Fluid Mechanics and Clinical Success of Central Venous Catheters for Dialysis—Answers to Simple but Persisting Problems

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ABSTRACT

Over 60% of patients initiating chronic hemodialysis in the United States have a chronic central venous catheter (CVC) as their first blood access device. Although it would be better if these patients started dialysis with fistulas, the CVC is used because it is a reliable and relatively safe method for obtaining blood access over a period of months. Drawing blood from a vein at 300–400 ml/minute is a relatively delicate and somewhat unpredictable process, and there is always a tendency for the vein wall to draw over the arterial tip and obstruct flow. Several methods have been employed to minimize this problem and maximize blood flow, and differing catheter designs have resulted. With all of the different catheter designs now on the market, it is natural to ask what is the logic of different designs. Moreover, in the absence of many direct comparative studies it is natural to ask whether one design is really better than another. There is some misinformation regarding catheter design and function. The following is a list of 10 frequently asked questions In this review, the hydraulic features of CVC are discussed and explained, and logical answers are provided for the following questions:

1. Why do “D” catheters flow better than concentric or side by side catheters?
2. Why are all catheters about the same diameter? Does making them bigger really decrease the resistance to flow?
3. Why might a split tip catheter flow better than a solid body catheter?
4. What happens to injections of lock solution at catheter volume?
5. What’s better—numerous side holes or none?
6. Why does blood rise into some internal jugular catheters over time, displacing the lock solution?
7. How can a little kink (or stenosis) decrease flow so much?
8. Where should the tips be placed—superior vena cava or right atrium?
9. Which is really better, splitsheath or over-the-wire placement?
10. Which dialysis access has a lower complication rate—CVC or arteriovenous (AV) graft?

There remain important problems with CVC for dialysis. With a few more improvements, chronic CVC for dialysis could become a painless, effective and safe long-term access for the majority of dialysis patients and acceptable as an alternative to AV grafts.

History and Challenges of Chronic Central Venous Catheters for Hemodialysis

The use of central venous catheters (CVC) for removing and returning blood during dialysis is commonplace now but in the late 1970s this concept revolutionized dialysis (1). Before the development of CVC dialysis was possible only with a catheter within an artery, either through the internal/external arteriovenous (AV) silicone shunt or through separate catheters placed into an artery and a vein and removed after each treatment. The development of CVC for dialysis was not simple, especially for single-body catheters. Drawing blood from a central vein at 200–400 ml/minute is a delicate and somewhat unpredictable process. The pressure in central veins is much lower than in arteries and vein walls are thinner and more distensible, even though the flow of blood though central veins is the same as through central arteries. Removal of blood through the ports of a CVC in a vein creates a negative pressure around these ports due to direct suction or due to the Bernoulli effect. This negative pressure can cause the vein wall to collapse around the ports and obstruct flow into the ports, even if the flow through the vein is much higher than the flow of blood through the catheter. If a fibrous tissue sheath forms around the catheter and reaches the tip or if clots form around the tip, the entry port to the catheter

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becomes smaller and the velocity of blood flow is increased. The increased blood velocity creates a greater negative pressure around the ports, and increases the tendency to pull the vein wall over the tip.

There are four solutions to the problem of providing sufficient blood outflow through dual-lumen CVC for dialysis:

- Place the removal and return lumens within the right atrium, where the tips cannot rest against a venous wall and only one lumen usually rests against the atrial wall.
- Position the catheter with the removal lumen on the inside of the catheter curve, positioning this lumen away from the vein wall.
- Use a large catheter so that the removal lumen cannot be blocked by a small clot or a small amount of fibrous tissue.
- Provide multiple blood entry ports in all directions around the circumference of each catheter tip, so that some of the ports are always facing away from the vein wall.

There are problems and limitations of each of these approaches. Positioning the tips of the removal and return lumens at the middle of the atrium is somewhat difficult, especially as the relative positions of the catheter and the heart change when the patient stands up after lying on the procedure table. Positioning the catheter so that the removal lumen is on the inside of the catheter curve is not always easy, as the catheter course through the subcutaneous tissue and central veins is rather complex and tortuous. Placing a larger catheter is always more difficult and somewhat more traumatic than placing a smaller catheter, especially if the larger catheter is not round in shape. Providing multiple side holes in all directions around the catheter tips requires that two catheters be placed, or that one catheter must separate into two separate tips. Side holes in a catheter also have disadvantages. If they are too large or too many, blood will quickly flow through the tip of the catheter after placement and between uses, removing catheter lock solutions and promoting clotting at the tip. If the side holes are too small or too few then blood will flow in and out only through the tip of the catheter, thus diminishing any advantage of the side holes.

Central venous catheters for dialysis are classified into either "acute" or "chronic" catheters, depending on whether the catheters are expected to be used for only several days or months to years. Acute CVC are designed to be placed with a minimum amount of effort. Generally, acute CVC for dialysis are relatively rigid, pointed catheters with a conically shaped tip and central lumen so that the catheter can be advanced into the vein directly over a guidewire. The guidewire is inserted through a needle placed into a vein, and the point of the catheter follows the guidewire while the catheter body dilates the entry site while the catheter is advanced into the vein. Acute CVC for dialysis have no subcutaneous cuff or locking device.

Chronic CVC for dialysis are soft, blunt-tipped catheters, and have a subcutaneous "cuff" for tissue ingrowth or a plastic "grommet" to immobilize the catheters below the skin surface. Chronic CVC are generally placed through internal jugular veins into the superior vena cava with the goal of placing the tips of the catheter at the junction of the SVC and the right atrium. Alternative venous access points are external jugular veins, subclavian veins, and femoral veins. Due to their blunt shape chronic CVC have traditionally been placed through a "splitsheath," which is a cylindrical thin-walled plastic device advanced into the vein over a dilator. The dilator has a central lumen that follows the guidewire. The guidewire and dilator are then removed and the splitsheath opening is closed with a finger to prevent excessive bleeding. The catheter is then inserted through the splitsheath into the central vein. The splitsheath is split along two preformed grooves, and the halves are retracted around the catheter, leaving it in position within the central vein. More recently, techniques have been developed to allow placement of chronic CVC to be performed over a guidewire placed through a previously dilated tract, in a manner similar to acute CVC for dialysis (see below).

