbid obesity represents another challenging condition, as excess adipose tissue may obscure anatomic landmarks, deepen the target vessels, and complicate both needle trajectory and catheter tunneling. Careful positioning, longer needles, and routine use of ultrasound can help to offset some of these difficulties [30][31].

Because the risks associated with central venous access vary considerably by insertion site, site-specific contraindications must be evaluated on a patient-by-patient basis. The subclavian site, for example, is generally avoided in markedly coagulopathic patients due to the noncompressible location of the vein beneath the clavicle and its close proximity to the subclavian artery and pleural dome. In the event of arterial laceration or uncontrolled venous bleeding at this site, direct manual compression is technically difficult, and life-threatening hemothorax or mediastinal hemorrhage may ensue. For this reason, when significant coagulation abnormalities are present and cannot be promptly corrected, alternative sites such as the

internal jugular or femoral veins—where bleeding can be more easily compressed—are generally preferred. The internal jugular site may be relatively contraindicated in patients with rigid cervical collars following trauma, as neck immobilization can impede optimal positioning, limit access, and distort the usual anatomic relationships. Similarly, prior neck surgery, radiation, or the anticipated need for future neck procedures during the same admission may prompt avoidance of the IJ to preserve the site or reduce procedural risk. The femoral site, while advantageous in many emergent and coagulopathic scenarios, should be avoided if it is anticipated that the femoral vessels will be required for other interventions such as cardiac catheterization, percutaneous mechanical circulatory support, or endovascular procedures. In such cases, occupying the femoral vein with a central line may impede necessary future access or complicate interventional strategies. Ultimately, contraindications to central venous catheterization are dynamic considerations that must be weighed alongside the clinical necessity of central access. Absolute contraindications generally mandate choosing an alternative site or modality, whereas relative contraindications demand careful planning, optimization of correctable factors, selection of the safest possible site, and the use of adjuncts such as ultrasound guidance to minimize risk [30][31].

Equipment

The successful placement of a central venous catheter requires a comprehensive set of equipment that ensures procedural efficacy, sterility, and patient safety. Although catheter kits vary slightly by manufacturer, most contain the fundamental components necessary for cannulation using the Seldinger technique. The procedure also necessitates auxiliary materials and devices that support sterile technique, ultrasound visualization, and post-procedure catheter maintenance. A fully prepared procedural environment not only optimizes technical performance but also reduces the likelihood of mechanical, infectious, and procedural complications. A critical element of modern central venous access is the use of real-time ultrasound guidance. This requires an ultrasound machine equipped with a high-frequency linear transducer capable of producing detailed images of superficial vascular structures. To maintain sterility during the procedure, the ultrasound probe must be enclosed in a sterile cover with sterile transmission gel. The operator must don appropriate personal protective equipment, including a mask—preferably with an eye shield—a bouffant or surgical cap, sterile gown, and sterile gloves. The patient and procedural field must be prepared with wide sterile draping after skin cleansing with chlorhexidine or another suitable antiseptic solution. This antiseptic preparation reduces the microbial load at the insertion site, thereby decreasing the risk of catheter-associated bloodstream infections [30][31].

The central venous catheter kit is the procedural core and typically includes the catheter itself, which may be single-, double-, or triple-lumen depending on clinical need. Some clinical scenarios require a large-bore introducer catheter or a specialized dialysis catheter to facilitate high-flow extracorporeal therapies. The kit commonly contains an 18-gauge introducer needle attached to a syringe for venipuncture, a flexible guidewire for advancement into the central venous system, and a small #11 scalpel for skin incision. The Seldinger technique is supported through the presence of vessel dilators that expand the tract before catheter insertion. Additional components often include suture material—typically 3-0 silk on a straight needle or needle driver—for securing the catheter, catheter caps or Luer-lock connectors for each lumen, and saline locks. Vasodilators may also be included to facilitate venous dilation and smooth passage of the catheter. Adequate anesthetization of the insertion site is achieved with 1% lidocaine administered using a small-gauge needle (25- or 27-gauge) and a syringe. Sterile saline flushes in 10-mL syringes are required to confirm catheter patency and to clear each lumen following insertion. After successful placement, a sterile occlusive dressing is applied to protect the site, often supplemented with a chlorhexidine-impregnated disk such as a BioPatch to reduce microbial colonization. In summary, the equipment required for central venous catheter insertion reflects the complexity and precision of the procedure. From ultrasound devices and sterile barriers to specialized catheter kits containing needles, guidewires, and anchoring materials, each component supports a key procedural step. Proper preparation and the availability of all necessary tools are essential to achieving safe, efficient, and complication-free central venous access [31][32].

