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Chapter 7

Dangers of Peripheral Intravenous Catheterization: The Forgotten Tourniquet and Other Patient Safety Considerations

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Abstract

Intravenous catheterization is a widely used invasive procedure, with applications in both ambulatory and hospital settings. Due to its inherently invasive nature, intravenous (IV) therapy is associated with a number of potential complications, many of which are directly relevant to patient safety (PS). PIV-related morbidity may be due to mechanical or nonmechanical factors. The most frequent nonmechanical peripheral venous catheterization adverse events (PVCAEs) include insertion site pain, phlebitis, hematoma formation, and infusate extravasation. The most common mechanical PVCAE is catheter obstruction/occlusion and dislodgement. Significant complications can also occur with the administration of incorrect type or wrong amount of IV fluids. Moreover, simultaneous infusion of incompatible medications can result in infusate precipitation. Finally, less frequent but significant complications have been reported, including bloodstream and local infections, air embolization, nerve damage, arterial puncture, skin necrosis associated with vasopressor infusions, and limb-threatening forgotten tourniquet events. Taken together, the above complications can lead to substantial patient discomfort, unnecessary or prolonged hospitalization, increased costs, and additional downstream morbidity. Efforts to prevent PVCAEs and improve patient outcomes should involve thorough provider education, clinical vigilance by all involved healthcare providers, health service level strategies, as well as the proactive participation of all stakeholders, including patients and their families.

Keywords: complications, intravenous therapy, peripheral intravenous catheter, patient safety

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1. Introduction

Intravenous therapy (IVT) is a treatment modality based on infusing various compatible fluids (e.g., solutions, medications, blood, or blood products) directly into a vein [1–3]. Modern clinical efforts at IVT began in the early seventeenth century, but due to complications and generally poor results, the practice was largely abandoned until the nineteenth-century cholera epidemic [4, 5]. Early publications on IVT date back to the 1880s, when Dr. Thomas Latta described its use during the cholera epidemic in Britain [4, 6]. The standard IV use of saline solutions did not begin until the early 1900s. Further advances in IVT occurred in the 1930s, but this modality was not widely available until the 1950s [3, 7, 8]. It was not until the twentieth century, after the two world wars, and the discovery of blood group types and pyrogens, that clinical use of IVT gained more traction [5, 9]. The introduction of plastic bags and IV catheters in the late twentieth century, combined with modern infection control practices, resulted in IVT becoming a widespread and lifesaving therapeutic option [5, 10]. Intravenous administration of fluids in the emergency setting (e.g., trauma, sepsis) can be a lifesaving maneuver and represents the primary method of ensuring adequate intravascular fluid status for patients who are unable to tolerate enteral nutrition [11, 12]. It is estimated that hundreds of millions of PIV catheterizations are performed worldwide each year [13]. The vast majority of these procedures are conducted by nursing staff, with the remainder performed by specialty teams [14]. Of note, approximately 80% of all hospitalized patients receive IVT [15, 16]. At the same time, the frequency of "idle catheters" (e.g., with no active medication or fluid infusion) can be as high as 16%, with approximately 12% reporting at least one sign/symptom of phlebitis [14]. The results of a more recent retrospective cohort study of 3829 patients by Limm et al. showed that 50% of PIVCs inserted in the ED went unused. Of the 43% of patients with idle catheters then admitted to the hospital wards, these continued to be unused 72 h later [17]. There is an increasing awareness (and concern) of the possible morbidity, including life and limb injury, associated with the highly prevalent usage of IVT [18]. The purpose of this chapter is to provide a comprehensive overview of all major complications and patient safety considerations associated with PIVs and IVT in the adult population. In addition, we provide an illustrative case of a "forgotten tourniquet" to illustrate the importance of patient safety measures in this important area of clinical care.

2. Types of venous access

Safe, dependable venous access for infusions is a critical part of patient care. There are two primary types—peripheral and central venous access. The type of access is selected based on the anticipated duration of IVT, the type of medication or solution to be infused, and patient-specific considerations [19, 20]. The focus of this chapter, the PIV catheter, is a short intravenous catheter placed via venipuncture into a peripheral vein, while central venous catheters are inserted into large veins of the central circulation system (e.g., subclavian, jugular, and femoral). Performed an estimated 150–200 million times annually in North America alone, the impact of PIVs is difficult to comprehend [21]. Moreover, up to 8–23% of patients in the

emergency department experience difficult PIV placement (e.g., multiple attempts, infiltration, and other placement-related complications). These patients are more likely to require central venous access, which includes significantly higher associated morbidity. Ultrasound-guided PIV catheterization can reduce the need for central venous access, thus potentially reducing morbidity [21]. Not only does the ultrasound-guided PIV access decrease the reliance on central venous access, but it also decreases the overall time, number of attempts, and needle redirections compared to more traditional placement methods [22, 23]. While PIVs are the preferred access mode for short-term IVT, central venous access is utilized for long-term administration of medications or parenteral nutrition [23–27]. At times, when PIV access cannot be established or is quantitatively insufficient for the delivery of desired volume or fluid type, central venous access may be the only viable option to consider [15, 28].