Chronic CVC for dialysis have a subcutaneous tunnel leading from the vein insertion site to a distant exit site. A polyester felt (Dacron^{TM}, Dupont, Wilmington, DE) cuff (or sometimes a solid plastic grommet) attached to the catheter fixes the catheter in position and prevents bacteria at the exit site from migrating around the catheter. The cuff also serves as the outer limit for the fibrous tunnel that develops around the catheter from the central vein. The tunnel is similar to a vein wall and is contiguous with the internal jugular vein (or other vein of insertion). The tunnel stops at the Dacron cuff where it melds into the fibrous tissue surrounding the cuff. Without the cuff, as in acute catheters, this tunnel continues all of the way to the skin exit site over time, creating potential for back-and-forth movement of the catheter and potential for peri-catheter bacterial migration around the catheter. Canaud devised a catheter system composed of two 10 French catheters, each placed into the vena cava and with tips leading to the right atrium. Flow rate was excellent over many months of use (2,3). Tesio added subcutaneous cuffs and the catheter became more popular. More recent versions of the Canaud catheters have included a subcutaneous plastic grommet to fix the catheter limbs in place, and the Schon catheter has a similar device.

Placing a chronic CVC for dialysis requires additional skill and takes 10–20 minutes more time than placing an acute CVC. With proper equipment the placement can be made in the ICU setting or in a procedure room with suitable patient monitoring. Placement of catheters into previously un-cannulated right internal jugular veins can be made without fluoroscopy, though fluoroscopy is still highly recommended. Tip position can be obtained in the right atrium by using external landmarks and careful physical examination (tip of catheter 2" above the bottom of the sternum or the level of the diaphragm as determined by percussion). Placing one chronic catheter can often provide access throughout the entire course of acute renal failure episode and avoid the need for several acute catheter placements and replacements. Using a chronic CVC for acute dialysis provides: higher blood flow rates, longer duration of use, diminished risk of infection, and less trauma to veins over the course of treatments (due to use of only one soft catheter versus many stiff acute catheters). The placement of a chronic CVC in patients with acute renal failure can minimize physician work, maximize dialysis efficiency and minimize catheter complications. One situation in which an acute CVC should be placed is in patients with suspected septicemia. In these patients placing an acute CVC for dialysis until the septicemia is cleared is a logical choice.

Over 60% of patients initiating chronic hemodialysis in the US have a chronic CVC as their first blood access device (4). There is no doubt that these patients would have been better served if an AV fistula had been placed some months earlier and if it were fully developed and functional when dialysis was implemented. In all of the single-minded enthusiasm of the Fistula First program, we sometimes forget that chronic CVC are used in patients starting dialysis because they offer some advantages. As summarized by Beathard (5), advantages of tunneled CVC for dialysis are noted in Table 1.

Features for Successful Function of Chronic CVC for Dialysis

The requirements for successful function of chronic CVC for dialysis are numerous:

- Provision of high blood flow rates at moderate pressure drops, consistently throughout each dialysis, with few instances of outflow failure and pressure alarms.
- Adequate hydraulic function regardless of patient fluid status (even when volume depletion decreases the size and stiffness of the SVC).
- Minimal trauma to the vein intima to avoid thrombosis and venous stenosis.
- Resistance to occlusion by fibrous sheathing.
- Prevention of bacterial migration around the catheter after placement.
- Avoidance of contamination of the catheter lumen.
- Avoidance of seeding of the catheter during bacteremia or after tip contamination allowing the catheter to remain in place with proper antibiotic treatment of bacteremia (systemic and local, by lock).
- Avoidance of clotting at the tip or within the catheter.
- Biocompatibility of the catheter surfaces, avoiding removal of white cells or platelets.
- Avoidance of lumen collapse under negative pressure.
- Avoidance of kinking of catheter segments at points of bending.
- Physical strength and integrity to avoid breaks or disconnections of any component (ability to replace broken connectors is desirable).
- Resistance to deterioration of the catheter material by antiseptic agents that might be applied at the skin exit site.
- Placement procedures with minimum trauma, difficulty and risk.
- Radiopaque appearance on X-ray, for evaluation of location during placement and after use.

The evolution of chronic CVC for dialysis is a history of new ideas being applied to solve these requirements for CVC (6). Obviously, no catheter yet designed has satisfactorily met all of these requirements.

Designs of Chronic CVC for Dialysis

Figures 1–6 include schematic diagrams of chronic CVC used for dialysis from the 1960s to the present. The design and function of these catheters is described below, in order of increasing complexity of the devices:

A. Canaud designed two 10 French catheters for hemodialysis designed to be placed side by side through the jugular vein and superior vena cava into the right atrium (2,3). Each catheter has side holes arranged in a spiral around the tip of the catheter. The catheters initially had no cuffs, but more recently are secured by a subcutaneous grommet (a plastic component connecting the two catheters). Tesio added subcutaneous Dacron® cuffs to each of these catheters, to fix the catheters in position in the subcutaneous tract (7,8). Canaud and Tesio catheters have been used for dialysis access for months to years, though they may require radiologic procedures to restore patency. The largest resistance to use of the Canaud and Tesio catheters was from surgeons and radiologists who did not wish to perform two separate IJ punctures for guidewire placement, two catheter insertions through splitsheaths, and two separate tunneling procedures.

B. Mahurkar designed a chronic CVC of soft materials and blunt tips and double-d blood flow lumens (9). Each D-shaped lumen ended in a single port. The arterial lumen entry port was

TABLE 1. Advantages and disadvantages of tunneled central venous catheters for dialysis

Advantages	Disadvantages
Universally applicable (functional in nearly 100% of patients)	High morbidity caused by thrombosis and infection
Ability to insert into multiple sites	Risks of permanent central venous stenosis or occlusion
Maturation time not required	Discomfort and cosmetic disadvantage of external appliance
Venipuncture not required	Lower blood flow rates, requiring longer dialysis times
No hemodynamic consequences (no CP recirculation)	
Ease and low cost of placement and replacement	
Ability to provide access over a period of months	
Ease of correcting thrombotic complications	