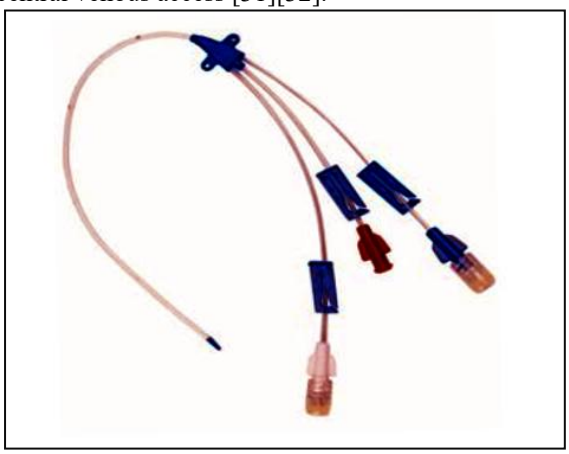

Fig. 3: Central Line, Triple Lumen.

Personnel

Central venous catheter (CVC) insertion is a complex invasive procedure that should be undertaken only by clinicians who are appropriately trained and competent in both the technical and cognitive aspects of the technique. The primary

operator—whether an intensivist, anesthesiologist, emergency physician, surgeon, or other qualified clinician—must possess a thorough understanding of the relevant anatomy, ultrasound-guided vascular access, aseptic technique, and complication management. Competency encompasses not only the mechanical skills required to cannulate a central vein and place the catheter, but also the ability to appropriately select the access site, assess contraindications, interpret hemodynamic implications, and recognize early signs of mechanical, infectious, or thrombotic complications.

Preparation and Procedures:

Although the procedure can be performed by a single skilled clinician, optimal practice usually involves at least one assistant, typically a nurse or another practitioner, particularly in critically ill or unstable patients. The assistant plays an important role in safety and efficiency: confirming patient identity, ensuring that informed consent has been obtained when possible, preparing monitoring equipment, administering sedation or analgesia when indicated, and maintaining a calm, organized environment during the procedure. The assistant also helps manage supplies, maintain the sterile field, adjust patient positioning, and observe for any changes in vital signs or clinical status. In high-acuity environments such as the intensive care unit or emergency department, additional personnel, including respiratory therapists and advanced practice providers, may contribute to airway management, hemodynamic support, or resuscitation while the central line is being placed. Meticulous preparation is essential for safe and efficient CVC insertion. Whenever feasible, informed consent should be obtained from the patient or their surrogate decision-maker prior to the procedure. This discussion should address the indication for central venous access, anticipated benefits, and potential risks, including bleeding, infection, pneumothorax, arterial injury, arrhythmia, thrombosis, and need for further interventions if complications arise. The clinician should verify that consent is documented in accordance with institutional policy. In emergent life-threatening situations in which consent cannot be obtained, the procedure may proceed under implied consent, but this should be clearly documented afterward. Once the decision to proceed has been made, the procedural team should inform the bedside nurse and other relevant staff that a central venous catheter will be inserted so that the room can be prepared appropriately. Visitors and non-essential personnel should be asked to leave the immediate area to minimize distractions, preserve patient privacy, and reduce contamination risk. The operator should then gather all necessary equipment, including the central line insertion kit, ultrasound machine, sterile ultrasound probe cover, antiseptic solution, sterile drapes, personal protective equipment, and all adjunctive items such as syringes, saline flushes, suture materials, and dressings. Having all materials assembled in advance minimizes interruptions and reduces the risk of breaks in sterility [31][32].

A preliminary ultrasound survey of the proposed access site is an important preparatory step. Using a high-frequency linear transducer, the operator should evaluate the internal jugular, subclavian, or common femoral veins, depending on the intended site, paying close attention to vessel size, depth, patency, and the presence of thrombus. The relationship of the target vein to adjacent arteries and other structures should be noted, and any anatomic variation should be identified. This pre-scan assists in selecting the most suitable site and side, especially in patients with prior central lines, anatomic distortion, thrombosis, or trauma. It also enables the operator to anticipate technical difficulties and adjust their approach accordingly. Patient positioning is crucial to procedural success. All central line insertions should be performed with the patient connected to continuous cardiac and pulse oximetry monitoring, with non-invasive blood pressure cycling at frequent intervals, typically every five minutes or more frequently in unstable patients. For internal jugular or subclavian access, the patient is generally placed in a slight Trendelenburg position—head-down tilt of approximately 10 to 15 degrees—if hemodynamically tolerated. This maneuver increases venous filling, enlarges the vein diameter, and may reduce the risk of air embolism by creating a positive venous pressure gradient. The head should be positioned neutrally or with minimal rotation to one side; excessive rotation can distort the relationship between the carotid artery and internal jugular vein and hinder ultrasound visualization. For femoral access, the patient is positioned supine with the hip slightly abducted and externally rotated to expose the groin [32].