3. Indications and common anatomic sites of peripheral intravenous catheterization

PIV catheterization is indicated for short-term use across a broad range of clinical scenarios, including administration of IV fluids, drugs, blood/blood products, dyes, and contrast media [28, 29]. Several factors must be considered when selecting a site for PIV catheterization. Although common sites of insertion are generally described as the lower arm and the dorsum of the hand, superficial veins of the lower limbs can also be used for cannulation in certain clinical situations [30]. The direct and indirect risks of complications can be curtailed by a more thorough assessment of the vascular anatomy prior to choosing the optimal site, based on both infusion- and patient-related factors [31–35]. Carr et al. reported that the antecubital fossa (ACF), the most common insertion site cannulated in their study of 252 ED patients, was associated with the best rates of insertion success (54.78%), but a secondary analysis revealed that these successfully inserted PIVCs repeatedly failed to last for the intended 3-day dwell time after transfer from the ED to the general hospital units [31]. In a project to reduce infusion pump alarms, Matocha [34] reported that occlusion alarms (60%) represented the highest volume of alarms in a medical oncology unit. After intervention, occlusion alarms were reduced by 17% but still represented the highest volume of alarms, which the author hypothesized might be associated with the majority of catheter placements in the antecubital area due to flexion at the site. Decreasing antecubital area placement in the first place through staff education regarding vascular access planning and insertion competency was suggested as one way of reducing occlusion alarms. Alarm frequency may interfere with patients' sleep, cause unnecessary anxiety, and potentially negatively impact healing [32, 33]. It is imperative to consider the clinical status of the patient carefully before selecting the site. Such assessment should consider the general condition of the veins, tortuosity, locations of valves, bifurcations [36], the size of cannula, type of drug to be administered, infusion rate, and duration of the intended IVT [30]. Intravenous cannula gauge and site of placement are critical factors in defining the success and longevity of PIV cannula [37]. Of note, larger gauge ($P = 0.0002$, RR = 1.17, 95% CI 1.08–1.27) and forearm placement ($P = 0.005$, RR = 0.7, 95% CI 0.55–0.9) are among the strongest predictors of longer functional cannula life [38]. Evidence demonstrates the usefulness of multimodality methodology in improving in first-time insertion success rate [2, 37].

Overall, success rates for PIV placement range between 61 and 90%, with successful insertions being associated with visible or palpable veins, providers with greater procedural volumes, and inserters who were able to predict that placement would be successful [39]. Level of successful venous access also appears to be associated with various patient factors (e.g., age, body mass index, etc.) [40]. Difficult venous access is characterized by non-visible and non-palpable veins for various reasons, including chronic disease, history of intravenous drug use, history of chemotherapy, obesity, or malnourishment [41]. In addition to excellent technical skill and clinical knowledge, various vein visualization devices and ultrasound-based approaches can be helpful in facilitating successful PIV insertion [36]. Such devices include infrared vein visualizers and ultrasound; however, operator experience is required for optimal outcomes and success rates [42]. The ability to leverage adjunctive devices to identify more veins can lead to greater placement and successful and speedier cannulations [40]. In addition, assistive devices may help reduce the number of insertion attempts and diminish complications such as unintended arterial puncture [43, 44].

4. Clinical vignette

A 49-year-old female with type 2 diabetes mellitus and morbid obesity underwent an abdominoplasty due to recurrent lower abdominal cellulitis. Following a series of failed PIV placement attempts in the left forearm, venous access was established on the dorsum of left hand with an 18G cannula. This PIV was then used during the induction of anesthesia, without any apparent problems. The complex operation took approximately 5 h to complete. During this time, fluid replacements were given intravenously. During the procedure, there was no evidence of left upper extremity swelling, color, or temperature change. The point of insertion of the PIV cannula appeared unremarkable when the patient arrived in the postanesthesia care unit (PACU).

Within 4 h, however, the patient reported severe pain in her left hand. This pain persisted despite escalating doses of analgesics. There was a mild but visible swelling in the left hand as compared to the right side, along with decreased capillary refill and distal paresthesia. When the patient's surgeon came to examine the patient, he exposed the entire left upper extremity and discovered an intravenous tourniquet still in place, hiding behind the hospital gown sleeve. The tourniquet was immediately removed, but it was too late to reverse the resultant extremity compartment syndrome. The PIV was also discontinued, and a new catheter is placed in the contralateral hand. An emergency fasciotomy was performed, allowing salvage of the left hand and forearm, at the cost of a large left forearm scar. This substantially increased the length of stay and associated costs and reduced the patient’s hospital experience. Fortunately, there were no signs of ischemic injury or permanent nerve damage, and the patient had good functional recovery.