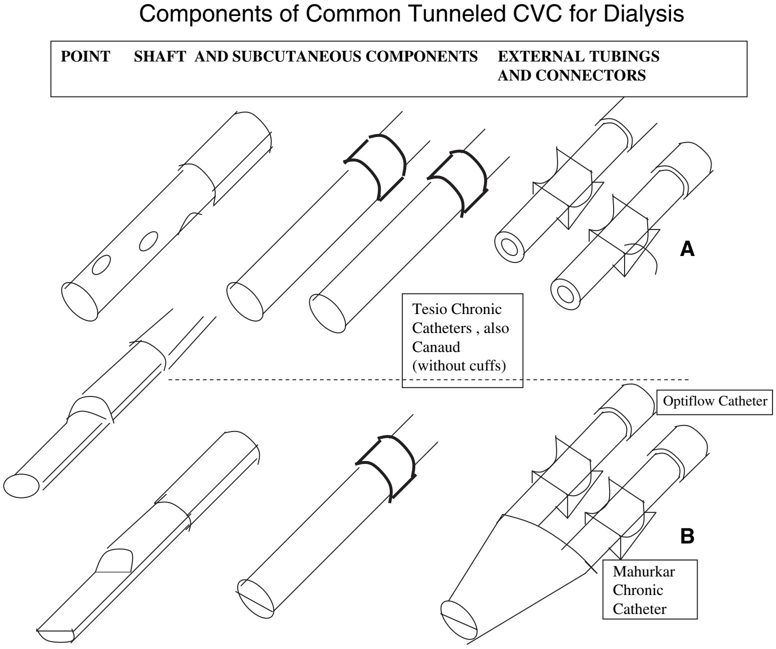


FIG. 1. Single body step-tipped CVC for dialysis.

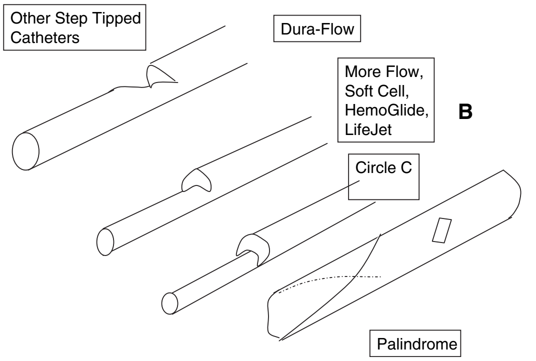


FIG. 2. Other single body designs.

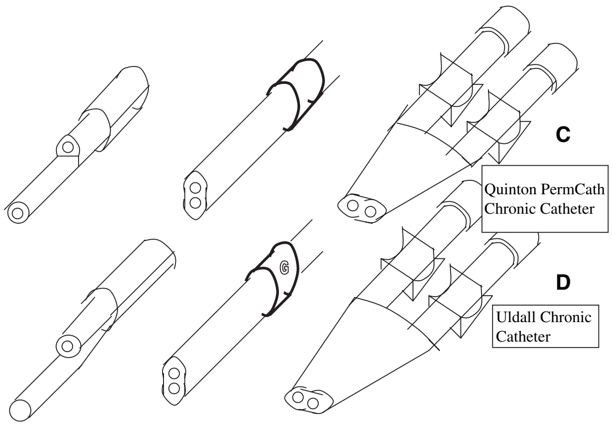


FIG. 3. Oval body designs.

about 3 cm proximal to the venous port. The double-d design allowed a relatively low hydraulic resistance, similar to the Tesio and Canaud catheters. A subcutaneous cuff fixed the catheter in position within the subcutaneous space. The catheter was placed through a single splitsheath into position with tips within the right atrium. There have been several recent variations on double-d, step-tipped catheter design. One is the Optiflow catheter, which has a return lumen that is somewhat round in shape, and a removal lumen that is more C-shaped. This same general design is included in the LifeJet, Circle C, More-Flow and HemoGlide catheters. Another variation is the Dura-Flow catheter. In this catheter the arterial lumen is back-cut, creating a shape which may be less likely to be blocked by fibrosis or clot. The venous lumen also enlarges from D-shape to circular, resulting in a larger end port also making it somewhat more resistant to blockage. The Palindrome catheter is a double-d catheter with both lumens having the same length, but with oppositely angled long ports.

C. Quinton designed the PermCath dual lumen chronic catheter, an oval-shaped chronic catheter of about 20 French circumference and including two cylindrical 8 French lumens (10,11). The tip was cut to create two entry ports the shorter being the arterial and the longer being the return lumen. The catheter was the first chronic catheter for dialysis, and the first hemodialysis catheter to employ a subcutaneous cuff, yet it is still being placed and used. The catheter is placed through an oval-shaped splitsheath that is advanced over a guidewire and an oval-shaped, pointed dilator. It is one of a few chronic CVC for dialysis made of silicone. An adaptation of this shape is used in the Niagara acute catheter, having a preformed 180 degree

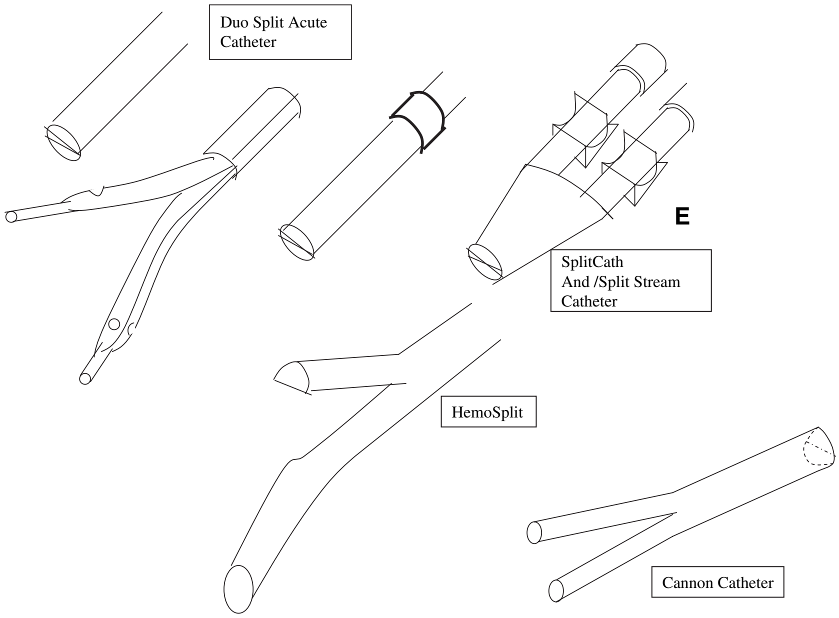


FIG. 4. Split-tip designs.