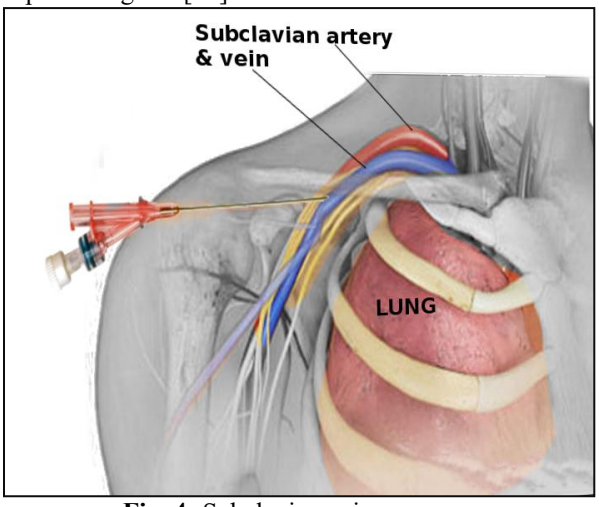

Fig. 4: Subclavian vein access.

Before establishing the sterile field, any clothing, jewelry, or non-essential monitoring devices obstructing the intended site must be removed or repositioned. Once the operator has performed hand

hygiene and donned a mask and cap, they may open the sterile central line kit and associated supplies. Sterile drapes are arranged to create a wide sterile field around the insertion site, preferably covering the patient from head to toe for upper-body access, in accordance with maximal barrier precautions. The skin over the chosen site is scrubbed with chlorhexidine-based antiseptic (or povidone-iodine if chlorhexidine is contraindicated or in certain trauma settings), using a systematic back-and-forth motion and allowing adequate contact time for antiseptic effect before draping. The ultrasound probe is then prepared. The transducer is cleaned, and sterile ultrasound gel is placed into a sterile probe cover, which is then carefully applied to maintain sterility. The cord may be secured to the drapes or the bed using a clamp or needle driver from the kit to prevent inadvertent contamination as the procedure progresses. Meanwhile, the central venous catheter is prepared on the sterile field. Each lumen is attached to a saline lock and flushed with sterile saline using 10-mL syringes to confirm patency and to ensure there are no leaks or obstructions. The most distal port is usually left open (without a saline lock) to facilitate connection to pressure transduction or high-flow infusions immediately after insertion. Local anesthesia is prepared by drawing 1% lidocaine into a syringe fitted with a small-gauge needle, which will later be used to infiltrate the skin and deeper tissues at the insertion site. Suture material, often 3-0 silk, is made ready to secure the catheter hub once placement is complete. The final large sterile drape is then placed over the patient, with an opening centered over the prepared site, creating an isolated sterile workspace. All instruments, including the introducer needle, guidewire, dilator, scalpel, and catheter, should be arranged logically and within easy reach to avoid unnecessary movements and reduce the risk of contamination [31].

Immediately before initiating the venipuncture, the procedural team should conduct a formal “time out” in accordance with institutional safety protocols. During this pause, the operator and nurse verify the patient’s identity, the planned procedure, the intended site and side of insertion, the indication for the line, and any known allergies or critical clinical issues such as anticoagulation, platelet count, or hemodynamic instability. This moment also provides an opportunity to confirm that resuscitation equipment is available, that sedation and analgesia have been appropriately administered if indicated, and that all team members understand their roles. Only after this structured safety check is completed should the operator proceed with venipuncture and catheter insertion. In sum, safe central venous catheter placement is not a solitary technical act, but a coordinated process that integrates skilled personnel, careful pre-procedural planning, stringent aseptic technique, and clear team communication. The quality of preparation and personnel coordination significantly influences procedural success, complication rates, and, ultimately, patient outcomes [32].

