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Infection risks associated with peripheral vascular catheters

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Abstract

Background: Peripheral vascular catheters (PVC) are the most frequently used invasive medical devices in hospitals, with 330 million sold each year in the USA alone. One in three UK inpatients at any one time has at least one PVC *in situ* according to the Scottish National Prevalence survey.

Method: A narrative review of studies describing the infection risks associated with PVCs.

Results: It is estimated that 30–80% of hospitalised patients receive at least one PVC during their hospital stay. Despite their prevalence, PVCs are not benign devices, and the high number of PVCs inserted annually has resulted in serious catheter-related bloodstream infections and significant morbidity, prolonged hospital stay and increased healthcare system costs. To date, PVC infections have been under-evaluated. Most studies focus on central venous catheter rather than PVC-associated bloodstream infections. Risks associated with PVC infection must be addressed to reduce patient morbidity and associated costs of prolonged hospital admission and treatment.

Discussion: This article discusses the sources and routes of PVC-associated infection and outlines known effective prevention and intervention strategies.

Keywords
Catheter-related bloodstream infections, infection control, infection risk, peripheral vascular catheters

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Introduction

Peripheral vascular catheters (PVC) are the most frequently used invasive medical devices in hospitals, with 330 million sold each year in the USA alone (Hadaway, 2012). One in three UK inpatients at any one time has at least one PVC *in situ* according to the Scottish National Prevalence survey (Reilly et al., 2007). PVCs have traditionally been considered a low risk for catheter-related bloodstream infection (CRBSI). By definition, CRBSI is identified when a patient with a central venous catheter (CVC) has a positive blood culture result obtained from a peripheral vein, clinical manifestations of infection (e.g. fever, chills and/or hypotension) and no apparent source for bloodstream infection (with the exception of the catheter). One of the following should be present: a positive result of semi-quantitative (15 cfu per catheter segment) whereby the same organism (species) is isolated from a catheter segment and a peripheral blood culture; or differential time to positivity (growth in a culture of blood obtained through a catheter hub is detected by an automated blood culture system at least 2 h earlier than a culture of simultaneously drawn peripheral blood of equal volume) (Mermel et al., 2009).

While the incidence of PVC-related infection (0.2–0.7 episodes per 1000 calendar days) is reportedly lower than for CVCs, the far greater number of PVCs in use means that the absolute infection rates for PVCs approach the absolute infection rates for CVCs (Lolom et al., 2009; Maki et al., 2006).

This paper reviews recent evidence regarding infection risks associated with PVCs and recommends evidence-based infection control strategies to prevent PVC-related infection. In 2009,

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Zingg and Pittet published a well-received article on PVC complications, in which they considered the key risk factors for PVC complications were catheter-related, drug-related, patient-related, healthcare-related and dressing-related (Zingg and Pittet, 2009). Research conducted in the past 7 years adds new findings to this original paper, and these are discussed below.

Method

A narrative review was undertaken to synthesise the accumulated state of knowledge and trends within PVC infection risks. This paper follows the recommendations for narrative review methodology (Green et al., 2006). All studies that focused on the underpinning principles involved in PVC infection risk are included in the review.

PVC complications

PVC thrombophlebitis

Phlebitis is inflammation of the vein, and when phlebitis is combined with thrombus formation, it is called thrombophlebitis. PVC thrombophlebitis is a frequent PVC complication, with rates in the range of 2–80% (Malach et al., 2006; Uslusoy and Mete, 2008). This remarkable variation is due to the distinct study settings and lack of internationally accepted phlebitis definitions (Ray-Barruel et al., 2014). The clinical signs include redness, swelling, tenderness, pain, warmth, palpable cord or purulent discharge. Stricter definitions of phlebitis require the presence of almost all clinical signs, but more generous definitions require the presence of one or any two clinical signs. The heterogeneous use of thrombophlebitis definitions makes it difficult to compare study results. Scoring systems have been suggested to quantify thrombophlebitis, but these may complicate rather than facilitate the situation (Lundgren et al., 1996). It is hypothesized that mechanical irritation of the vascular walls by infusates, stiff catheter material or bacterial colonisation damages the endothelium (Lanbeck et al., 2002). This process provokes inflammation of the vascular wall, with fibrin deposition and thrombus formation. Early thrombus formation is found close to the puncture site (damage of vascular integrity by catheter insertion), whereas late thrombus formation is more often found around the catheter tip (damage of vascular integrity by mechanical irritation from the catheter tip) (Everitt et al., 1997). Thus, damage of vascular integrity is a prerequisite for thrombophlebitis formation.

