The Challenges of Hemodialysis Catheter Use

By identifying the potential difficulties associated with tunneled hemodialysis catheters, we can improve blood flow rates and optimize dialysis efficiency.

BY THOMAS M. VESELY, MD

In the United States, the majority of patients (75%) begin hemodialysis treatment with a central venous catheter as their initial vascular access.[1] Most patients will have a tunneled (cuffed) hemodialysis catheter inserted into their internal jugular vein.[2] Three times each week, the hemodialysis catheter is connected to the hemodialysis machine for 3 to 4 hours per treatment session.

According to the Centers for Medicare & Medicaid Services, the percentage of patients using a tunneled hemodialysis catheter as their primary vascular access decreased from 29% in January 2007 to 24% in April 2010.[3] The majority of patients who begin hemodialysis treatment using a central venous catheter will transition to an arteriovenous fistula or prosthetic graft as their permanent vascular access. According to the National Kidney Foundation Kidney Disease Outcomes Quality Initiative Guidelines, each patient should have a functional fistula or graft within 90 days of starting chronic hemodialysis treatment.[2] As reported by Lee et al, however, a significant number of patients will continue to use a tunneled hemodialysis catheter for the first 6 to 12 months of their hemodialysis treatment[4]

HEMODIALYSIS CATHETER DYSFUNCTION

Hemodialysis catheter dysfunction is commonly defined as the inability to aspirate blood, a blood flow rate < 300 mL/min, and increased arterial or venous pressure or the inability to deliver an adequate dialysis prescription.[5,6]

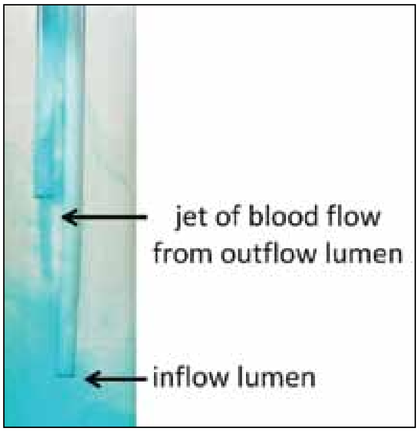

Figure 1. Benchtop testing shows recirculation when split-tip catheter is connected to the hemodialysis machine in reverse configuration of blood lines. Jet of blood flow exiting the outflow lumen is directed at the distal tip of the inflow lumen.

Griffiths et al reported an analysis of 3,364 hemodialysis patients with tunneled central venous catheters who underwent 268,363 hemodialysis sessions.[7] Catheter dysfunction occurred during 7.1% of hemodialysis treatment sessions, and the median time to the first episode of catheter dysfunction was 95 days.[7] Sixty-three percent of patients had at least one episode of catheter dysfunction, and 30% of patients had ≥ 1 episode of catheter dysfunction per month.

Some studies have reported that tunneled hemodialysis catheters may not be able to provide adequate dialysis treatment as determined by dialysis kinetics.[4,8] Moist et al reported the results of a prospective study of 259 patients with tunneled hemodialysis catheters and found that catheter blood flow rates < 300 mL/min may provide adequate hemodialysis treatment.[6] These investigators found that a catheter blood flow rate < 300 mL/min occurred during only 10% of hemodialysis treatment sessions, but 75% of these patients had adequate dialysis kinetics. In the study, Moist et al suggest that catheter flow rates < 300 mL/min may not be associated with inadequate hemodialysis treatment.[6] Furthermore, defining catheter dysfunction as a blood flow rate < 300 mL/min may result in unnecessary catheter-related interventions. A suboptimal rate of blood flow often causes the nursing personnel to reverse the configuration of the dialysis blood lines to maintain a catheter blood flow rate > 300 mL/min.[6]

HEMODIALYSIS CATHETER RECIRCULATION

The inability to achieve an adequate rate of blood flow through a tunneled hemodialysis catheter is often managed by reversing the dialysis blood lines. Reversal of the arterial and venous blood lines often improves the rate of blood flow through the catheter, but this maneuver may be associated with significant access recirculation. A prospective study of 102 patients with tunneled hemodialysis catheters reported that 35% of catheters had suboptimal rates of blood flow, leading to reversal of the arterial and venous lumens to achieve adequate blood flow.[9] Hemodialysis catheters that worked well with the dialysis blood lines in the standard configuration had a mean blood flow rate of 391 mL/min, and catheters that required reversal of the blood lines had a mean blood flow rate of 384 mL/min.[9]

Access recirculation occurs when dialyzed blood exiting the outflow lumen directly re-enters the inflow lumen thereby bypassing the systemic circulation (Figure 1). Recirculation reduces the effective clearance of a solute by diluting the inflow concentration and thereby reducing the driving force for diffusion across the dialyzer membrane.[10] A hemodialysis catheter recirculation rate > 10% reduces the effectiveness (adequacy) of hemodialysis treatment.

CATHETER TIP POSITION

A hemodialysis catheter functions in a complex environment. Several clinical studies have demonstrated that the performance and durability of hemodialysis catheters is improved if the tip is positioned within the right atrium.[11-13]

A critical concept to understand is that there are significant changes in the position of a catheter tip when the patient changes position. The direction and degree of catheter tip movement is depends on several variables, including the type of catheter, the insertion site, and the body habitus of the patient.