Treatment

The technical performance of central venous catheter (CVC) insertion is a structured, stepwise process that integrates optimal patient positioning, meticulous aseptic technique, real-time ultrasound guidance, and careful wire and catheter manipulation. The procedural sequence must be executed with precision to maximize first-pass success, minimize complications, and ensure correct catheter placement within a central vein. Proper positioning of the patient is the first critical step once indications have been confirmed and preparation completed. For internal jugular or subclavian venous access, the patient is typically placed in the Trendelenburg position, with the head of the bed lowered by approximately 10 to 15 degrees if tolerated hemodynamically. This head-down tilt increases venous return and distends the target veins, thereby enlarging their caliber and reducing the likelihood of venous collapse during needle advancement. It may also reduce the risk of air embolism by increasing central venous pressure relative to atmospheric pressure. For common femoral venous access, a flat, supine position is used, with the hip slightly abducted and externally rotated to provide better exposure to the groin. In some patients, especially those undergoing subclavian cannulation, a small cushion or rolled towel can be placed beneath the upper thoracic spine or between the scapulae to elevate the chest slightly, accentuate the infraclavicular space, and facilitate more favorable alignment between needle trajectory and vessel path. After sterile preparation and draping, the procedure begins with ultrasonographic localization of the target vein. Using a high-frequency linear probe enclosed in a sterile cover, the operator identifies the vein in a transverse or longitudinal plane and distinguishes it from adjacent arteries and other structures. The vein should be confirmed as compressible with gentle probe pressure. When uncertainty exists, color Doppler can be applied to differentiate venous from arterial flow patterns. In an awake or lightly sedated patient, 1% lidocaine is infiltrated into the skin and subcutaneous tissues at the planned puncture site to provide local anesthesia and improve tolerance of the procedure. Adequate anesthetization of the deeper tissues along the anticipated needle path further reduces discomfort and facilitates cooperation [31][32][33].

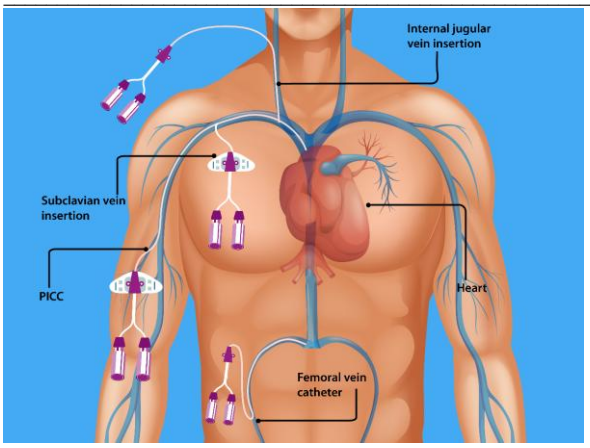

Fig. 5: Central Venous Catheterization Body Access.

Venipuncture is then performed under dynamic ultrasound guidance. A small-gauge finder needle or the 18-gauge introducer needle attached to a 10-mL syringe is advanced through the anesthetized skin toward the vein at an angle that may range from approximately 45 to 90 degrees relative to the skin surface, depending on the depth and location of the vessel. Throughout this maneuver, the operator maintains continuous visualization of the needle tip on the ultrasound screen to avoid overshooting the vessel or passing into deeper structures. Gentle traction is maintained on the syringe plunger to create negative pressure as the needle advances. Entry into the vein is indicated by a flashback of dark, non-pulsatile venous blood into the syringe. If no flash is obtained, or if bright red pulsatile blood is seen suggestive of arterial puncture, the needle should be withdrawn and repositioned under direct sonographic guidance until venous access is confirmed. Once venous blood is aspirated and venous location is reasonably assured, the needle must be stabilized carefully, generally with the dominant hand, to prevent inadvertent movement. The syringe is detached from the needle hub while the needle remains securely in place within the vein. A flexible guidewire is then introduced through the needle lumen and advanced into the vessel. Under normal circumstances, the wire should pass smoothly and without resistance. Any resistance to advancement suggests that the needle tip may not be fully within the lumen, that the wire is encountering a venous valve or anatomic obstruction, or that the J-tip is deflecting in an unintended direction, including retrograde. In such situations, the operator should withdraw the wire, confirm needle position, and attempt gentle readvancement; if difficulty persists, the needle should be repositioned or the vein re-accessed. Excessive force must never be applied, as this can result in vessel injury or wire kinking. As the guidewire progresses centrally, it may occasionally enter the right atrium or ventricle. When this occurs, ectopic beats or arrhythmias may be visible on continuous cardiac monitoring. Should any ectopy or arrhythmia arise temporally with wire advancement, the wire must be withdrawn immediately by a few centimeters until the rhythm normalizes. In most cases, it is not necessary to remove the wire completely; it can remain in a stable position within the superior vena cava or proximal vein once the arrhythmia resolves [31][32][33].