5. Overview of peripheral IV catheter complications

As outlined above, PIV catheters are routinely used for short-term delivery of intravascular fluids and medications, thus being among the most important and the most frequent invasive

procedure performed in hospitals. However, PIVs often fail before IVT is completed, with the cited malfunction rate of about 90% [2]. A prospective observational study, the CATHEVAL Project, suggested that the incidence of PVCAEs is significantly underestimated [1]. The incidence rate of at least one PVCAE was 52.3%, with "clinical" PVCAEs occurring significantly more frequently than "mechanical" PVCAEs [1]. The most frequent clinical PVCAEs were phlebitis (20.1/100 PIVs), followed by hematoma (17.7/100 PIVs) and fluid/blood leakage (13.1/100 PIVs). In terms of mechanical complications, obstruction/occlusion of PIV was the most frequent event (12.4/100 PIVs) [1]. Of interest, the authors also reported on post-removal PVCAEs (21.7/100 PIVs) as well as infections (0.4/100 PIVs) [1]. Moreover, significant complications can occur if the incorrect quantity (volume) of IV fluids or incorrect medication infusion/dosage is administered [45, 46].

The prevalence of difficult IV access can be substantial, with one study reporting 23% of patients classified as "moderately difficult" and 5% classified as having "difficult access" [47]. Of interest, female gender and a previous history of several IV placement attempts may be associated with greater risk of difficult venous access, which in turn can increase the overall complication risk [48, 49]. Currently, there is no internationally accepted definition of a "difficult access" patient. Based on clinical observations many have tried to develop a predictive scale to identify adult patients with difficult intravenous access: the DIVA scale [50]. Such scales can be used to recognize patients with high probability of a difficult intravenous access. In such cases various assessment devices (near-infrared and ultrasound) or call for assistance of more experienced individuals in an earlier time frame can prove beneficial to the patient [41, 50].

Globally speaking, prevention of PVCAEs should be the preferred approach, and despite ongoing efforts to improve the current state of affairs, PVCAEs continue to occur, prompting the need for maintaining awareness and reinforcing provider education in this critical important area [18]. In a multicenter prospective study of 1498 patients by Cicolini et al. [51], the authors cited that anatomical site selection and a lack of adherence to in situ PIVC placement recommended guidelines resulted in increased rates of phlebitis. They concluded that additional staff education was needed [51]. DeVries et al. reported a 19% reduction in PIVC-associated bloodstream infections after implementing a fundamental PIVC insertion and education bundle for bedside nurses that increased staff awareness of proper skin preparation, aseptic technique, and the importance of the care and maintenance of dressings [52]. Nursing education leaders in another tertiary healthcare setting developed an educational intervention to improve the recognition and reporting of infiltration and phlebitis on medical-surgical units, which was identified by the risk management database as a concern. Although the differences between pre- and post-knowledge scores were not significant ($P = 0.21$), the unexpected results of the research served as a catalyst to develop annual PIVC procedural education to validate competency related to PIVC-related complications [53].

A standardized approach to education and competency assessment across the healthcare system is recommended. A simulation-based multimodal educational method should be considered, including self-study and deliberate practice, with objective outcome monitoring and feedback using well-designed, validated, and reliable checklists [36, 54–56]. After all, it is the responsibility of the entire healthcare team to monitor for signs and symptoms of PVCAEs and intervene in a timely and appropriate fashion [30].

Subsequent paragraphs of this chapter will discuss PVCAEs grouped into "localized" or "systemic" categories.

6. Local PVCAEs

Phlebitis: Phlebitis is an inflammation of the vein and causes pain, swelling, redness, and tenderness. It can be caused by various sources like mechanical, chemical, or infective insults to the vein [2]. The mechanical cause; irritation with cannula rubbing the vein, chemical cause; medications with a hypertonic or acidic/alkaline solution, or an infective phlebitis; microorganism entering the vein through the puncture site can cause the inflammation [30]. *Diagnosis:* It is one of the most talked about complication in the literature [2]. The diagnosis of superficial phlebitis can be made by physical examination of the site. Redness, warmth, tenderness, and swelling along the course of the vein can help make the diagnosis, although there are more than 70 tools used in the literature and none well validated [57]. In certain cases, an ultrasound of the affected area is needed to make or ignore the diagnosis. *Prevention and treatment*: Most complications are preventable if simple hand hygiene and safe principles are observed at every point of contact with the patient [2]. According to a recent secondary analysis, the antecubital fossa is associated with lower phlebitis rates as compared with upper arm and wrist veins [37]. Another systemic review showed that the antecubital veins had lower rate of phlebitis as compared to hand veins [58]. The treatment of phlebitis depends on the location, extent, symptom, and underlying medical conditions. Typically, it should be removed and documented with the time, date, and reason of removal [59]. Documentation can improve the staff compliance and help to improve quality of care of the patients with PIVC [60, 61]. Superficial phlebitis can be treated by applying warm compresses, elevation of the involved extremity, and oral or topical anti-inflammatory medications. External compression with fitted stockings may be beneficial for lower extremity superficial phlebitis. If left untreated, superficial phlebitis can complicate to local infection and abscess formation, clot formation, and progression to a deep venous thrombosis and pulmonary embolism. Deep vein thrombosis can further lead to postphlebitic syndrome.

