Navigating Venous Access: A Guide for Hospitalists

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Word Count: 3210

Abstract Word Count: 117

Conflicts of Interest: None

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ABSTRACT

Venous access is the foundation for safe and effective hospital-based care. Inpatient providers must have a deep knowledge of the different types of venous access devices (VADs), their relative indications, contraindications, and appropriateness. However, such knowledge is difficult to come by and usually only gleaned through years of clinical experience

To bridge this gap, we provide an in-depth summary of the relevant anatomical considerations, physical characteristics, advantages, and disadvantages of VADs commonly used in the hospital setting. In doing so, we seek to improve the safety and share the science of vascular access with frontline clinicians. To aid decision-making, we conclude by operationalizing the available data through algorithms that outline appropriate vascular access for the hospitalized patient.

INTRODUCTION

Reliable venous access is fundamental for the safe and effective care of hospitalized patients. Venous access devices (VADs) are conduits for this purpose, providing delivery of intravenous medications, accurate measurement of central venous pressure, or administration of life saving blood products. Despite this important role, VADs are also often the source of hospital-acquired complications. Although inpatient providers must balance the relative risks of VADs against their benefits, the evidence supporting such decisions is often limited. Advances in technology, scattered research, and growing availability of novel devices has only further fragmented provider knowledge in the field of vascular access[1].

It is not surprising, then, that survey-based studies of hospitalists reveal important knowledge-gaps with regards to practices associated with VADs[2]. In this narrative review, we seek to bridge this gap by providing a concise and pragmatic overview of the fundamentals of venous access. We focus specifically on parameters that influence decisions regarding VAD placement in hospitalized patients, providing key takeaways for practicing hospitalists.

METHODS

To compile this review, we systematically searched Medline (via Ovid) for several keywords, including: peripheral intravenous catheters, ultrasound-guided peripheral catheter, intraosseous, midline, peripherally inserted central catheter, central venous catheters and vascular access device complications. We concentrated on full-length articles in English only; no date restrictions were placed on the search. We reviewed

guidelines and consensus statements (e.g., from the Center for Disease Control [CDC] or Choosing Wisely® criteria) as appropriate. Additional studies of interest were identified through content experts (MP, CR) and bibliographies of included studies.

Scientific Principles Underpinning Venous Access

It is useful to begin by reviewing VAD-related nomenclature and physiology. In the simplest sense, a VAD consists of a hub (providing access to various connectors), a hollow tube divided into one or many sections (lumens), and a tip that may terminate within a central or peripheral blood vessel. VADs are classified as central venous catheters (e.g., centrally inserted central catheters [CICCs] or peripherally inserted central catheters [PICCs]) or peripheral intravenous catheters (e.g., midlines or peripheral intravenous catheters) based on site of entry and location of the catheter tip. Therefore, VADs entering via proximal or distal veins of the arm are often referred to as ‘peripheral lines’ as their site of entry and tip both reside within peripheral veins. Conversely, the term ‘central line’ is often used when VADs enter or terminate in a central vein (e.g., subclavian vein insertion with the catheter tip in the lower superior vena cava).

Attention to a host of clinical and theoretical parameters is important when choosing a device for venous access. Some such parameters are summarized in **Table**

Venous Access Devices

We will organize our discussion of VADs based on whether they terminate in peripheral or central vessels. These anatomical considerations are relevant as they

determine physical characteristics, compatibility with particular infusates, dwell time, and risk of complications associated with each VAD discussed in **Table 2**.

(1) Peripheral Venous Access

a. Short Peripheral Intravenous Catheter

Approximately 200 million peripheral intravenous catheters (PIVs) are placed annually in the United States, making them the most common intravenous catheter[3]. PIVs are short devices, 3-6 cm in length that enter and terminate in peripheral veins **(Figure 1A)**. Placement is recommended in forearm veins rather than those of the hand, wrist or upper arm, as forearm sites are less prone to occlusion, accidental removal, and phlebitis[4]. Additionally, placement in hand veins impedes activities of daily living (e.g., hand-washing) and is not preferred by patients[5]. PIV size ranges from 24-gauge (smallest) to 14-gauge (largest); larger catheters are often reserved for fluid resuscitation or blood transfusion as they accommodate greater flow and limit hemolysis. To decrease risk of phlebitis and thrombosis, the shortest catheter and smallest diameter should be used. However, unless adequately secured, smaller diameter catheters are also associated with greater rates of accidental removal.[4, 5]

By definition, PIVs are short-term devices. The CDC currently recommends removal and replacement of these devices no more frequently than every 72-96 hours in adults. However, a recent randomized controlled trial found that replacing PIVs when clinically indicated (e.g., device failure, phlebitis) rather than on a routine schedule added 30 hours to their lifespan without an increase in complications[6]. A systematic review by the Cochrane Collaboration echoes these findings[3]. These data have thus been

incorporated into recommendations from the Infusion Nurses Society (INS) and the National Health Service in the UK[5, 7]. In hospitalized patients, this approach is relevant as it preserves venous access sites, maximizes device dwell, and limits additional PIV insertions. In turn, these differences may reduce the need for invasive VADs such as peripherally inserted central catheters (PICCs). Furthermore, the projected 5-year savings from implementation of clinically-indicated PIV removal policies is USD$300 million and 1 million health worker hours in the United States alone[4].