PVC infection mechanisms

There are four possible pathways leading to PVC infection. The first is migration of microbes down the catheter tract, that is, through the 'wound' created to insert the catheter. These microbes may be from the patient's skin, contaminated disinfectant or healthcare workers' hands. The process may happen on insertion if the catheter is contaminated and then introduced into the patient or via microbial migration at any time while the catheter is in situ. The insertion of a PVC provides a potential portal of entry for bacteria to cross from an unsterile external environment to the normally sterile blood. The second route is via the catheter hub, which can become contaminated by healthcare workers' or patients' skin flora during connection of fluids, medicine administration or during extraction of blood. Recently, Nishikawa reported that bacterial contamination was more common in the hub area than indwelling catheter segments, and the hub seems an important risk in post-insertion care, in addition to adequate aseptic technique on catheter insertion (Nishikawa et al., 2010; Zingg and Pittet, 2009). The third route is for catheters to be contaminated directly by bacteria circulating in the bloodstream. That is, the patient has an existing bloodstream infection, and microbes are able to attach to the catheter as they pass by the device. The fourth is that of contaminated infusate, which may occur at the manufacturing stage (intrinsic) or during manipulation by healthcare workers (extrinsic). Recent research confirms that infusates other than water, including heparin, have great potential to form crystals in the intraluminal surface of PVCs, which can induce bacterial attachment and colonisation (Nishikawa et al., 2010).

Microbial attachment on the PVC surface is likely to be followed by biofilm development and maturation and dispersion of microbial cells from the biofilm into bloodstream. The most frequently isolated bacteria from PVCs are coagulase-negative staphylococci and *Staphylococcus aureus.* These bacteria can originate from the cutaneous flora of the patient or the hands of medical personnel and then reach the patients' tissues and organs via the blood, causing serious infections and high mortality rates. Thus the infectious route for these organisms is likely skin–bloodstream; i.e. the bacteria enter the bloodstream through PVC wounds in the skin and cause subsequent infection in other organs. The next most common pathogens for PVC-related infections are Gram-negative bacilli. These microorganisms are generally acquired from the hospital environment, such as *Enterobacter spp, Stenotrophomonas maltophilia, Burkholderia cepacia* and *Citrobacter freundii* (Raad and Hanna, 2002). Fungi, such as *Candida species*, from the hands of healthcare personnel, contaminated infusions or parenteral nutrition, are also important pathogens isolated from catheters (Strausbaugh et al., 1994). Initially PVCs are often primarily colonised by a single microorganism species, but multiple species enter subsequent to the development of biofilms (Passerini et al., 1992).

PVC infection risk factors

Catheter-related risk factors

Catheter dwell time is one of the major risk factors of PVC infection, yet routine removal of PVCs does not reduce risk

(Rickard et al., 2012). This confirms that it is overall exposure to PVC use that increases risk.

Stabilisation of PVCs is directly related to catheter dwell time and occurrence of patient complications. When PVCs are not properly secured, micromotion within the blood vessel can cause migration of organisms along the catheter and into the bloodstream leading to CRBSI (Marsh et al., 2015b; Zhang et al., 2011). Furthermore, an inappropriately secured PVC often leads to unscheduled insertion of another PVC, causing a delay in patient treatment, unnecessary patient discomfort, patient dissatisfaction, safety concerns and increased costs (Bausone-Gazda et al., 2010). Therefore, appropriate stabilization of PVCs is important in maintaining the integrity of the device and preventing various potential complications.

Healthcare-related risk factors

Insertion and maintenance of PVCs by untrained personnel has long been associated with higher risk of PVC infection (Palefski and Stoddard, 2001; Soifer et al., 1998; Tomford et al., 1984). Inadequate skin antisepsis technique or insufficient drying time prior to insertion are also risk factors for PVC infection. The recommended method of skin antisepsis is a back and forth scrubbing motion with 2% chlorhexidine gluconate in 70% isopropyl alcohol, or povidone iodine in alcohol for patients with sensitivity to chlorhexidine, then allow the site to air dry prior to the insertion of a catheter (Hadaway, 2012; Loveday et al., 2014). Newer vein visualisation technologies hold great promise for smoother and more efficient insertion practices, but the effect of such techniques on PVC infection rates is currently unknown. Documentation of PVC insertion and regular assessment is often missing from the patient's medical record (Alexandrou et al., 2015).