When the wire has reached a sufficient intravascular length—often indicated by markings on the wire, such as three hash marks at approximately 15 cm—the operator stabilizes the wire by grasping it firmly between two or more fingertips. The introducer needle is then withdrawn along the wire and removed from the field, taking particular care to avoid a needlestick injury. At no point should the operator release control of the guidewire; continuous contact with the wire is an essential safety principle to prevent loss of intravascular access and avoid embolization of the wire. After the needle is removed, the position of the guidewire must be verified. Ultrasound is used again to image the vessel in both transverse and longitudinal planes, confirming that the wire lies centrally within the venous lumen and not in adjacent structures. The wire should appear as a bright, linear echo within the dark, anechoic lumen of the vein. If the wire cannot be clearly visualized within the vessel, the operator should not proceed further. Instead, the wire should be removed, hemostasis achieved with direct pressure, and a new attempt made at accessing the vein—either at the same site or at an alternative site—under sonographic guidance. In some settings, particularly when dynamic ultrasound visualization is limited or when subclavian access is pursued, clinicians may employ manometry as a secondary method to confirm venous placement prior to dilation. In this technique, an angiocatheter is advanced over the guidewire, the wire is removed, and a sterile extension tubing is attached and held vertically. As blood travels up the tubing, a slowly rising column that plateaus at a low height suggests venous pressure, whereas a rapidly rising column under higher pressure suggests inadvertent arterial cannulation. However, this method has limitations, especially in hypotensive or shock states where venous and arterial pressures may be abnormally low, and it is more time-consuming than ultrasound. Consequently, it is used selectively, often as an adjunct when sonographic confirmation is incomplete [31][32][33].

Once correct wire position is confirmed within the vein, tissue dilation is performed to create a tract through which the catheter can be advanced. To minimize blood loss and ensure a controlled entry path, the dilator is “preloaded” onto the guidewire and advanced until its tip is close to the skin entry point, leaving a short segment of wire exposed. A small skin incision is then created at the entry point using a #11 scalpel, with the blade guided along the wire to make an approximately 0.5-cm incision to a shallow depth. This incision allows the dilator to pass through the skin and subcutaneous tissues without

excessive resistance or tearing. The scalpel is then removed from the field. The dilator is advanced over the wire and through the incision into the soft tissue toward the vessel. It is usually grasped at its midportion, and firm but controlled pressure is applied with a slight rotational or twisting motion to gently dilate the tract. Depending on the site and the length of soft tissue overlying the vessel, approximately one-third to one-half of the dilator length may need to be inserted. The operator must remain vigilant to maintain continuous control of the guidewire throughout this process, ensuring that the wire does not migrate further into the circulation or out of the vessel. When using larger-bore catheters, such as those intended for hemodialysis, multiple stages of dilation with progressively larger dilators and repeated small skin incisions may be necessary to create an adequately sized tract. After sufficient dilation, the dilator is withdrawn while keeping sterile gauze over the insertion site to contain bleeding and preserve sterility. Again, the guidewire must not be released at any point. The central venous catheter is then threaded over the guidewire, usually beginning with the distal (tip) end of the catheter passed onto the wire. To help control the wire, the operator can withdraw a small portion of the wire so that a short segment lies outside the skin, allowing one hand to stabilize the wire while the other advances the catheter [31][32][33].

The catheter is advanced along the wire and into the soft tissue tract, through the vessel wall, and into the lumen. The operator typically holds the catheter near its distal end to maintain control and prevent kinking at the insertion site. The catheter is advanced until its hub lies flush with or just above the skin surface at the entry site, placing the distal tip in the anticipated central venous location, guided by knowledge of appropriate insertion depth for the chosen site and patient size. Once the catheter is fully seated, the guidewire is removed by gently pulling it out through the distal port, often the brown-colored lumen in standard multi-lumen catheters. Smooth removal of the wire without resistance suggests that the catheter is appropriately positioned and not kinked or knotted. Each catheter lumen must then be tested. Using a sterile syringe, the operator aspirates venous blood from each port to confirm patency and intravascular position. Any air is evacuated from the lumens, and they are subsequently flushed with sterile saline to ensure unimpeded flow. Luer-lock caps or saline locks may be attached to the ports at this stage if not already in place. In some settings, a transducer may be connected to the distal lumen to measure central venous pressure, although this is optional and dependent on clinical needs. Securing the catheter is essential to prevent dislodgement and minimize infection risk. The catheter hub is typically anchored to the skin using at least two sutures placed through the catheter's fixation points and the dermis, often with 3-0 silk. A chlorhexidine-impregnated disk or BioPatch is placed snugly around the catheter at the skin entry site to reduce microbial colonization. A sterile, transparent occlusive dressing is then applied over the insertion site and catheter hub, allowing continuous visualization of the entry site while maintaining a barrier against contamination. All used drapes and non-sharp materials are discarded in biohazard containers, and needles, scalpel blades, and guidewires are disposed of in designated sharps containers. The patient is returned to a position of comfort, and vital signs are reassessed [31][32][33].