PIVs offer many advantages. First, they are minimally invasive and require little training to insert. Second, they can be used for diverse indications in patients requiring short-term ($\leq$1 week) venous access. Third, PIVs do not require imaging to ensure correct placement; palpation of superficial veins is sufficient. Fourth, PIVs exhibit a risk of bloodstream infection that is about 40-fold lower than more invasive, longer-dwell VADs[8] (0.06 bacteremia per 1000 catheter days).

Despite these advantages, PIVs also have important drawbacks. First, a quarter of all PIVs fail through occlusion or accidental dislodgement[4]. Infiltration, extravasation, and hematoma formation are important adverse events that may occur in such cases. Second, thrombophlebitis (pain and redness at the insertion site) is frequent, and may require device removal, especially in patients with catheters $\geq$20g [9]. Third, despite their relative safety, PIVs can cause localized or hematogenous infection. Septic thrombophlebitis (superficial thrombosis and bloodstream infection) and catheter-related bloodstream infection, though rare, have been reported with PIVs and may lead to serious complications[8, 10]. In fact, some suggest that the overall burden of bloodstream

infection risk posed by PIVs may be similar to that of CICCs given the substantially greater number of devices used and greater number of device-days[8].

PIVs and other peripheral VADs are not suitable for infusion of vesicants or irritants, which require larger, central veins for delivery. Vesicants (drugs that cause blistering on infusion) include chemotherapeutic agents (e.g., Dactinomycin, Paclitaxel) and commonly used non-chemotherapeutical agents (e.g., diazepam, piperacillin, vancomycin, esmolol or TPN)[11]. Irritants (phlebitogenic drugs) cause short-term inflammation and pain and thus should not be peripherally infused for prolonged durations. Common irritants in the hospital setting include acyclovir, dobutamine, penicillin, and potassium chloride.

Of note, about one-quarter of PIV insertions fail owing to difficult intravenous access[12]. Ultrasound-guided peripheral intravenous catheter (USGPIV) placement is emerging as a technique to provide peripheral access for such patients in order to avoid placement of central venous access devices. Novel, longer devices (>8cm) with built-in guide wires have been developed to increase placement success of USGPIVs. These new designs provide easier access into deeper arm veins (brachial or basilic) not otherwise accessible by short PIVs. Although studies comparing the efficacy of USGPIV devices to other VADs are limited, a recent systematic review showed that time to successful cannulation was shorter and fewer attempts were required to place USGPIVs compared to PIVs.[13] A recent study in France found that USGPIVs met the infusion needs of patients with difficult venous with minimal increase in complications[14]. Despite these encouraging data, future studies are needed to better evaluate this technology.

b. Midline Catheter

A midline is a VAD that is between 7.5-25 cm in length and is typically inserted into veins above the antecubital fossa. The catheter tip resides in a peripheral upper arm vein, often the basilic or cephalic vein, terminating just short of the subclavian vein (**Figure 1B**). Midline-like devices were first developed in the 1950s and were initially used as an alternative to PIVs because they were thought to allow longer dwell times[15]. However, because they were originally constructed with a fairly rigid material, infiltration, mechanical phlebitis and inflammation were common and tempered enthusiasm for their use[15, 16]. Newer midline devices obviate many of these problems and are inserted by ultrasound guidance and modified Seldinger technique[17]. Despite these advances, data regarding comparative efficacy are limited.

Midlines offer longer dwell times than standard PIVs owing to termination in the larger diameter basilic and brachial veins of the arm. Additionally, owing to their length, midlines are less prone to dislodgement. As they are inserted with greater antisepsis than PIVs and better secured to the skin, they are more durable than PIVs[5, 9, 18]. Current INS Standards recommend use of midlines for 1-4 weeks[5]. Because they terminate in a peripheral vein, medications and infusions compatible with midlines are identical to those that infused through a PIV. Thus, total parenteral nutrition, vesicants or irritants, or drugs that feature a pH <5 or pH >9, or >500mOsm should not be infused through a midline[15]. New evidence suggests that diluted solutions of vancomycin (usually pH <5) may be safe to infuse for short durations (<6 days) through a midline and that concentration rather than pH may be more important in this regard[19]. While it is possible

that the use of midlines may extend to agents typically not deemed peripheral access compatible, limited evidence exists to support such a strategy at this time.