Tissue infiltration and extravasation: Tissue infiltration occurs when the infusate solution is inadvertently administered (or leaks out) into the surrounding tissues. It can be caused by improper placement, dislodgement, or distal puncture/erosion of the catheter and can be associated with relative movement of the patient and the catheter. Extravasation arises when a solution or medication is administered and inadvertently leaks into the surrounding tissues, causing tissue damage. This unintended leakage can be caused by the same reasons as infiltration, including improper placement or dislodgement of the catheter. Certain sites are more prone to extravasation injuries like dorsum of the foot, ankle, antecubital fossa, and the areas near joints where there is little protection for underlying structures [18]. Of interest, extravasations tend to be more common during night hours and thus may be more likely to go undetected, even in closely monitored situations. Extravasation is more likely to occur in patients with fragile, mobile, thrombosed, and difficult to cannulate veins [18]. The degree of subsequent cellular injury is determined by the volume of the infiltrating solution and physiochemical characteristics, such

as pH, osmolarity, and dissociability [18]. *Diagnosis*: The diagnosis of infiltration is usually made by observing local tissue edema, cool skin with blanching, and decreased (or stopped) flow rate. The patient usually complains of discomfort, burning, and tightness of the involved extremity/anatomic location [62]. Comparison to the contralateral limb may help confirm this diagnosis. In the case of extravasation, signs and symptoms may be similar to infiltration but will additionally include burning, irritation, redness, blistering, mottling, ulceration, or permanent damage like necrosis of the affected tissue. The damage can spread to involve nerves, tendons, and joints even months after the original insult [18]. It can additionally include disfigurement, complex regional pain syndrome, and loss of function [63]. *Prevention and treatment:* Prevention of infiltration includes the avoidance of PIV placement in the hand, antecubital fossa, and upper arm, properly securing the catheter and monitoring the IV site frequently [2, 36]. It is important to check the patient's pulse and capillary refill [64]. Clinical management includes stopping the infusion, removing the PIV, elevating the limb, and general measures to alleviate patient discomfort. It has also been reported that local application of hyaluronidase may help, primarily through breaking down subcutaneous cellular components and speeding up the reabsorption of the extravasated fluids [65, 66]. Finally, the original infusion should be restarted at a different site, with all pertinent interventions documented in the medical record.

Prevention of extravasation includes careful placement of PIV cannula, close monitoring of active intravenous fluid infusions, flushing the catheter with sterile saline to ensure patency, and the use of suitable dressings and securements to prevent undue movement [18]. Once extravasation is recognized, the infusion needs to be stopped and the cannula removed. This is especially important when the medication/fluid being infused is potentially toxic to local tissues. Palpable effusion in the subcutaneous tissues may need to be drained, and the limb should be immobilized and elevated above the level of the heart. Application of cold packs can provide symptomatic relief. Indications for surgery include full-thickness skin necrosis, ulceration, and persistent pain [67]. If appropriate treatment is delayed, surgical debridement, skin grafting, and amputation may be the end result of such an injury [18].

Hemorrhage/hematoma: Hemorrhage is defined as bleeding from the puncture site, while hematoma is a localized collection of extravasated blood, usually clotted, within an organ or tissue. Both hemorrhage and hematoma may be caused by blood leaking out of the vein into the tissue due to puncture or trauma. The COSMOS study found that PIV catheters based on a compact closed system were associated with lower rate of hematomas when compared to a mounted open system [68]. Patients who receive antiplatelet therapy or therapeutic anticoagulation are especially predisposed to hematoma/ecchymosis formation [69]. *Diagnosis*: The signs and symptoms of swelling, tenderness, and reddish discoloration at the site are usually sufficient to diagnose PIV-related hematoma. *Prevention and treatment*: The first management step is the application of appropriate localized pressure until the bleeding stops. This is followed by a sterile transparent dressing that can prevent hematoma formation or expansion. Proper PIV insertion, frequent monitoring of the site, and application of pressure after removal of cannula can help prevent hemorrhage and formation of hematoma. At the same time, patients, providers, and nurses should be mindful of using extended external compression times at the insertion site, especially in older patients with impaired skin conditions, as this can lead to further tissue injury [1]. The majority of PIV-related bleeding and hematomas are fortunately self-limited.

Nerve injury: When tissue infiltration associated with a PIV catheter affects a nerve coursing the surrounding tissues, nerve injury can occur. It is also possible for the IV needle to lacerate, puncture, and potentially injure a nerve. Finally, localized bleeding/hematoma may irritate a nerve. *Diagnosis*: Patients may not experience any discomfort in the beginning, but it is possible for localized numbness or tingling, loss of sensation to pin prick to emerge later on [70, 71]. Nerve injury can range from neurapraxia with complete recovery (minor injury) to neurotmesis with Wallerian degeneration distal to the site of injury (severe injury) [70]. *Prevention and treatment*: The avoidance of nerve injury requires good procedural skills and knowledge of pertinent anatomy. The PIV placing provider should be conscious of venipuncture sites associated with the greatest risk, including the distal sensory branches of the radial and ulnar nerves for sites in the dorsal hand, the superficial radial nerve at the cephalic vein of the radial wrist, the median nerve on the volar aspects of the wrist, the median and anterior interosseous nerves at or above the antecubital fossa, and the lateral and medial antebrachial nerves for the antecubital fossa [36]. The needle insertion should be as shallow as possible, preferably at an angle of 5–15° relative to the skin and using the non-dominant arm [71]. Although nerve injury is rare, the patient should still be aware of this complication and encouraged to inform the nurse immediately if he or she experiences any strange sensation during PIV placement. Nerve damage tends to be self-limited, with typical recovery times of a few weeks or months. Surgical exploration may be required in patients with intractable pain, severe functional loss, or those without recovery signs within 3–6 months after the initial injury [72–74].