Verification of correct catheter placement and identification of early complications must follow. In addition to dynamic ultrasound confirmation during the procedure, several post-procedural methods can be employed. A venous blood gas drawn from the distal lumen can confirm venous positioning by demonstrating venous oxygen saturation and chemistry, although this is not strictly required in all cases. Measurement of central venous pressure through the distal lumen can corroborate the catheter's presence in a low-pressure venous system. However, the most universally recommended confirmatory test for internal jugular and subclavian catheters is a chest radiograph. A post-procedural chest x-ray should be obtained in all such cases to verify that the catheter tip lies appropriately within the superior vena cava or at the cavoatrial junction, and not within smaller tributary veins or the right atrium. The radiograph also serves to detect mechanical complications such as pneumothorax, hemothorax, or malposition. For femoral CVCs, imaging is less frequently required immediately unless malposition or complications are suspected, but in some cases, abdominal or pelvic imaging may be obtained to confirm tip position within the inferior vena cava. When properly performed, this structured approach to central venous catheter insertion—rooted in sound anatomical knowledge, strict aseptic technique, real-time imaging, and systematic post-placement verification—minimizes risk and maximizes the utility of the catheter for resuscitation, monitoring, and advanced therapies in critically ill patients [31][32][33].

Complications

Central venous catheterization is associated with a broad spectrum of potential complications, which may arise either during the insertion procedure itself or later as a consequence of the indwelling device. Procedural complications predominantly reflect mechanical or technical issues encountered during vascular access, whereas post-procedural complications are often infectious, thrombotic, or structural in nature. Awareness of these risks and rigorous adherence to best practices are essential to minimize morbidity. During insertion, arrhythmias are a well-recognized complication, typically in the form of ventricular ectopy or bundle branch blocks.

These usually occur when the guidewire or catheter tip irritates the atrial or ventricular endocardium and are often transient once the wire is withdrawn to an appropriate position. Arterial puncture is another significant procedural risk, particularly when anatomical landmarks are used without ultrasound guidance. Accidental cannulation of the carotid, femoral, or subclavian artery may result in hematoma, pseudoaneurysm, or, if dilated and catheterized, major hemorrhage or stroke. Pulmonary puncture, with or without resulting pneumothorax or hemothorax, is a serious complication especially associated with subclavian and, to a lesser extent, internal jugular access. In severe cases, respiratory distress and hemodynamic instability may ensue, requiring chest tube placement or additional interventions. Bleeding can also present as local hematoma formation, which in the neck may compromise the airway and necessitate urgent airway control or surgical evacuation. Injury to adjacent structures, including the trachea, is a rare but potentially catastrophic event [32][33].

Air embolism is another notable procedural complication that can occur during venous puncture, guidewire manipulation, or catheter removal, particularly if the patient is in an upright position or if the catheter hub is left open to air. Venous air emboli may cause acute cardiorespiratory compromise and, in the presence of intracardiac shunts, paradoxical cerebral or coronary embolization [32]. Post-procedural complications reflect longer-term interactions between the catheter and the vascular system. Catheter-related bloodstream infections, caused by bacterial or fungal organisms, are among the most serious device-associated complications and are associated with increased length of stay, costs, and mortality [33]. Central vein stenosis may develop over time, especially with repeated catheterizations in the same vessel, leading to impaired venous drainage, edema, and difficulty establishing future access. Thrombosis of the catheterized vein is another frequent complication, potentially manifesting as limb swelling, pain, or catheter dysfunction, and may predispose to pulmonary embolism. Delayed bleeding can occur, particularly in coagulopathic individuals or those who have undergone multiple insertion attempts and may present hours after the procedure as expanding hematoma, occult blood loss, or hemodynamic instability [32][34]. Collectively, these complications underscore the need for meticulous technique, vigilant monitoring, and prompt recognition and management of adverse events [34].