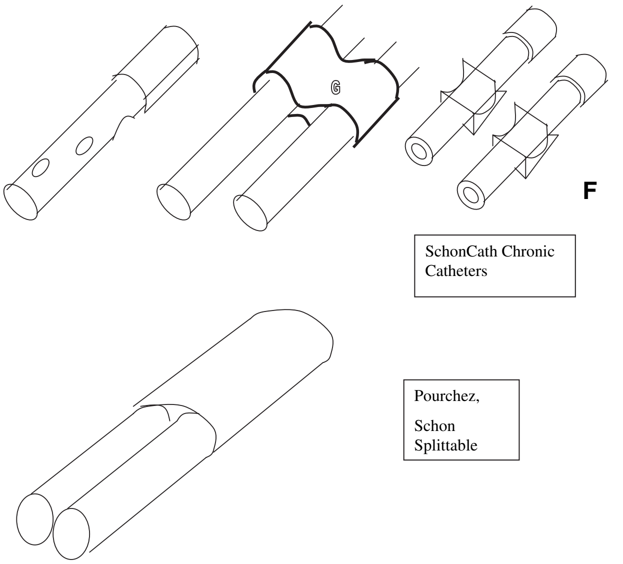


FIG. 5. Dual catheters.

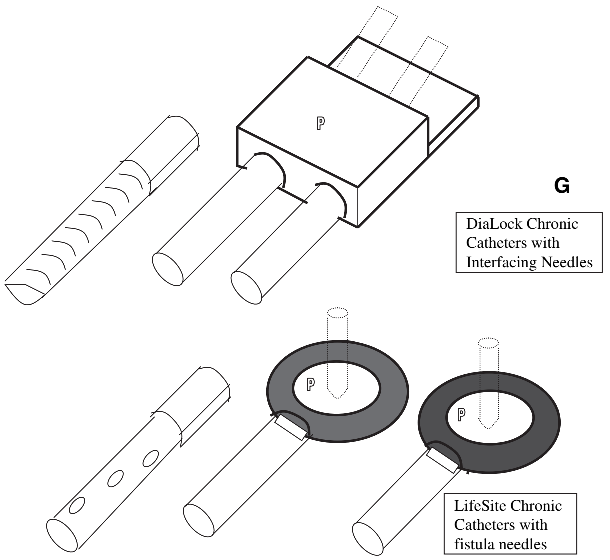


FIG. 6. Subcutaneous ports with dual catheters.

bend to conform over the clavicle and point downward.

D. Uldall created a chronic catheter with roughly the same body shape as the Quinton PermCath, but with two separate tips and a thin-wall and collapsible return lumen. The collapsible return lumen allows the distal portion of the device to be inserted through a cylindrical splitsheath, like most chronic catheters, instead of an oval-shaped splitsheath. The mid-body of the catheter is oval shaped, and advances into the vein after the splitsheath is removed.

The Ash Split Cath chronic catheter has a double-d configuration in the mid-body, but separates into two separate distal tips, each with side holes in all directions (6,12). One goal of having two tips was to combine the simplicity of placement of a single-body cylindrical catheter with the low hydraulic resistance of double-d lumens and the excellent hydraulic properties of blood flow through holes on all sides of each distal limb (similar to the Tesio catheters). Another goal was to purposefully separate the limbs of the catheter, making them softer and more flexible and thus diminishing and distributing contact pressure of the catheter limbs against the wall of the vena cava (also similar to Tesio catheters). A unique feature is the step-down in diameter at the tip of the removal and return limbs. This step down slightly increases the pressure drop at the tip, assuring that blood will enter or exit through all of the side holes, at almost any blood flow rate (in comparison with the Tesio catheter which passes blood through the side holes only when flow is over 300 ml/minute). The catheter is tunneled from the exit site through the primary incision with the tips together. The tips are split to the length desired, the cylindrical splitsheath is advanced into the superior vena cava and the dilator removed. The tips are grasped together and advanced through the splitsheath, and the splitsheath removed.

Overall hydraulic function of the catheter is similar to the Tesio and Canaud catheters, with somewhat higher flow and less recirculation that other single-body catheters (13,14). The Split Cath II and later versions are constructed of Carbothane. Variations on the split tip design include the Cannon catheter which has a double-d shaped body ending in two separate tips, similar to the Split Cath. One major difference is that the tips are preformed to separate at an angle of about 30 degrees. This pre-set separation requires that the catheter tips be placed within the right atrium rather than "at the junction of the superior vena cava and the right atrium" (as stated in the product literature of most chronic CVC). This catheter is tunneled from inside-out, interfacing with a hub having two d-shaped stainless connectors. The HemoSplit catheter also has preformed split cylindrical ends leading from a double-d body, but the degree of separation of the tips is much lower, about 10 degrees. The venous end is larger than the arterial end but smaller than the body of the catheter.

E. The SchonCath includes two catheters with intravenous and subcutaneous portions identical to the Canaud catheters and Tesio catheters (but without the subcutaneous cuffs). Instead of cuffs, there is a plastic grommet that fixes the two catheters together. Initially this grommet was placed in the subcutaneous space below the primary incision but more recently the grommet has been modified to enter the jugular vein as an oval shape linking the two catheters. The internal catheter portions are placed into the central vein through an oval splitsheath placed over guidewire and dilator. The grommet is advanced into the hole in the internal jugular vein to block bleeding through the hole. The external portions of the catheter are tunneled independently to exit sites from the primary incisions. Hydraulic function and long-term results of function of this catheter are similar to the Canaud and Tesio catheters. The Pourchez catheter also has two separate Tesio-like tips and like the Schon catheter has a cylindrical shape of the part entering the vein. However, like the Uldall or Quinton catheter the cylindrical shape continues through the subcutaneous course through the exit site.

F. Two subcutaneous ports have been developed for chronic CVC catheters. Both had separate arterial and venous catheters, similar to Canaud catheters but without any side holes. Neither is currently available for the market. The DiaLock catheter had a single block to receive blunted needles through the skin, connected to wire-reinforced catheters with a "fish mouth" end and no side holes. The LifeSite had separate ports to receive sharp needles and catheters with side holes.