Occlusion: Occlusion is defined as the slowing or cessation of fluid infusion. It can occur due to the mechanical blockage within the cannula or fibrin deposition in/around the tip of the cannula. In addition, it may be due to swollen phlebitic veins, or insertion at a point of flexion, both of which may collapse the catheter and prevent flow [75]. There may be a higher incidence of occlusion associated with insertion in the hand, antecubital fossa, or upper arm, when compared to forearm placement [2, 37]. 25.6% had failed catheterization due to PIV occlusions in an analysis from a randomized controlled trial in Australia. The occlusion was associated with infusions of antibiotics, hydrocortisone, in the setting of concurrent infection, and the use of subsequent (rather than initial) catheters [37]. In a single-center prospective study done in Australia, catheter failure due to occlusion/infiltration was reported to be 14%. In the same study, flucloxacillin, female gender, and 22-gauge PIVs were significant predictors of occlusion [49]. *Diagnosis*: Occlusion can be diagnosed by the presence of discomfort, blood within the line, or PIV not running. *Prevention and treatment*: Actively checking for kinks and removing nonfunctioning cannulas will help reduce the overall duration of functional occlusion. Insertion of PIV by a trained specialist may also help reduce the risk of occlusion [37]. Various methods have been tried to prevent occlusion. In recent randomized trial, the rate of occlusion was lower with heparin infusion compared to placebo infusion [59].

Dislodgement: Dislodgement can occur when IV catheter was incorrectly secured with standard medical tape or another adhesive securement device. More frequently, catheters that are correctly secured become dislocated when more forces are applied upon the catheter than the securement method was intended to endure. IV dislodgement can lead to an unscheduled IV restart or more invasive central line. Dislodgement rate has been reported in the range of 3.7–9.9% in a prospective randomized study with a mean of 6.9%. Even a greater rate of 17.5%

was observed in prospective observational studies [2]. At almost 10% dislodgement rate, financial dislodgement burden can be tremendous translating to 33 million, if approximately 330 million IV catheters are sold in the USA [76]. *Diagnosis:* Cannula location is estimated by the flow of IV fluids and/or IV flushes. To evaluate PIVC fiction or dislodgement, we need to ask questions like does the IV flush easily and does the IV fluid flow easily? *Prevention and treatment*: Transparent and semipermeable polyurethane or sterile gauze and tape dressing are both recommended [77, 78]. Catheters with stabilization features like wings may help to secure the catheter due of an additional adhesive dressing contact area [79]. To decrease catheter movement and increase the adhesive surface area, attaching extension tubing to the catheter hub may prove beneficial [80]. Effective securement reduces the motion within the vessel which can in turn minimize the irritation, inflammation, occlusion, and risk of infection [77, 81]. At the same time, increase in catheter complex bulk may make the catheter more vulnerable to displacement due to clothing grabbing onto the catheter complex [38].

Venous spasm: Venous spasm is a complication of various minor procedures, including PIV insertion and arterial line placement [82]. Venous spasm can occur in the presence of cold IV fluid infusion, drug-related irritation, or trauma to the vein during insertion [82–84]. *Diagnosis:* The signs and symptoms of pain, blanching at the insertion site, slowing of IV infusion, and difficulty in palpating the vein can help facilitate the diagnosis. *Prevention and treatment:* Applying a warm compress, slowing the infusion rate, and potential application of a topical vasodilator, in addition to patient reassurance [82, 85] See **Table 1**.

7. Systemic complications

Air embolism: Air embolism is defined as an unintended venous administration of air through an intravenous access device or insertion site. It is usually associated with central venous catheters but can also occur with peripheral intravenous central catheters and less commonly with short peripheral catheters. The incidence of this complication may be low, but it is potentially fatal, with reported mortality as high as 30% [86]. Clinical signs and symptoms may vary depending on the patient, rate of infusion, volume of air, and anatomical location [87]. Physiologic injury can be due to associated ischemia, infarction, thrombotic, or inflammatory response. *Diagnosis:* Clinical signs and symptoms of air embolism may be nonspecific and not readily recognizable, yet immediate intervention is critical to adequately address the problem and prevent/minimize associated harm. Patient may present with sudden onset of dyspnea, cough, wheezing, chest or shoulder pain, tachypnea, tachycardia, hypotension, and/or neurological findings of cerebrovascular accidents [86, 88]. *Prevention and treatment*: For peripherally inserted catheters, prevention includes the avoidance of air, both primarily and by so-called "air traps" built into the IV circuit. When placing and removing central venous catheters, the patient should be placed in Trendelenburg (during catheter removal), followed by supine (subsequent 20–30 min) position. Prompt diagnosis and focused treatment are mandatory in cases of air embolism. After stabilizing the patient, immediate evaluation and management should be instituted [89]. Affected patients should be transferred to intensive care for close monitoring, with considerations given to hyperbaric oxygen therapy as an adjunct [88].