Clinical Significance

When performed with appropriate technique and safeguards, central venous catheter insertion is a safe, effective, and frequently life-saving procedure that underpins much of modern critical care, perioperative medicine, and emergency resuscitation. Its clinical significance lies not only in its capacity to enable delivery of life-sustaining therapies and hemodynamic monitoring but also in the potential severity of complications if best practices are not followed. Thus, several key principles should consistently guide the proceduralist. Thorough preparation is foundational. Before needle-to-skin contact, the operator should ensure that all necessary equipment is present, functional, and arranged within the sterile field and that appropriate personnel are available to monitor the patient and assist as needed. Inadequate preparation magnifies the impact of any unanticipated difficulty, increasing procedure time, the number of attempts, and the likelihood of mechanical or infectious complications. Maintaining maximal barrier precautions and strict aseptic technique at every stage is critical, as central line–associated infections carry substantial morbidity and mortality. Sterile integrity must be verified before use; any compromised or contaminated product should be discarded. Post-procedural imaging plays a central role in confirming correct catheter placement and excluding early complications. For internal jugular and subclavian lines, a stat portable chest radiograph is standard practice to confirm that the catheter tip resides within the superior vena cava and to rule out iatrogenic pneumothorax or malposition. Radiographic confirmation should precede routine use of the catheter for critical infusions whenever possible [35][36].

Site selection strategies can also influence risk. If an internal jugular attempt fails and another site is required, many experts recommend favoring the ipsilateral subclavian vein rather than the contralateral internal jugular to reduce the risk of bilateral pneumothoraces. Anticipating this possibility, the operator may choose to prep and drape both the ipsilateral IJ and subclavian areas at the start of the procedure. In situations where ultrasound images are suboptimal and guidewire position is uncertain, venous manometry can provide adjunctive confirmation that the wire is in a low-pressure venous system rather than an artery, though clinicians must recognize that in profound shock, arterial pressures may be deceptively low and this method can be misleading. Subclavian access appears to be associated with lower infection rates than some other sites but may carry higher procedural complication rates, especially in the hands of less experienced operators [35]. Across all access sites, the use of real-time ultrasound guidance has been shown to improve success rates and reduce mechanical complications, reinforcing its role as a standard of care for internal jugular, subclavian, and femoral cannulation. Throughout the procedure, the clinician must maintain continuous control of the guidewire; loss of the wire into the central circulation can result in embolization to the right ventricle or inferior vena cava and may necessitate complex retrieval procedures. Finally, proper placement of the catheter should be verified through one or more

methods, including radiographic imaging, assessment of central venous pressure, and analysis of a venous blood gas from the distal port [36]. Excessive force should never be applied during needle insertion, dilation, or catheter advancement. Gentle, controlled movements reduce the risk of vascular, pleural, or soft tissue injury. Adhering to these principles ensures that central venous catheterization remains a high-yield, low-complication intervention that supports critical aspects of patient care [35][36].

Enhancing Healthcare Team Outcomes

The safe and effective use of central venous catheters extends far beyond their initial insertion and depends heavily on ongoing management by an interprofessional healthcare team. Once a CVC is in place, nurses assume primary responsibility for its daily care, monitoring, and utilization. Their role includes recognizing both immediate and delayed complications, ensuring that the insertion site and catheter system are maintained under optimal hygienic conditions, and communicating any concerns promptly to the responsible clinicians. Nurses must be adept at detecting early signs of infection, such as erythema, warmth, tenderness, or purulent drainage at the catheter site, as well as systemic manifestations including fever, chills, or hemodynamic instability. They must also be vigilant for mechanical problems, including hematoma, catheter occlusion, malposition, and signs of pneumothorax or bleeding. Their continuous presence at the bedside positions them as the frontline observers in detecting subtle changes that may herald serious complications. Clear, timely communication between all members of the healthcare team is vital for optimal patient outcomes [37]. After catheter insertion and verification of proper placement, the clinician must explicitly inform the bedside nurse that the line is safe to use. Until this confirmation is provided, nurses should refrain from using the catheter for medication administration or infusions that would be hazardous if delivered extravascularly or into an unintended location. Both clinicians and nurses should document and remain aware of the date and time of line placement, as the duration of catheterization is a key determinant of infection risk. Central venous catheters are intended to be temporary, and the probability of complications increases when they remain in situ longer than necessary [37].