Material/Design Requirements for Successful Chronic CVC for Dialysis

The materials used for chronic CVC for dialysis have evolved over the years as more options have existed, but the requirements have stayed the same or become more stringent. In some ways, requirements are intrinsically contradictory:

- *Thickness*: To provide maximal blood flow, the inner lumens of CVC for dialysis must be as large as possible, while the overall size as small as possible. Therefore, the catheter walls should necessarily be as thin as possible.
- *Strength*: The body of the catheter, hub joints, and connectors and tubing clamp segments must be strong enough to avoid cracks or breaks on the body of the catheter, at the hub joints, or in the connectors or tubing clamp segments. This requirement has become more stringent as chronic catheters are used for longer periods of time (up to several years for some chronic CVC).
- *Flexibility*: Chronic CVC have a relatively straight course within the vein, but bend fairly sharply in the subcutaneous tunnel. Also they remain within the SVC or femoral vein for a long time, with some continued pressure on the vein wall. Therefore the body of the catheter must have flexibility. The tips and material of the catheter should be as soft as possible.
- *Rigidity*: During placement, while the catheter is relatively straight, it must be rigid enough to slide over a guidewire (for acute CVC or over-the-wire placement of chronic CVC) or through a splitsheath (for chronic CVC). Therefore there is a limit to the intrinsic softness of a catheter. Some catheter materials such as polyurethanes have thermoplastic qualities, so that they have some rigidity during placement and are softer when they reach body temperature. Catheters must also be rigid enough to avoid collapse of the removal lumen under negative pressures up to 350 mmHg.
- *Resistance to crimping*: When chronic CVC are bent, they must resist the tendency to have a lumen collapse or "crimp" or "kink" at the apex of the bend in the subcutaneous tunnel. The solution is partly solved by materials; generally softer materials have less tendency to crimp. Design is also important; oval-shaped catheters bend naturally without kinking in the direction perpendicular to the flat surface, double-d catheters configurations bend easily in the direction perpendicular to the flat internal wall, and relatively thick walls in cylindrical catheter limbs help prevent bending.
- *Moldability*: With the increasing complexity of CVC designs, it has become necessary to change diameters and shapes of the body components after the body of the CVC is extruded. This requires that the material is moldable under heat or stress, to obtain the desired shape.

- *Bondability:* The various components of a CVC must all be glued or welded together to create a catheter with overall integrity. Materials that dissolve into solvents allow solvent glues to make the strongest bonds. Materials that can be heat welded can also create solid bonds. Bondability requires that connectors be made of plastic materials rather than metal, in general.
- *Conformance to the body shape*: At the skin surface, the catheter usually penetrates the skin at some upward angle to the skin surface. The external portions of the catheter are sutured or taped to the skin surface, meaning that there must be some degree of bend at the exit site. Further, the external connections and extension tubings must be bandaged next to the skin. Some catheter designs include increased material at the skin exit site (such as the Split Cath XL). Some acute catheters have a 180-degree bend preformed in the body of the catheter to bend over the clavicle, or a 150-degree bend preformed into the clamping segment. The materials chosen must have the capability to be formed into these relatively permanent shapes.
- *Effective clamping and expansion of extension tubings*: The extension tubings of chronic CVC for dialysis must remain clamped between dialysis procedures, to serve as a second-line defense against bleeding or air passage in case the cap comes off of the connectors. The tubings must also be clamped whenever the cap is removed for connection to dialysis lines or injection with a syringe. During dialysis however the tubings must expand to allow passage of blood and avoid collapse (especially on the arterial limb). Rotating the position of the clamp on the tubing is helpful, but most extension tubings still develop a "set" over time and require some squeezing and coaxing to open properly. Some materials like silicone function better in this regard than polyurethane.
- *Resistance to dissolution by chemicals*: For almost every material there is a nemesis, a chemical that will dissolve the material. Stringent chemicals are often used as antiseptics at the exit site and on catheter hubs. Catheters should be created of materials that resist dissolution by commonly used antiseptics such as alcohols, iodine, or peroxide.
- *Radiopacity*: In order for plastic materials to be visualized on X-ray they need to contain some elements with high atomic density to be seen on X-ray. Barium is the most commonly added component, which is mixed in with the plastic before extrusion. It is the barium which makes the catheter materials white rather than nearly clear, as natural silicone and polyurethane). If too little barium is added, the catheter is barely visible. If too much is added then the structural integrity and surface properties of the materials are affected.

The materials used for acute and chronic CVC for dialysis have included:

- Polyethylene
- Teflon
- Silicone
- Polyurethane
- Carbothane (polyurethane/polycarbonate copolymer)

Polyethylene is intrinsically somewhat rigid. Therefore, it was well suited for acute CVC that require relative rigidity and a pointed tip to follow over a guidewire, such as Shaldon catheters. However, in more complex forms it becomes too rigid, it is difficult to glue to dissimilar materials (though it can be heat welded), kinks when bent and is difficult to extrude with thin walls. Its stiffness is too great for safe use in any chronic CVC.

Teflon is also quite rigid, and has been used for over-the-guidewire acute CVC. However, it cannot be molded after extrusion and is difficult to glue to any material, including Teflon. It is not used in any CVC for dialysis at this time, though it is used in peripheral IV catheters.

Silicone is intrinsically a soft and flexible material, an advantage for chronic CVC. However, to have sufficient strength it must be somewhat thick. Silicone catheters generally require a thicker wall than catheters of other materials to avoid lumen collapse, provide some rigidity and avoid kinking. Silicone is easily and strongly glued to other silicone components by solvent glues, but difficult to glue to other materials. It is used in several chronic CVC, but less than other materials. Silicone is greatly weakened by iodine, but is only slightly degraded by povidone–iodine solutions or to peroxide. It is compatible with most alcohols and ointments.

Polyurethane can be created in forms that are fairly rigid or soft and flexible. It has a high material strength, so that catheter walls can be made quite thin with preservation of some rigidity in the longitudinal axis and avoidance of lumen collapse at high negative pressures. Polyurethane has thermoplastic properties, becoming softer in at body temperature, especially Tecothane® (Noveon, Cleveland, OH) a mixture of polyurethanes of differing molecular weight. Polyurethane can be easily bonded to several types of plastic materials, and has excellent moldability. Most CVC today are made from polyurethanes. Polyurethane's nemesis is alcohol. Ointments containing polyethylene glycol (such as Mupirocin® Ointment or Crème or povidone–iodine ointment, GlaxoSmithKline, Middlesex, UK) can weaken the catheter considerably. One antibiotic ointment that can safely be used at the exit site of polyurethane catheters is Neosporin® (J&J, New Brunswick, NJ), which has a petroleum base.