Pulmonary edema: Pulmonary edema or fluid overload is caused by excess fluid accumulation in the lungs, due to excessive fluid in the circulatory system [90]. Elderly, pregnant women, children, infants, and patients with cardiac, pulmonary, or renal disease are at risk of developing hypervolemia. In the context of IVT, fluid overload usually represents a combination of errors, from miscalculated IV rate, to inadvertently prolonged infusion, to lack of diagnostic recognition of early clinical symptoms. *Diagnosis:* Patients usually present with restlessness, breathlessness, tachycardia, dyspnea, cyanosis, and pink frothy sputum. Chest radiography can show typical findings of cephalization, interstitial edema, pulmonary vein enlargement, hilar fullness, Kerley lines, cardiomegaly, and pleural effusion [91]. Associated findings may include decreased oxygen saturation, increased respiratory rate, and pulmonary crackles on auscultation. Finally, increased body weight (e.g., "water weight") may be noted [92]. *Prevention and treatment*: The diagnosis of acute fluid overload requires immediate medical attention and treatment. This involves stopping the infusion, raising the head of the bed, applying oxygen, taking vital signs, complete cardiovascular assessment, diuresis when indicated, and appropriate education of the involved medical providers.

Catheter fragment embolism: Intravascular embolization of catheter fragment is a rare complication that occurs when a small part of the cannula breaks off and flows into the vascular system [93, 94]. *Diagnosis:* Symptomatology and diagnostic identification of intravascular embolization of catheter fragments are variable, largely depending on the location and size of the object. Most events are completely asymptomatic and only found incidentally on imaging performed for unrelated reasons [94]. Larger fragments, especially those that migrate into more central venous and pulmonary circulation, may result in palpitations, arrhythmias, chest pain, shortness of breath, cough, pain, and/or hypotension [86]. Chest X-rays may help assess the presence of any fragment. *Prevention and treatment*: Prevention starts with a careful inspection of the cannula and more specifically its distal end, to see if the PIV is structurally intact. Catheters should not be removed against unexpected resistance, which should prompt further investigation (e.g., ultrasound) before proceeding. PIV devices should be protected from twisting, bending, entanglement, etc. Repairs should only be done through official channels involving the manufacturer. Each event should be documented and disclosed to patients and their families, in accordance with existing guidelines [86].

Infection: Local infection is caused by lack of asepsis at insertion or regrowth of skin bacteria which then enter the PIV site. It can present as purulent drainage from the site; usually after 2–3 days it takes the body to mount a response after PIV placement. The majority of serious bloodstream infections are associated with central venous catheters, especially when catheters are placed emergently or used for prolonged periods of time [59]. For PIV catheters, the situation is different, since these are placed in less acutely unwell patients and typically require shorter periods of hospitalization and IVT. Although bacterial colonization of PIV catheters can increase with dwelling times of more than 72 h, there does not seem to be an elevated risk of associated phlebitis or infection regardless of whether the PIC catheter is replaced due to clinical indication or subject to routine replacement between 72 and 96 h [1, 2, 95, 96]. Thus, international guidelines now recommend removal of PIVCs when treatment is completed or sooner if any complication develops [97, 98]. Despite the