Dressing-related risk factors

A PVC insertion site can be best described as a wound and, as such, to prevent PVC-related infection it is essential that the dressing covering the insertion site should keep it clean and dry, and offer protection from external contamination (Morris and Heong Tay, 2008). However, in current practice complications for PVCs remain high and in part are associated with the PVC dressing or securement.

There are many different products currently available for dressing or the securement of PVCs, however, the most common type of dressing in use is either gauze and tape or a semi-permeable transparent dressing. Gauze dressings range from complex, commercially marketed products that combine sterile tape with a gauze design, to clinician-assembled gauze and non-sterile tape. They are reported to be comfortable for the patients as well as keeping the wound dry by absorbing exudate from the insertion site (Gabriel, 2010). However, they do not provide a waterproof barrier, and once wet, offer an environment suitable for bacterial proliferation (Campbell and Carrington, 1999). They require regular dressing changes, increasing the opportunity for microbial site contamination or movement of the catheter in and out of the vein, which may encourage microbial entry into the wound (Marsh et al., 2015a). Additionally, the site cannot be regularly observed for signs of infection or complications (Campbell and Carrington, 1999; Gabriel, 2010).

Semi-permeable dressings (SPDs) are recommended by international guidelines for the securement of intravascular devices (Loveday et al., 2014; O'Grady et al., 2011b) and are a commonly used product in hospital environments. They have evolved over time to offer greater vapour permeability, which increases the rate of evaporation of fluid from the insertion site, keeping the site dry and reducing the risk of infection (Gabriel, 2010; Loveday et al., 2014; Webster et al., 2011; Wille et al., 1993). The SPD transparent properties also allow for visual inspection of the insertion site, making it easy to identify early signs of infection (Gabriel, 2010; Webster et al., 2011). They are specifically designed and shaped to fit securely over a PVC site (Campbell and Carrington, 1999) and more recent products have been created with a reinforced edge or border to offer additional securement. A limitation of SPD is during its application to the site. They have been described as difficult to apply, and if creases appear in the dressing's surface, it can cause a possible route for bacteria to enter under the dressing and track to the insertion site, increasing the risk of local and systemic infection (Campbell and Carrington, 1999). A point prevalence survey conducted in the general medical and surgical wards of a large tertiary hospital found that 25.1% of patients' dressings were assessed as not clean, dry or intact (New et al., 2014). The same hospitals cancer care wards reported that 8.6% of audited PVCs were not clean, 6.9% not dry and 17.2% not intact (Russell et al., 2014).

Other products are commercially available that offer additional catheter securement minimising movement at the catheter hub. These products claim to reduce the pistoning action of the catheter in and out of the vein, which can cause the migration of organisms along the PVC and into the bloodstream (Marsh et al., 2015a). One such product type has either anchor points or clips that hold the PVC to the skin (Marsh et al., 2015a) and is used in conjunction with a SPD. A limitation of these products can include residue left on the skin and the increased cost associated with PVC securement (Bausone-Gazda et al., 2010). Another novel product, tissue adhesive (TA), was recently tested with PVCs (Marsh et al., 2015a; Rickard et al., 2015). The medical grade superglue was applied to the insertion site and under the catheter hub and was used in conjunction with an SPD. In a recent pilot trial conducted in the medical and surgical wards of a large tertiary hospital, TA had the lowest rate of catheter failure (Marsh et al., 2015a). This was similar to results in an adult emergency department, where they reported a 10% reduction in overall catheter failure when PVCs were secured with TA compared to standard care (Bugden, 2016). In addition, TA has also been

described as inhibiting the growth of Gram-positive organisms. Simonova et al. (Simonova et al., 2012) identified in an in vitro study that PVCs dressed with an SPD had *Staphylococcus aureus* and *Staphylococcus epidermidis* present at PVC insertion site and along the tract at 72 h but not with catheters secured with TA. However, the pilot trial found that TA caused four incidents of either skin tear, rash or blister, and concluded that the product may not being suitable for all patient skin types (Marsh et al., 2015a).

