Vascular Access for Continuous Renal Replacement Therapy

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ABSTRACT

A working vascular access is essential for performing continuous renal replacement therapy (CRRT) efficiently and without interruption. Dual-lumen temporary hemodialysis catheters are the catheters of choice, although tunneled catheters can also be utilized if therapy is expected to be prolonged. Hemodialysis catheters have to be inserted under ultrasound guidance by trained personnel, using aseptic conditions. The right internal jugular vein is the preferred site. Catheter malfunction and catheter-related infections can be reduced by adhering to preventive guidelines such as ultrasound guidance for placement, strict hand hygiene, gauze dressings, and sterile techniques during catheter handling. Antibiotic or antiseptic-coated catheters and lock solutions may be beneficial in certain patients, but these are not widely used due to the concern for resistant organisms and allergic reactions.

A well functioning vascular access is a prerequisite for successful continuous renal replacement therapy (CRRT). This is usually obtained by inserting a double-lumen noncuffed, nontunneled hemodialysis catheter (HDC) into one of the central veins at the bedside under ultrasound guidance. Arterio-venous fistulas (AVF) or grafts (AVG) are not suitable for CRRT, given risk of needle dislodgement and bleeding as well as continuous needle trauma to the access. Tunneled, cuffed HDCs can be utilized if the patient is expected to need renal replacement therapy (RRT) for more than 3 weeks, but generally this should be not the initial choice in the intensive care unit. Continuous arterio-venous techniques are rarely, if at all, used anymore and will not be discussed here.

Characteristics of Hemodialysis Catheters

The hemodialysis catheter is made of polymers (usually polyurethane or silicone) that ensure adequate resistance combined with softness and hemocompatibility. Semi-rigid catheters are preferred over rigid catheters to avoid trauma to the vessel wall. Some of the newer polyurethane catheters are semi-rigid during insertion, then soften inside, at body temperature, thereby minimizing trauma to the vessel wall. The outer diameter of the dual-lumen catheter usually varies between 11 and 14 French with the arterial and venous lumens arranged side-by-side or in a coaxial manner. The arterial port ends about 2–3 cm proximal to the venous port to reduce recirculation. Most companies manufacture the catheters in three different lengths to suit the site of insertion. The right internal jugular (IJ) vein typically requires a 15–16 cm catheter and the left IJ and subclavian veins require 19–20 cm catheter; a 24 cm catheter is utilized for the femoral veins, since this has been shown to reduce recirculation in intermittent hemodialysis (IHD).

A triple-lumen temporary HDC is available, with an extra port for administering medications or intravenous fluids. A multicenter prospective study did not reveal any difference in blood flow rates or infectious complications compared to dual lumen HDCs.

Tunneled, cuffed HDCs are made of silicone or other soft polymers, which are believed to be less thrombogenic compared to the temporary catheters. The configurations of these catheters vary from double lumen to two separate single lumen catheters. They are usually inserted into the IJ veins and rarely, if there is bilateral occlusion of the central veins, the femoral veins are utilized. These catheters are larger than the temporary HDCs and provide higher blood flows. This will become pertinent as newer methods of renal replacement therapy with higher blood flow requirements (e.g. sustained low-efficiency dialysis and accelerated veno-venous hemofiltration) become incorporated at more and more institutions.

Placement and Location

Temporary HDCs are inserted at the bedside into the IJ, subclavian or femoral veins by modified Seldinger

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technique under utmost sterile conditions. Chlorhexidine 2% is the preferred skin disinfectant, but povodone iodine or 70% alcohol can be substituted if chlorhexidine is not available.

Ultrasound guidance should be a mandatory requisite for all HDC insertions. Given the variability in venous anatomy, even experienced personnel can have difficulty with "blind" central venous cannulation using anatomical landmarks. One analysis of 104 patients documented a variation in the IJ vein anatomy in 27% of the patients (1). In another study of 100 catheter placements in 79 patients, 28 patients had significant findings such as total occlusion of the vessel, thrombus, stenosis or anatomic variation (2). A meta-analysis demonstrated that ultrasound guidance reduced placement failure (RR 0.32), decreased complications from placement (RR 0.22), and the need for multiple attempts (RR 0.60) (3). A more recent, prospective study of 900 patients demonstrated that ultrasound guided catheter placement in the IJ vein not only increased success rate and decreased complication rates, but also reduced catheter associated infections (4). The 2006 National Kidney Foundation Outcomes Quality Initiative (KDOQI) guidelines recommend the use of ultrasound guidance for vascular catheter placements. Continuous electrocardiographic monitoring is recommended during the placement of subclavian and IJ catheters to detect arrhythmias, and a chest X-ray should be performed prior to using these catheters to ensure appropriate position of the catheter tip and rule out pneumothorax (5).