Peripheral venous catheter adverse events (PVCAEs)	
Local complications	**Systemic complications**
Tissue infiltration and extravasation Infusate solution leaks out into the surrounding tissue *Diagnosis*: detecting local tissue edema, cool skin, decreased flow rate, and comparison with contralateral limb *Prevention:* avoiding PIV too close to the joint, securing the catheter, and monitoring site frequently	**Air embolism** Rare unintended venous administration of air through IV site *Diagnosis:* nonspecific sudden onset of dyspnea, cough, wheezing, tachypnea, and/or neurological signs of CVAs *Prevention:* avoidance of air-traps in IV circuit; patient is in Trendelenburg position followed by supine position during catheter removal
Hemorrhage/hematoma Bleeding from puncture site/localized collection of extravasated blood *Diagnosis*: swelling, tenderness, and reddish discoloration *Prevention:* application of pressure after removal of cannula, usage of sterile transparent dressing	**Pulmonary edema** Fluid overload caused by excess fluid accumulation in the lungs *Diagnosis:* breathlessness, tachycardia, dyspnea, cyanosis, pink frothy sputum, chest radiography, decreased oxygen saturation *Prevention:* avoidance of miscalculation IV rate and prolonged infusion, early recognition of symptoms
Nerve injury Due to tissue infiltration, IV needle laceration, hematoma irritation *Diagnosis:* localized numbness or tingling, loss of sensation to pin prick *Prevention:* good knowledge of anatomy, shallow insertion at 5–15 degrees relative to the skin	**Catheter fragment embolism** Small part of the cannula breaks off and flows into the vascular system *Diagnosis:* symptomatology depends on the location, incidental finding on imaging, chest X-ray *Prevention:* careful inspection of cannula; catheters should not be removed against unexpected resistance; repairs should only be done by manufacturer
Occlusion Slowing or cessation of fluid infusion *Diagnosis:* presence of discomfort, blood within the PV line, PIV not running *Prevention:* check the kinks; remove the nonfunctioning cannula	**Infection** Purulent discharge from the site after 2–3 days *Diagnosis:* presence of purulent discharge, and/or temperature, blood count, D-dimer *Prevention:* hand hygiene, aseptic technique
Dislodgement Due to more forces applied upon the catheter than the securement method was intended to endure *Diagnosis:* checking the flow of IV fluids or IV flushes *Prevention:* effective securement; use of catheters with wings, extension tubing for movement	**Hypersensitivity** A severe hypersensitivity can be life- threatening *Diagnosis:* sudden fever, joint swelling, rash, urticarial, bronchospasm, wheezing *Prevention:* ask about any previous history of allergies, stay with the patient for five to ten minutes to detect early signs
Venous spasm Due to cold IV fluid infusion, drug-related irritation, or trauma to the vein *Diagnosis:* pain, blanching at the site, difficulty in palpating vein *Prevention:* apply warm compress; slow infusion rate	**Intra-arterial placement** Misplacement of PIV due to lack of vigilance *Diagnosis:* detection of pulsatile blood, changes in capillary refill, appearance of ischemia, blood gas analysis, ultrasound *Prevention:* recollecting that veins are more superficial than arteries, immediate removal of PIV after detecting pulsatile bleeding

Table 1. Local and systemic complications of peripheral venous catheter.

low occurrence of both local and bloodstream infections involving PIV catheters, severe infections can still significantly contribute to patient morbidity simply because of the ubiquitous nature of peripheral catheters [59]. *Diagnosis:* Local infection can be diagnosed by signs and symptoms of tenderness, swelling, erythema, purulent drainage, temperature, and appropriate laboratory testing (e.g., comprehensive blood count or D-dimer in cases of phlebitis) [99]. Of note, lower extremity PIVs are associated with higher incidence of infections when compared to upper extremity PIVs [100]. *Prevention and treatment*: To reduce morbidity and financial burden of PIV-related infections, appropriate education and multidisciplinary efforts should be implemented. For all PIV catheters, a clean, dry, intact dressing is recommended because any soilage will facilitate microorganism growth. Any soilage covered by nontransparent dressings can increase the risk of not detecting infection [1]. The density of skin flora at the site plays an important role in infection. From purely procedural perspective, the first and essential parts of the process should involve removal of the infected PIV cannula and cleansing of the site using sterile technique. Hand hygiene, clipping of excess hair, skin preparation with alcoholic chlorhexidine solution, proper aseptic technique, and maximal sterile barriers including cap, mask, sterile gown, and gloves during insertion can reduce the incidence of infection [59]. During the PIV insertion process, the antiseptic scrubbing technique also modulates the risk of infection [76]. Post-insertion, infection prevention is still crucial and is achieved by meticulous attention to hand hygiene, aseptic preparation of injectates and infusates, needleless connector decontamination with effective antiseptic, and technique. The insertion site requires weekly redressing (or sooner if the dressing is compromised), including recleaning of the insertion site with alcoholic chlorhexidine. Under certain circumstances, such as neutropenic patients, filling and flushing the lumen of the catheter with an antibiotic solution may provide some prophylactic benefits [59]. A final and very simple way to prevent PIVC-associated infections is to ensure the PIVC is reviewed daily and documented, and there is consideration of removal, for example, with the patient moved to oral medication [101] and vigilance for "idle PIVCs" See **Table 1**.

8. Special topics

Intra-arterial placement and injection: An intra-arterial misplacement of PIV, including the initiation of intra-arterial infusion, occurs seldom but is considered a matter of serious concern. Although the precise number of inadvertent intra-arterial PIV cannulation and subsequent injection is unknown, the frequency has been estimated to be as low as 1 in 56,000 and as high as 1 in 3440 [102]. However, the potential consequences of missing the diagnosis can be devastating. If not promptly recognized, its consequences may include arterial spasm, distal ischemia, and eventual development of limb-threatening gangrene [103]. Risk factors associated with unintentional arterial PIV placement include morbid obesity, dark skin, lack of patient cooperation, significant hypotension, and lack of vigilance [103, 104]. *Diagnosis:* Diagnosis can be made by detecting red pulsatile blood, observing changes in capillary refill, the presence of intense pain, and/or the appearance of distal ischemia. Confirmation is done by blood gas analysis, pressure transducer placement, and ultrasound [104]. *Prevention and*

treatment: Prevention is the most important measure in this setting. Providers must take great care that the PIV catheter is inserted into a vein, remembering that peripheral veins tend to be more superficial than arteries. Except for very few clinical circumstances (e.g., catastrophic hypotension), arterial cannulation will result in readily visible, pulsatile bleeding from the PIV catheter. In the case of inadvertent intra-arterial injection, it is primarily the intravenous drug that will be most likely to contribute to subsequent problems, as opposed to the ordinary intravenous electrolyte solution. Management consists of PIV catheter removal, assurance of hemostasis, prevention/management of vasospasm, and treatment of any distal complications See **Table 1**.