Polyurethane/polycarbonate copolymers (such as Carbothane®, Noveon) have all of the advantages of polyurethane, but with a greater strength. Catheters created from copolymers can have thinner walls and the same physical properties as catheters made from polyurethane. The copolymer materials are resistant to iodine, peroxide, and alcohols. Copolymer materials will be used for construction of most chronic CVC in the future, and possibly also acute CVC.

Merely inspecting a catheter, it is difficult to determine the material from which it is made. It is important to have a list of chronic CVC used in a dialysis unit, their material and what chemicals must be avoided. For current CVC used for dialysis the following table elucidates the materials of construction and incompatible chemicals:

Material	Incompatible chemicals
Polyurethane	Alcohols including isopropyl alcohol and ointments containing polyethylene glycol (PEG) such as mupirocin ointment and crème and povidone–iodine ointment. Povidone–iodine solution is OK. Possible deterioration with chlorhexidine
Silicone	Tincture of Iodine. Potential degradation by povidone–iodine solution over long times. Degradation in some patients with ointments
Carbothane	None known

CVC—What We Do Know?: Answers To Some Questions Relating to CVC Flow and Longevity

With all of the different catheter designs now on the market, it is natural to ask what is the logic of different designs. Moreover, in the absence of many direct comparative studies it is natural to ask whether one design is really better than another. There is some misinformation regarding catheter design and function. The following is a list of 10 frequently asked questions:

1. Why do "DD" catheters flow better than concentric or side by side catheters?
2. Why are all catheters about the same diameter? Does making them bigger really decrease the resistance to flow?
3. Why might a split tip catheter flow better than a solid body catheter?
4. What happens to injections of lock solution at catheter volume?
5. What's better—numerous side holes or none?
6. Why does blood rise into some IJ catheters over time, displacing the lock solution?
7. How can a little kink (or stenosis) decrease flow so much?
8. Where should the tips be placed—SVC or right atrium?
9. Which is really better—splitsheath or over-the-wire placement?
10. Which dialysis access has a lower complication rate—CVC or AV graft?

Before beginning to answer these questions, it is helpful to define a term. "hydraulic resistance" is a measure of the ease (or difficulty) of passing blood through a confined space (like a catheter or a needle). Hydraulic resistance is defined by the relationship between pressure drop and flow, data that is easily obtained from a standard dialysis machine. For a dialysis catheter, assuming that central venous pressure is about zero, the arterial pressure or venous pressure recorded is essentially the pressure drop. Figure 7 demonstrates the pressure drop versus flow for the venous limb of Split Cath catheters, for all patients in our dialysis unit with this type of CVC. The arterial pressure curve looks essentially the same, except that the pressures are negative. The slope of the line is the hydraulic resistance. For comparison purposes, Fig. 8 is a similar graph of venous pressure versus flow for patients with 15 gauge needles and an AV graft. Realizing that some of this pressure is due to intrinsic pressure within the graft, the slope of the line is essentially the same as for the CVC. Thus, CVC have essentially the same hydraulic resistance as a graft and associated veins in our unit, and comparable flow rates. The hydraulic resistance at full blood flow is not significantly different between the Split Cath and the grafts and fistulas in our unit ($p > 0.10$). Further, the average flow rates automatically recorded during hemodialysis with the Split Cath were not significantly different from blood flow rates during dialysis with grafts or fistulas ($p > 0.10$) (12).

KDOQI guidelines on vascular access from NKF state in Guideline 30, "Cuffed catheters are associated with lower blood flow rates compared to AV access" (15). The five references given for this conclusion are all from 1996 or before. If fully studied now, it is likely that the blood flow from catheters would be closer to those of

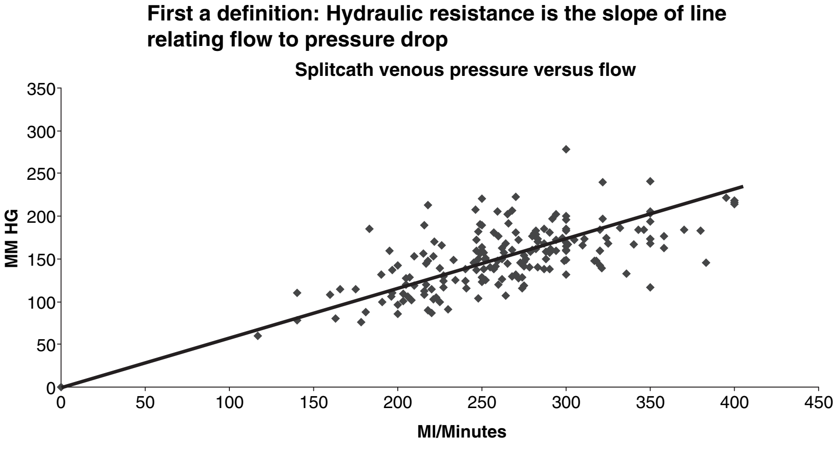


FIG. 7. Venous pressure versus flow for typical CVC for dialysis.

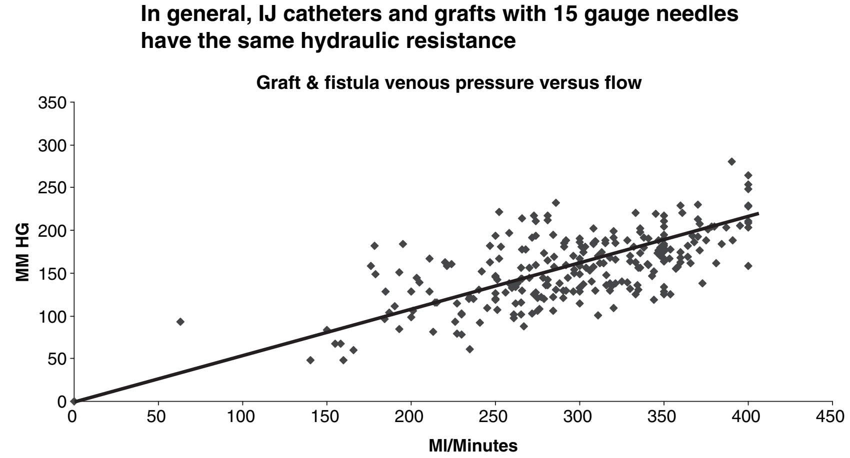


FIG. 8. Venous pressure versus flow for 15-guage needle in fistula or graft.