There have been developments with antimicrobial impregnated discs or SPDs designed to reduce skin colonisation around the insertion site, which has been identified as the leading cause of both local and systemic infection (O'Grady et al., 2011b). However, they are still being independently tested using randomised study designs in PVCs to explore their benefits in preventing local and systemic infection, as well as identifying potential risks for chlorhexidine-associated skin complications and chlorhexidine resistance.

Infection prevention strategies

Most complications associated with the use of PVCs are preventable (Harbarth et al., 2003). Based on factors that contribute directly to PVC infections, various preventive strategies have been successfully developed. Some traditional preventive measures are training and education of healthcare practitioners and patients, performance feedback, specialised intravenous treatment teams, documentation with peripheral cannula care plans, hand hygiene, skin preparation, use of sterile semipermeable dressings, selection of catheter insertion site and catheter replacement strategies (Morris and Heong Tay, 2008; Raad et al., 2007; Zingg and Pittet, 2009).

Education

Staff training and education is a key element in reducing catheter-related infections (Raad et al., 2007). Evidence-based cannulation training, theory and simulated practice, combined with a subsequent period of supervised training in the workplace, are great learning procedures to help inexperienced novices become fully competent (Morris and Heong Tay, 2008). Research has shown that intensive education programmes can improve overall cannula care leading to significantly decreased incidence of CRBSI (Morris and Heong Tay, 2008; Warren et al., 2004). Furthermore, staff can also educate patients to look out for early signs of infection at the cannula site to help early detection (Morris and Heong Tay, 2008). Before discharge from hospital, patients with PVCs and their carers should be taught techniques to prevent infection and manage their intravascular devices (Loveday et al., 2014). In addition to staff training and education, performance feedback is another important strategy in reducing infection (Assanasen et al., 2008; Eggimann et al., 2000). As a well-established intervention method in healthcare, performance feedback has led to a 28% improvement in staff implementation of a PVC bundle over 6 months (Boyd et al., 2011). There is unequivocal evidence that performance feedback contributes to improved professional practices and better healthcare outcomes (Frampton et al., 2014; Jamtvedt et al., 2006). Intravenous teams are also associated with better PVC outcomes. In a controlled clinical trial, 22% of patients with catheters maintained by ward nursing staff developed catheter-related inflammation, which only occurred in 8% of patients whose catheters were maintained by the specialised intravenous team (Soifer et al., 1998).

Documentation of each catheter insertion using an intravenous device care plan could help reduce the incidence of catheter-related infection (Morris and Heong Tay, 2008). Evidence indicates that healthcare workers maintain poor records including documentation of cannula insertion (Hindley, 2004). Initiating the recording of cannula insertions encourages others to maintain ongoing cannula care, such as inspection of the cannula site for complications and removal of unwanted cannulae as early as possible (Grol and Grimshaw, 2003).

Hand hygiene

Inadequate hand hygiene by healthcare workers is a direct risk factor for PVC infection (Loveday et al., 2014; Morris and Heong Tay, 2008). If not decontaminated appropriately, healthcare workers' hands become ideal vectors for spreading microorganisms among patients. Unequivocal epidemiological evidence demonstrates that hand-mediated transmission is a main contributing factor in acquiring and spreading infection in hospitals (Loveday et al., 2014). Results from a prospective multi-centre study involving 1132 PVCs in three hospitals suggested that, with regard to PVC-related infections, simple hand washing was no better than no hand hygiene (Hirschmann et al., 2001). Appropriate disinfection of hands before PVC insertion or before donning gloves significantly reduced the incidence of infection (Hirschmann et al., 2001). Thus, all practitioners must adhere to the correct hand decontamination technique before and after any contact with the PVC or insertion site; this includes decontaminating hands using an alcohol-based hand rub or by washing with liquid soap and water if the hands are soiled or contaminated with blood or body fluids (Loveday et al., 2014). To further minimise infection risk, practitioners should avoid wearing wristwatches, stoned rings, long sleeves and long fingernails (Morris and Heong Tay, 2008). In addition, practitioners should wear gloves when performing cannulation and discard them after the procedure (Morris and Heong Tay, 2008).