Forgotten tourniquet: Phlebotomy tourniquets are simple devices used to temporarily restrict venous blood flow, making veins more prominent and easier to see prior to PIV catheter placement. Some considerations regarding the use of tourniquets include the need for optimized location of placement (3–4 inches above intended PIV site), avoiding too much tension to prevent tourniquet from rolling up on itself/twisting and causing discomfort and releasing the tension within approximately 1 min of application [105]. Fortunately a rare occurrence, a phlebotomy tourniquet left in place for prolonged periods of time (e.g., hours) can result in the development of extremity compartment syndrome—a potentially limb-threatening condition [106, 107]. Compartment syndrome is a serious injury defined by an increase in pressure within a fascia-enclosed muscle compartment that results in compromised circulation leading to nerve damage and muscle necrosis [108]. This can lead to permanent disability, amputation, or even death from the release of toxic metabolites. Many of the above findings may not be present until late in the disease process. Thus, early diagnosis is imperative [109, 110]. A high degree of suspicion is crucial to allow an early diagnosis. Pain requiring analgesia in the extremity with the PIV should raise awareness and prompt a thorough examination of the entire extremity. Diagnosis can be especially challenging in children, intubated and sedated patients, and patients with neurological compromise or altered mental status. Increased vigilance must occur in these patients. If compartment syndrome is suspected once a "forgotten tourniquet" event occurs, an urgent surgical consult should be obtained. To prevent this serious omission and thus improve PS, appropriate education/training and procedural checklist implementation may be helpful [111]. Such occurrences, due to the potential for associated patient harm, should be viewed and treated as sentinel events [112]. In addition to compartment syndrome, this complication can also lead to the development of deep vein thrombosis in the affected limb [107]. This chapter's *Clinical Vignette* was based on a hypothetical scenario involving this rare but potentially severe occurrence.

9. Discussion

Due to its ubiquitous nature, IVT is associated with significant number of complications, both in terms of absolute quantity and taxonomy. In a recent survey, approximately one-third of pediatric patients and one-fourth of adult patients reported experiences involving a potentially preventable IVT-related complication. As outlined throughout this book series,

patient safety is a "team sport" [111, 112]. Consequently, active participation of all stakeholders is required to optimize patient outcomes. This involves active involvement of all those who directly or indirectly participate in IVT—providers, patients, and families. Our *Clinical Vignette* demonstrates the dangers inherently associated with increasingly complex systems, where transitions of care occur frequently and where several different teams care for the same patient over a period of just several hours. In such environments, even the smallest mistake can result in catastrophic sequelae.

In this chapter, we outlined key considerations around two primary types of PVCAEs—local and systemic. We also discussed intra-arterial PIV catheter placement and the rare but devastating scenario involving the "forgotten tourniquet." Each topic was presented in a clinically relevant fashion, incorporating a brief description, diagnosis, management, and finally prevention. Clinical approach to preventing PVCAEs is multipronged and includes a broad variety of considerations, such as checklists, knowledge of procedures and equipment, proper sterile technique, and the maintenance of appropriate PIV site cleanliness. Providers must also be aware of subtle clinical signs of PVCAEs, including PIV site erythema, IVT-related tissue injury, manifestations of air embolization, and signs of PIV catheter occlusion [2, 113]. In addition, each of the sections outlined specific strategies to prevent PVCAEs and PIV catheter failure. With growing numbers of patients needing vascular access for a range IVTs, providers need to show an understanding of the broad range of vascular access devices and corresponding clinical management aspects, including specific indications for various device types. Finally, providers need to be aware of patient needs, preferences, and concerns. After all, for many patients it is not the procedure that is of maximum concern but rather the clinician's communication skills, competence, and appropriate selection of PIV insertion site [114]. Patients and their families may be greatly untapped allies in preventing, monitoring, and reporting adverse events [101].

10. Conclusion

In summary, PVCAEs continue to be quite common and can lead to substantial patient discomfort, unnecessary or prolonged hospitalization, increased costs, and additional downstream morbidity. To improve patient outcomes, enhance patient safety, and reduce healthcare costs, there has been a substantial interest to implement measures aimed at reducing the incidence of PVCAEs [2]. Efforts to prevent PVCAEs should involve thorough provider education, clinical vigilance by all involved healthcare providers, as well as the proactive participation of all stakeholders, including patients and their families.

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