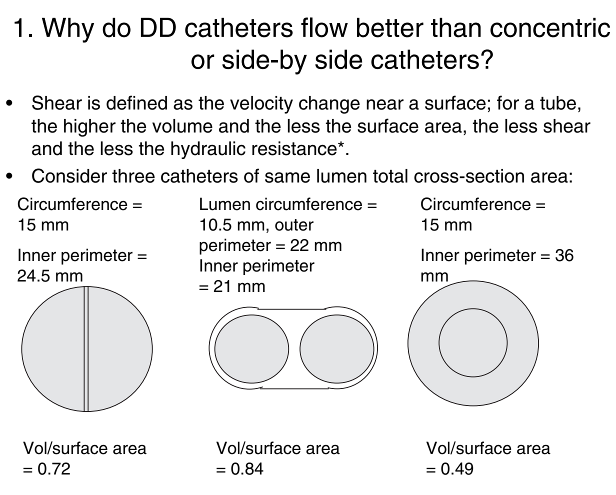
fistulas and grafts, unit wide. Now for answers to our questions above:

1. Why Do DD Catheters Flow Better Than Concentric or Side-by-Side Catheters of the Same or Larger Size?

Restated, why do most of our CVC catheters have lumens that are shaped like two "D" letters, back to back? The reason is that this catheter shape provides a high lumen volume, low surface contacting the blood, and a modest total circumference. The volume-to-surface ratio determines "shear rate" within the catheter, which means the velocity of blood near the inner catheter surface. The higher the volume and the lower the surface area of the catheter, the less the shear rate and the less the hydraulic resistance (16). Figure 9 gives examples of three catheters; round with DD lumens, oval with side by side circular lumens, and round with concentric lumens. All of the catheters have the same cross-sectional area for the arterial and venous lumens. For the DD catheter the circumference is 15 mm (15 French) and the blood contacting perimeter on the inside of the lumens measures 21 mm. For the concentric catheter, the circumference is also 15 mm but because the wall of the venous lumen contacts blood both on the inside and outside of this lumen, the total inner perimeter is 36 mm. The oval catheter has an inside perimeter slightly less than the DD catheter, but the outside perimeter is 22 mm (22 French). Comparing volume/surface ratios, the DD catheter is better than the concentric catheter. The oval catheter actually has the highest volume/surface ratio, but also has a considerably larger outside perimeter.

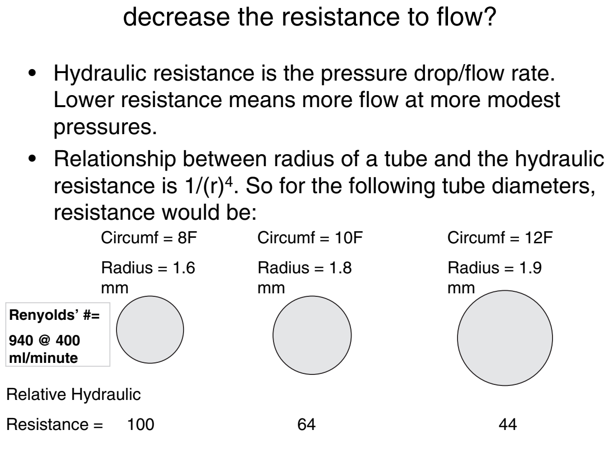
2. Why Are All Catheters About the Same Diameter? Does Making Them Bigger Really Decrease the Resistance to Flow?

As described above, hydraulic resistance is the pressure drop/flow rate; lower resistance means more flow at modest pressures. The relationship between the radius of a tube and the hydraulic resistance is $1/r^4$. Consider three cylindrical catheters with radii that seem pretty close, 1.6, 1.8 and 1.9 mm and very thin walls (Fig. 10). The resultant outer perimeter is 8, 10 and 12 mm (or French), respectively, and the relative hydraulic resistance is 100, 80 and 44, respectively. Thus, increasing the radius only by 3/16 cuts the hydraulic resistance in more


1. Why do DD catheters flow better than concentric or side-by side catheters?

- Shear is defined as the velocity change near a surface; for a tube, the higher the volume and the less the surface area, the less shear and the less the hydraulic resistance*.
- Consider three catheters of same lumen total cross-section area:

FIG. 9. Explanation of Question 1.


2. Why are all the catheters about the same diameter? Does making them bigger really decrease the resistance to flow?

- Hydraulic resistance is the pressure drop/flow rate. Lower resistance means more flow at more modest pressures.
- Relationship between radius of a tube and the hydraulic resistance is $1/(r)^4$. So for the following tube diameters, resistance would be:

FIG. 10. Explanation of Question 2.

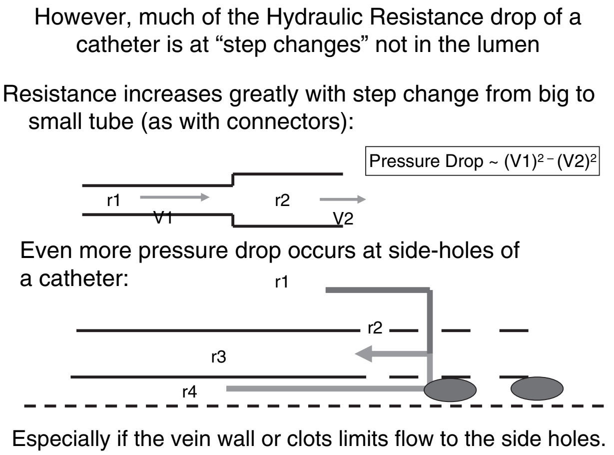


FIG. 11. Explanation of Question 2, continued.

than ½. Of course, shear rate increases with the smaller catheter and this is the reason for the higher hydraulic resistance. Reynolds number indicates the relationship between kinetic forces and viscous forces, and is therefore related to shear rate. For blood at flow rate of 400 ml/minute in a catheter with radius of 1.6 mm, the calculated Reynolds number is 940. Turbulence begins at a Reynolds number of about 2300. So, relatively small catheters of 8 French size running at 400 ml/minute operate at Reynolds number close to causing turbulence. Add some restrictions at the tip of an 8 French lumen and the resulting turbulence can cause hemolysis and other blood changes.