Midlines offer several advantages. First, because blood flow is greater in the more proximal veins of the arm, midlines can accommodate infusions at rates of 100-150 mL/min compared to 20-40 mL/min in smaller peripheral veins. Higher flow rates offer greater hemodilution (dilution of the infusion with blood), decreasing the likelihood of phlebitis and infiltration[20]. Second, midlines do not require x-ray verification of tip placement; thus, their use is often favored in resource deplete settings such as skilled nursing facilities. Third, midlines offer longer dwell times than peripheral IVs and can thus serve as "bridge" devices for short-term IV antibiotics or peripheral-compatible infusions in an outpatient setting. Available evidence suggests that midlines are associated with low rates of bloodstream infection (0.3-0.8 per 1000 catheter days)[17]. The most frequent complications include phlebitis (4.2%) and occlusion (3.3%)[20]. Given these favorable statistics, midlines may offer a good alternative to PIVs in select patients who require peripheral infusions of intermediate duration.

c. Intraosseous Vascular Access

Intraosseous (IO) devices access the vascular system by piercing cortical bone. These devices provide access to the intramedullary cavity and venous plexi of long bones such as the tibia, femur, or humerus. Several insertion devices are now commercially available and have enhanced the ease and safety of IO placement. Using these newer devices, IO access may be obtained in 1-2 minutes with minimal training.

By comparison, a central venous catheter often requires 10-15 minutes to insert with substantial training efforts for providers[21-23].

IO devices thus offer several advantages. First, given the rapidity with which they can be inserted, they are often preferred in emergency settings (e.g., trauma). Secondly these devices are versatile and can accommodate both central and peripheral infusates[24]. Third, a recent meta-analysis found that IOs have a low complication rate of 0.8%, with extravasation of infusate through the cortical entry site being the most common adverse event [21]. Of note, this study also reported zero local or distal infectious complications, a finding that may relate to the shorter dwell of these devices [21]. Some animal studies suggest that fat embolism from bone may occur at high rates with IO VADs[25]. However, death or significant morbidity from fat emboli in humans following IO access has not been described. Whether such emboli occur or are clinically significant in the context of IO devices remains unclear at this time.[21]

(2) Central Venous Access Devices

Central venous access devices (CVADs) share in common tip-termination in the cavo-atrial junction, either in the lower portion of the superior vena cava or in the upper portion of the right atrium. CVADs can be safely used for irritant or vesicant medications as well as for blood withdrawal, blood exchange procedures (e.g., dialysis) and hemodynamic monitoring. Traditionally, these devices are 15-25 cm in length and are directly inserted in the deep veins of the supra- or infra-clavicular area, including the internal jugular, brachio-cephalic, subclavian or axillary veins. PICCs are unique CVADs in that they enter through peripheral veins but terminate in the proximity of the cavo-

atrial junction. Regarding nomenclature, the term centrally inserted central catheter (CICC) will be used to denote devices that enter directly into veins of the neck or chest, whereas PICC will be used for devices that are inserted peripherally, but terminate centrally.

a. Peripherally Inserted Central Catheter

PICCs are inserted into peripheral veins of the upper arm (e.g., brachial, basilic or cephalic vein) and advanced such that the tip resides at the cavo-atrial junction (**Figure 1C**). PICCs offer prolonged dwell times and are thus indicated when patients require venous access for weeks or months[26]. Additionally, they can accommodate a variety of infusates and are safer to insert than CICCs given placement in peripheral veins of the arm rather than central veins of the chest/neck. Thus, insertion complications such as pneumothorax, hemothorax, or significant bleeding are rare with PICCs. In fact, a recent study reported that PICC insertion by hospitalists was associated with low rates of insertion or infectious complications[27].

However, like CICCs, PICCs are associated with central-line associated bloodstream infection (CLABSI), a serious complication known to prolong length of hospital stay, increase costs, and carry a 12-25% associated mortality[28, 29]. In the United States alone, over 250,000 CLASBI cases occur per year drawing considerable attention from the CDC and Joint Commission, who now mandate reporting and non-payment for hospital-acquired CLABSI[30-32]. A recent systematic review and meta-analysis found that PICCs are associated with a substantial risk of CLABSI in hospitalized patients[33]. Importantly, no difference in CLABSI rates between PICCs and

CICCs in hospitalized patients was evident in this meta-analysis. Therefore, current guidelines specifically recommend against use of PICCs over CICCs as a strategy to reduce CLABSI[34]. Additionally, PICCs are associated with 2.5-fold greater risk of deep vein thrombosis (DVT) compared to CICCs; thus they should be used with caution in patients with cancer or those with underlying hypercoagulable states.