The majority of hemodialysis catheters are inserted in the anterior chest wall while the patient is in the supine position. The catheter is fixed to the patient's anterior chest wall. When the patient moves to a standing position, the anterior chest wall will move inferiorly due to gravity.[14-16] In the supine position, the mediastinal structures, including the central veins, are compressed by the abdominal contents. When the patient moves to an upright position, the abdominal contents descend, the central veins lengthen, and the right atrium expands. Because the external segment of a tunneled hemodialysis catheter is fixed (sutured) to patient's chest, this lengthening of the mediastinal structures will cause a relative change in the position of

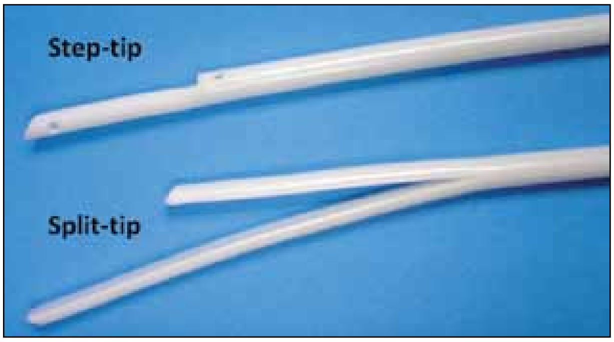

Figure 2. A comparison of the step-tip type hemodialysis catheter to the split-tip type catheter.

the catheter tip with respect to the superior vena cava and right atrium. The tip of a tunneled central venous catheter that is initially positioned within the upper right atrium will often retract upward into the superior vena cava when the patient moves from the supine to a standing position.

The tip of a central venous catheter is not in a fixed location but will exhibit a range of motion as the patient changes body positions. A correctly placed catheter tip will likely be one that undergoes a range of movement (2–3 cm) between the superior vena cava and the upper right atrium. The long axis of the catheter should be parallel to the wall of the superior vena cava, and the tip of the catheter should move freely within the vascular lumen. The vascular access practitioner should understand the direction and the degree of anatomic forces that are acting to move a catheter tip.

BLOOD FLOW

Ideally, a hemodialysis catheter should be able to maintain a blood flow rate of 400 mL/min for at least 3 hours. The Hagen-Poiseuille equation states that a larger-diameter catheter should provide a significantly higher rate of blood flow when compared to a smaller-diameter catheter. The resistance to blood flow is directly related to catheter length and inversely proportional to the fourth power of the diameter of the hemodialysis catheter. A slight increase in the inner diameter of the arterial and venous lumens will result in a large increase in the rate of blood flow through the catheter.

Blood flow through the catheter is directly proportional to the pressure generated by the blood pump across the catheter and inversely proportional to resistance in the catheter itself. High pressure generated by the blood pump can damage red blood cells, so a goal of hemodialysis catheter design has been to reduce the resistance to blood flow.[10] Elevated shear stress can also damage red blood cells, and significant levels of shear stress are associated with the distal tip of the arterial lumen.[17]

Stagnating blood in regions of elevated shear stress may induce platelet activation and thereby promote thrombus formation.

There is continuing concern that large-diameter hemodialysis catheters may have a higher rate of complications such as thrombosis and central venous stenosis. However, there have been no published studies reporting an increased incidence of complications associated with large-diameter hemodialysis catheters.

TIP DESIGN

The three most common designs for the distal tip of a chronic hemodialysis catheter are the step tip, the split tip, and the symmetric tip (Figure 2). The step-tip catheter was originally designed to minimize recirculation of blood flow between the arterial and venous lumens. However, a step-tip catheter may not function well if the arterial lumen is oriented against the wall of the superior vena cava or right atrium. The split-tip catheter was designed to decrease the positional dependence of the catheter tip. In addition, the movement of the split tip within the central veins may decrease the accumulation of pericatheter thrombus and fibrin sheath formation around the catheter tip. The symmetric tip was designed to reduce recirculation when the dialysis blood lines are connected in reverse configuration. A symmetric-tip catheter should work equally well in standard and reversed configurations. The performance of these three common catheter tip designs is often debated, and no clear winner has emerged.

The arterial and venous end holes, located at the distal tip of the catheter, are separated (1–3 cm) to minimize mixing (recirculation) of blood during hemodialysis treatment. The average recirculation for a tunneled hemodialysis catheter with the distal tip positioned in the upper right atrium should be < 5%.[10]

The majority of tunneled hemodialysis catheters have at least one side hole in the distal tip. Hemodialysis catheters are constructed of soft material that may collapse when subjected to the high negative pressures used to achieve maximal blood flow rates during hemodialysis. Aspiration (vacuum) applied by the blood pump in the hemodialysis machine may also cause the distal tip of the catheter to adhere to the adjacent vessel wall. The presence of a side hole in the catheter tip may prevent both of these phenomena (collapse of the arterial lumen and adherence of the catheter tip to the wall of the superior vena cava). A side hole can also be useful for placement of a guidewire during over-the-wire catheter exchanges. However, the presence of a side hole may promote thrombus formation and predispose the catheter tip to thrombotic occlusion. Heparin lock solution is rapidly flushed out through the side holes, leaving the catheter tip filled with blood.[18] Tal et al reported a retrospective comparison of hemodialysis catheters with side holes versus an identical hemodialysis catheter without side holes.[19] There was no significant difference in mean blood flow rates between the two catheters. The average rate of blood flow in catheters with side holes was 344 mL/min compared to an average blood flow rate of 322 mL/min in catheters without side holes. Interestingly, there was a higher infection rate of catheters with side holes. The infection rate was 2.5 infections per 1,000 catheter-days for catheters with side holes and 0.25 infections per 1,000 catheter-days for catheters without side holes.[19]

CONCLUSION

Tunneled hemodialysis catheters continue to serve an important role in our management of patients with end-stage renal disease. Unfortunately, a significant number of hemodialysis catheters are unable to sustain a sufficient blood flow rate to achieve optimal hemodialysis treatment. Failure to provide the necessary blood flow rates can limit the efficiency of the dialyzer and lead to inadequate treatment or prolonged hemodialysis treatment times. ■

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