Skin disinfection

Studies have shown that appropriate skin preparation/cutaneous antisepsis before insertion helps prevent

PVC-related infections such as CRBSI (Morris and Heong Tay, 2008; Scales, 2009). The most common microorganisms found in cannulae-related infections are those that occur naturally on the skin, such as staphylococci (Morris and Heong Tay, 2008). Currently, a single-use application of 2% chlorhexidine gluconate in 70% isopropyl alcohol, or povidone iodine in alcohol for patients who are sensitive to chlorhexidine, is standard practice to disinfect the skin at the insertion site (Loveday et al., 2014). Intriguingly, results from a recent randomised controlled trial involving 1181 patients and 2612 catheters found that, compared to povidone-iodine alcohol, chlorhexidine alcohol had a lower incidence of catheter-related infections. The authors claimed that for skin antisepsis, chlorhexidine alcohol provides better protection against short-term catheter-related infections than does povidone-iodine alcohol (Mimoz et al., 2015).

Catheter dressing and securement

Due to their wound-like nature, all cannulae must be covered with a sterile dressing to avoid external contamination (Fletcher, 1999; Zingg and Pittet, 2009). Local catheter site infections are mainly associated with bacterial skin colonisation at the insertion site. Catheter dressings help to protect the catheter insertion site from potential external contamination (Maki and Ringer, 1987). Originally, gauze dressings were used for covering the catheter insertion site (Gillies et al., 2003; Hoffmann et al., 1992). Although gauze dressings are excellent in keeping the insertion site dry, they do not allow easy observation of the insertion site. As a result, transparent SPDs have replaced gauze dressing in some settings for protecting cannula sites. Transparent SPDs allow evaporation of moisture from the skin and direct visual observation of the insertion site (Gabriel, 2010). Furthermore, patients with a transparent dressing can shower or bathe without saturating the dressing, which is an important infection risk factor (Hindley, 2004).

PVC replacement

Routine replacement of PVCs every 3–4 days has been standard practice in many hospitals in the belief that this strategy could help prevent catheter-related infections. Results from early studies suggested that restricting duration of PVCs might prevent infection (O'Grady et al., 2002; Tager et al., 1983; Zingg and Pittet, 2009). Results from recent studies demonstrate that clinically indicated replacement of PVCs has equivalent infection risk as routine replacement (Rickard et al., 2012; Van Donk et al., 2009; Webster et al., 2013). Authors have stressed, however, that clinically indicated removal requires frequent close monitoring of the insertion site, with timely treatment cessation and prompt removal once treatment is complete, and continued monitoring for complications including suspicion of infection (Rickard et al., 2012). Clinically indicated replacement has several advantages over routine replacement, such as avoidance of unnecessary repeated skin punctures, potentially non-aseptic insertions and reduced health costs (Rickard et al., 2012).

Needleless connector decontamination

Needleless connectors (NCs) were introduced into clinical practice to minimise the risk of needlestick injury and facilitate nursing care and catheter management (Jarvis et al., 2009). They are used on almost all intravascular devices and provide an easy access for infusion connection (Moureau and Flynn, 2015). However, colonisation of NCs is regarded as a major cause of post-insertion catheter-related infections (Moureau and Flynn, 2015). Results from a recent systematic review found that 33–45% of NCs were contaminated and disinfection compliance was as low as 10%, making NC the greatest risk for contamination of the catheter after insertion (Moureau and Flynn, 2015).

Maintenance practices play an important role in preventing CRBSI. Many infection prevention guidelines recommend scrubbing the NC hub to minimise the risk of microbial contamination and subsequently reduce the risk of infection (Loveday et al., 2014). Improper disinfection of NCs can result in contamination of the internal lumen of the catheter with bacteria, resulting in the formation of biofilm and subsequent bloodstream infection (O'Grady et al., 2011a). Unfortunately, some catheter maintenance best practices remain undefined, including the best antiseptic and technique for disinfecting NCs.

Conclusion

The most frequently used medical devices in hospitals, PVCs are associated with a high risk of bloodstream infection, the most serious complication of catheterisation (O'Grady et al., 2011a; Pujol et al., 2007). In contrast with the many studies on central catheter infection risk factors and prevention strategies, the infection risks of PVCs are still largely under-evaluated in clinical practice and studies. Studies to date have focused on other PVC complications such as thrombophlebitis, but future studies evaluating PVC-associated CRBSI risk factors are needed to guide clinical decision-making.

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