Of particular import to hospitalists is the fact that PICC placement is contraindicated in patients with Stage IIIB or greater chronic kidney disease (CKD). In such patients, sequelae of PICC use, such as phlebitis or central vein stenosis, can be devastating in patients with CKD[35]. In a recent study, prior PICC placement was the strongest predictor of subsequent AV graft failure[36]. For this reason, Choosing Wisely® recommendations call for avoidance of PICCs in such patients[37].

b. Centrally Inserted Central Catheter

CICCs are CVADs placed by puncture and cannulation of the internal jugular, subclavian, brachiocephalic, or femoral veins (**Figure 1D**) and compose the vast majority of VADs placed in ICU settings[38, 39]. Central termination of CICCs allows for a variety of infusions, including irritants, vesicants, and vasopressors, as well as blood withdrawal and hemodynamic monitoring. CICCs are typically used for 7-14 days but may remain for longer durations if they remain complication-free and clinically necessary[40]. A key advantage of CICCs is that they can be placed in emergent settings to facilitate quick access for rapid infusion or hemodynamic monitoring. In particular, CICCs inserted in the femoral vein and may be useful in emergency settings. However, owing to risk of infection and inability to monitor central pressures, these devices should

be replaced with a proper CICC or PICC when possible. Importantly, while CICCs are almost exclusively used in intensive or emergency care, PICCs may also be considered in such settings[41, 42]. CICCs usually have multiple lumens and often serve several simultaneous functions such as both infusions and hemodynamic monitoring.

Despite their benefits, CICCs have several disadvantages. First, insertion requires an experienced clinician and has historically been a task limited to physicians. However, this is changing rapidly (especially in Europe and Australia) where specially trained nurses are assuming responsibility for CICC placement[43]. Second, these devices are historically more likely to be associated with CLABSI, with estimates of infection rates varying between 2-5 infections per 1000 catheter-days[44]. Third, CICCs pose a significant DVT risk with rates around 22 DVTs per 1000 catheter-days[45]. However, compared to PICCs, the DVT risk appears lower and CICC use may be preferable in patients at high-risk of DVT, such as critically ill or cancer populations[46]. An important note to prevent ICC and PICC-related insertion complications relates to use of ultrasound, a practice that has been associated with decreased infective and thrombotic complications for both devices (citation). Thus, availability of ultrasound may influence the risk of adverse events related to these devices.

c. Tunneled Central Venous Access Devices

Tunneled devices (either CICCs or PICCs) are characterized by the fact that the insertion site on the skin and site of ultimate venipuncture are physically separated (**Figure 1E**). Tunneling limits bacterial entry from the extra-luminal aspect of the CVAD to the bloodstream. For example, internal jugular veins are often ideal sites of puncture

but inappropriate sites for catheter placement as providing care to this area is challenging and may increase risk of infection[34]. Tunneling to the infra-clavicular area provides a better option, as it provides an exit site that can be adequately cared for. Importantly, any CVAD (PICCs or CICCS) can be tunneled. Additionally, tunneled CICCs may be used in patients with chronic or impending renal failure where PICCs are contraindicated because entry into dialysis-relevant vessels is to be avoided[47]. Such devices also allow regular blood sampling in patients who require frequent testing but have limited peripheral access, such as those with hematological malignancies. Additionally, tunneled catheters are more comfortable for patients and viewed as being more socially acceptable than non-tunneled devices. However, the more invasive and permanent nature of these devices often requires deliberation prior to insertion.

Of note, tunneled devices and ports may be used as long-term (>3 months to years) VADs. As our focus in this review is short-term devices, we will not expand the discussion of these devices as they are almost always used for prolonged durations.

OPERATIONALIZING THE DATA: AN ALGORITHMIC APPROACH TO VENOUS ACCESS

Hospitalists should consider approaching venous access using an algorithm based on a number of parameters. For example, a critically ill patient who requires vasopressor support and hemodynamic monitoring will need a CICC or a PICC. Given the potential greater risk of thromboses from PICCs, a CICC is preferable for critically ill patients provided an experienced inserter is available. Conversely, patients who require short-term (<7-10 days) venous access for infusion of non-irritant or non-vesicant therapy often only require a PIV. In patients with poor or difficult venous access,

USGPIVs or midlines may be ideal and preferred over short PIVs. Finally, patients who require longer term or home-based treatment may benefit from early placement of a midline or a PICC, depending again on the nature of the infusion, duration of treatment, and available venous access sites.

An algorithmic approach considering these parameters is suggested in **Figure 2** and a brief overview of the devices and their considerations is shown in **Table 3**.

CONCLUSIONS

With strides in technology and progress in medicine, hospitalists have access to an array of options for venous access. However, every VAD has limitations that can be easily overlooked in a perfunctory decision-making process. The data presented in this review thus provides a first-step to improving safety in this evolving science. Studies that further determine appropriateness of VADs in hospitalized settings are necessary. Only through such progressive scientific enquiry will complication-free venous access be realized.

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