The right IJ vein is the ideal location for a temporary catheter, given its more direct route to the superior vena cava (SVC). The tip of the temporary HDC should be advanced to the junction of the SVC and the right atrium. The left jugular vein has a more circuitous route to the right atrium and this can lead to inadequate blood flows and filter malfunction, especially in a nonsedated, restless patient with frequent neck movements. Femoral veins should be the second choice, given their easy accessibility. The subclavian veins can also be utilized for CRRT, but only used as a last resort, given the concern for subclavian stenosis, especially in a patient who might develop end-stage renal disease and may need an AVF or AVG in the ipsilateral arm.

Tunneled HDCs should be placed under fluoroscopic guidance after ultrasound localization of the vessel. In the IJ and subclavian veins, the tip of the tunneled catheter can be placed in right atrium, given its soft polymer construction.

Complications

Complications associated with HDC can occur either during placement or throughout the duration of its use. Complications during placement include bleeding, hematoma, arterial puncture, air embolism, recurrent laryngeal nerve palsy, hemo-mediastinum, atrial perforation, and even cardiac arrest. Ultrasound guidance during HDC placement is essential to prevent adverse events. In a study of 900 patients, the rates for carotid injury (10.6% vs. 1.1%), hematoma (8.4% vs. 0.4%), hemothorax (1.7% vs. 0%), and pneumothorax (2.4% vs. 0%) were reduced with ultrasound guidance, compared to landmark guided placement (4). The tip of the temporary HDC inserted into the IJ and subclavian veins should be located at the junction of the SVC and right atrium to prevent cardiac trauma. The longer term complications include catheter thrombosis, venous thrombosis, formation of fibrin sheath and infections.

Catheter Malfunction and Thrombosis

Catheter malfunction can occur as a result of intraluminal thrombus, fibrin sheath around the catheter tip, kinking of the catheter or mal-position of the catheter, with openings too close to the vessel wall. Malfunction of the HDC is usually manifested by poor blood flows and high access pressures, leading to inadequate hemodialysis. The lower blood flows (150–250 ml/minute) might be adequate for CRRT and the HDC can be used until the patient is more stable to be switched to IHD. One recent study of temporary HDCs showed that femoral localization was associated with a higher risk for thrombosis, when compared to the IJ site (6).

Instillation of heparin into both lumens of catheters is essential at the conclusion of hemodialysis or at any time the catheter is not being used for CRRT. The usual concentration of heparin is 5000 IU/ml, although lower concentrations of 2500 IU/ml or 1000 IU/ml have also been successful in preventing thrombosis. Intraluminal instillation of heparin has been associated with bleeding complications and therefore the lower concentration of heparin is preferred to prevent catheter thrombosis.

In a completely nonfunctional catheter, instillation of alteplase (recombinant tissue-type plasminogen activator, rtPA) 2 mg in each port can re-establish blood flows of greater than 200 ml/minute in a majority of the cases. In a study of 28 catheters, alteplase instillation restored patency 87.5% of the time, with median dwell time of over 24 hours (7). However for a patient on CRRT, duration of therapy is critical in achieving the prescribed dose. If there is a catheter malfunction in a patient on CRRT, then alteplase can be attempted with a dwell time of 30 minutes to 2 hours. This was successful 88% of the time in a small study of 30 patients with 164 dwells of alteplase (8). If the catheter is still not functional it should be changed over a guidewire or placed at a different site as soon as possible and CRRT resumed with as little interruption as possible. Fibrin sheaths that form outside the HDC, especially in tunneled catheters, are extremely resistant to thrombolytics and may require mechanical brushing or stripping.