Nursing, Allied Health, and Interprofessional Team Interventions

Routine, structured catheter care is essential to minimizing infection and maintaining catheter function. Daily inspection of the access site and assessment of device patency should be incorporated into nursing rounds. Each day, the nurse should examine the site for bleeding, expanding hematoma, or signs of local infection, such as erythema, warmth, induration, or purulent exudate [38]. The integrity of the dressing should be assessed to ensure that it remains clean, dry, and fully adherent. Injection ports, catheter hubs, and needleless connectors should be disinfected meticulously with institutionally approved antiseptic agents prior to each access, following the recommended contact time and friction technique. Intravenous infusion sets and administration tubing must be changed at intervals specified by hospital policy, with more frequent changes often recommended for lipid-containing solutions and total parenteral nutrition. When a dressing becomes loose, damp, or visibly soiled, it must be changed promptly under sterile conditions. Dressing changes should be performed using maximal aseptic technique, including wearing a bouffant cap, mask, and sterile gloves. The old dressing is removed carefully, the site is inspected, and the skin is cleaned with an approved antiseptic solution, usually chlorhexidine, and allowed to dry completely. A new sterile, transparent occlusive dressing is then applied, ensuring that the catheter is well-secured and that the insertion site remains visible. All manipulations of the catheter, including dressing changes, should be conducted with attention to minimizing contamination and avoiding unnecessary disconnections of the system [38]. Allied health professionals and the broader interprofessional team also play vital roles. Pharmacists help optimize antimicrobial use in suspected or confirmed catheter-related infections and provide guidance on compatibility and appropriate administration routes for complex medication regimens. Infection prevention specialists and quality-improvement teams may track catheter-associated infection rates, ensure adherence to central line bundles, and provide feedback and education to clinical staff. During multidisciplinary rounds, the continued necessity of each central venous catheter should be reassessed daily. If the catheter is no longer required for hemodynamic monitoring, vasoactive infusions, or specialized therapies, prompt removal is recommended to reduce the cumulative risk of infection and other complications [39].

Nursing, Allied Health, and Interprofessional Team Monitoring

Ongoing monitoring for complications is integral to the safe use of central venous catheters. Nursing staff must be familiar with both early and late adverse events that may occur following catheter placement. Immediately after insertion, careful observation for signs of respiratory distress, chest pain, hypotension, or neck and chest swelling is necessary to detect pneumothorax, hemothorax, air embolism, or major bleeding. Over subsequent days, nurses must remain alert for fever, chills, unexplained leukocytosis, catheter dysfunction, or localized signs of infection that may indicate catheter-related bloodstream infection [39]. Swelling or discomfort in the limb or region drained by the catheterized vein

may signal venous thrombosis, warranting further evaluation. Clinicians, for their part, should maintain a high index of suspicion for the catheter as a potential source whenever a patient with a central line shows new or unexplained clinical deterioration, particularly signs of sepsis. Blood cultures drawn from the catheter and peripheral veins, along with clinical assessment and imaging when indicated, can help identify catheter-related infection or thrombotic complications. Removal of the catheter is often necessary in the setting of confirmed infection, persistent bacteremia, or nonfunctional or malpositioned lines. Ultimately, optimal outcomes are achieved when nurses, physicians, and allied health professionals collaborate closely, communicate effectively, and remain proactive in preventing, detecting, and managing complications. Daily evaluation of line necessity, rigorous adherence to infection-prevention protocols, and prompt response to early warning signs significantly reduce the burden of central line–associated morbidity and support safer, more effective patient care [39].

Conclusion:

In conclusion, central venous catheterization is a fundamental, high-stakes procedure in critical care. Its safety and efficacy are maximized through the systematic application of evidence-based practices. The adoption of real-time ultrasound guidance represents a paramount advancement, dramatically enhancing procedural accuracy and reducing immediate mechanical risks. Successful outcomes extend beyond insertion, hinging on rigorous aseptic technique, including maximal sterile barriers and chlorhexidine skin preparation, to prevent life-threatening catheter-related infections. Optimal practice requires a patient-centered, site-specific strategy, weighing the unique risk profiles of the internal jugular, subclavian, and femoral veins against clinical urgency and patient anatomy. Furthermore, the role of the catheter does not end at placement; its ongoing management is critical. This necessitates daily interprofessional collaboration, with nurses monitoring signs of infection or dysfunction, clinicians reassessing line necessity, and all team members adhering to standardized care bundles for dressing changes and hub disinfection. Ultimately, a culture of safety, continuous education, and coordinated teamwork is essential to mitigate risks and ensure that CVCs serve as a reliable lifeline for critically ill patients.

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