Catheter Related Infections

Temporary and tunneled HDCs are associated with exit site infection as well as systemic bacteremia or sepsis. This is usually a result of contamination of the catheter

lumen or migration of the skin bacteria through the entry site into the blood stream, although occasionally it can occur from hematogenous spread from another source of infection. The usual causative organisms are Staphylococcus species and gram negative rods, but other skin derived bacteria and Candida can be seen as well. Temporary uncuffed catheters are associated with a higher risk of infection (3.8–6.6 episodes/1000 days vs. 1.6–5.5 episodes/1000 days) compared to tunneled HDCs (9). The risk factors for catheter related bacteremia are: the number of infusion ports, frequency of manipulation, severity of illness of the patient, indwelling time, emergency placement and the experience of the operator.

There are conflicting data regarding the site of the catheter and infection risk. Nonrandomized, prospective studies had shown an increased risk of infection associated with femoral veins, compared to IJ veins. However, in a recent randomized controlled study of 750 patients, the rate of infection was not statistically different between the IJ and femoral veins (2.3 vs. 1.5 per 1000 catheter days, respectively). Obese patients with body mass index greater than 28.4 were found to have a higher rate of colonization of the femoral site, but there was no difference in the rates of infection (10). Given the available data, one cannot conclude that femoral sites pose a higher risk for infection. However, appropriate skin and catheter care are vital to the prevention of infections, whatever the site. Betadine or antibiotic ointments on the catheter hubs and aseptic techniques during catheter manipulation can decrease the incidence of infections. Tight occlusive dressings can increase infection risk and therefore gauze dressings which are changed daily are preferred.

Prevention is crucial, since catheter related infections are associated with high morbidity and mortality. Guidelines for prevention include: education and training of nurses and physicians, complete aseptic precautions, hand hygiene and use of ultrasound guidance. The general recommendations are that femoral catheters should not be left in place for more than 7 days and IJ and subclavian catheters should be changed after about 3 weeks. Antiseptic or antibiotic coated catheters have shown to reduce the incidence of infection in prospective studies. However, due to the concern for the emergence of resistant organisms as well as allergic reactions, these are not widely used. Antibiotic or antiseptic "locks" (the solution is left in the catheter lumens between treatments) have also proven to reduce catheter related infections, but toxicity and bacterial resistance are a concern here as well (11). In a recent multicenter double-blind study of 291 patients with tunneled and temporary HDCs, trisodium citrate solution (30%) lock, when compared to heparin, reduced catheter related bacteremia from 4.1 to 1.1 per 1000 catheter days ($p < 0.001$) (12). No serious adverse events were noted. Sodium citrate, 4%, has also been used successfully in some centers. Citrate solution, a cheaper alternative to heparin, is available in Europe but is not FDA approved in the United States as a catheter lock solution.

Evidence of exit site infection should prompt the removal of a temporary HDC with placement of a new catheter at a different site. Tunneled catheters should be removed if there is evidence of tunnel infection, but exit site infections can probably be treated by topical antibiotics. For patients with evidence of systemic infection, empiric antibiotics should be started immediately after obtaining blood cultures and the HDC should be replaced. The biofilm that is created by microorganisms around the catheter makes it impermeable to antibiotics. To ensure that CRRT is continued with minimal disruption, the tunneled HDC has to be exchanged over a guidewire or replaced in a different location in a timely manner. Small studies have shown that replacing a catheter over a guidewire provides the same cure rate as placing a new catheter. Studies in the end stage renal disease population have demonstrated that antibiotic locks combined with intravenous antibiotics can have a cure rate of approximately 70% in tunneled HDC related bacteremia (13). However, this approach is not practical in a critically ill patient who requires immediate resumption of RRT.

Conclusion

In summary, successful CRRT and patient outcome depends greatly on a functioning hemodialysis catheter. Temporary dual-lumen catheters are preferred and these should be carefully placed under sterile conditions, under ultrasound guidance. Close vigilance is required to prevent catheter malfunction and infections. For CRRT to be truly continuous, catheters should be functional for a minimum of 20 hours a day. Replacing or restoring a malfunctioning or infected catheter should be a high priority in the intensive care unit to ensure continuous delivery of renal replacement therapy.

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