Making catheters with larger ID clearly decreases the hydraulic resistance and should make them flow better. However, up to ½ of the overall hydraulic resistance of a catheter is at step changes in diameter such as at the tip, extension sets and connectors. The exact pressure drop at a step change in diameter is related to the difference in $(\text{velocity})^2$ of the blood at each portion of the connection and is also increased by any change in direction of the blood (Fig. 11). A huge change in diameter occurs when blood leaves the vein and enters the tip or side holes, and another change occurs when blood enters the body of the catheter If clots or a sheath partly obstruct the catheter openings then the changes in blood velocity become accentuate. When catheters that once flowed well begin to lose flow rate, flow path blockage at the tip is the usual cause. . Making catheters larger also usually means that the tip port is also larger. This can make the catheter flow better initially and be less affected by clots or sheathing at the tip.

3. Why Might a Split Tip Catheter Flow Better Than a Solid Body Catheter?

DD catheters with a single body have lumens or side holes on one side of the catheter only, as shown in Fig. 12. If these lumens lie adjacent to the vein wall, then the soft vein wall will tend to occlude the ports, especially on the arterial side. If clots or fibrous deposits or fibrous sheath develop, these ports become even more easily occluded. This is the reason that during placement efforts are made to position the catheter to make the arterial port face away from the wall and towards the center of the vein. Of course these efforts are not always successful, especially if the venous pathway is tortuous (as with left-sided IJ catheters).

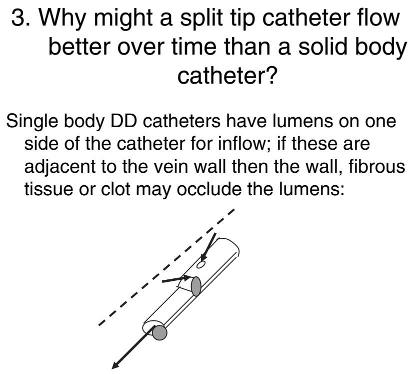
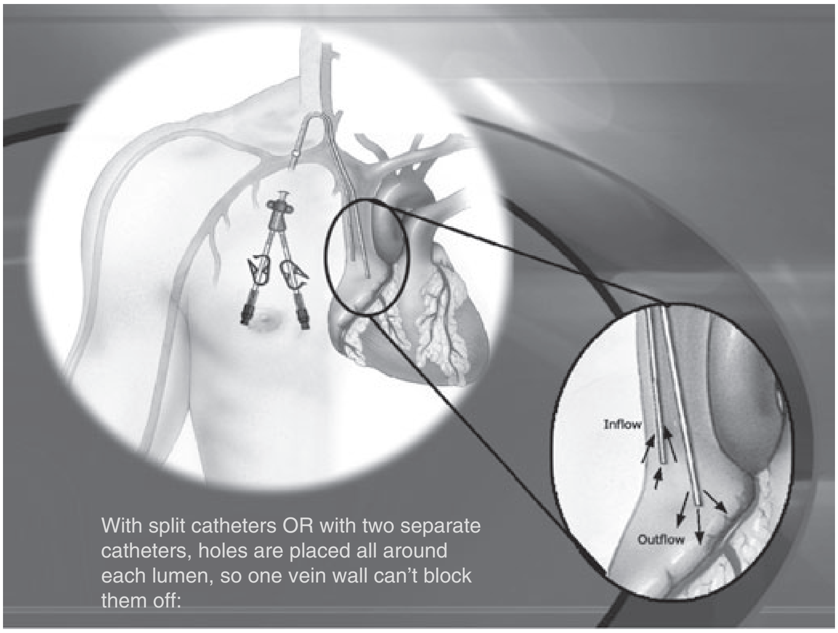


FIG. 12. Explanation of Question 3.

With two separate IJ catheters or split tip catheters it is possible to have side holes all the way around each catheter lumen. This means that even if one limb lies against the vein wall, there are still some side holes that are still facing the lumen. Some of the side holes are of course likely to become occluded, but others are open (Fig. 13). Other effects of splitting the tips include making each limb "floppier" and may result in less irritation of the vein wall. A step-down in diameter at the tip of the catheter forces blood flow through the side holes, both on the arterial and venous limbs (Fig. 14). In fact the catheter often works well even if the tip is clotted. Flow through the side holes may help to diminish sheathing at the location of the holes. The tapered tips make insertion over a guidewire easier using the "weave" technique (Fig. 15).

So, which is better—catheters with a split tip or a single body? There are several ways to answer this question. Trerotola et al. performed a randomized study of 12 ESRD patients receiving 14 F Split Cath catheters placed versus 12 patients receiving 13.5 F Hickman catheters (13). Weekly for 6 weeks the blood flow rate was measured using Transonic flow monitors, while the blood pump was set at speeds of 200, 300, 350, 400 and as high as possible with sustained flow. The measured blood flow rate at the highest pump setting was 422 ± 12 ml/minute for the Split Cath and 359 ± 13 for the Hickman ($p < 0.005$) (Fig. 16). Recirculation was significantly less at all pump settings for the Split Cath patients ($p = 0.01$–0.06), though for both catheters it remained below 6% (Fig. 17). One Split Cath failed at day 7 with poor flow and was removed and a fibrous sheath was noted (it was not stated whether the patient had previously had an IJ catheter for dialysis). Of patients with Hickman catheters 38% required urokinase infusion during the study. Three insertion complications occurred with the Split Cath group, two catheters with kinking (improved with manipulation) and two with bleeding from the catheter exit site (resolving with compression, occurring after heparin loading of the catheter).

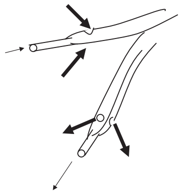


With split catheters OR with two separate catheters, holes are placed all around each lumen, so one vein wall can't block them off:

FIG. 13. Explanation of Question 3, continued.

How about long-term? Any advantages of Split-tip catheters?

- Split of catheter within the IJ/SVC may make the tips "floppier" causing less irritation of the vein wall, resulting in less sheathing
- Step-down of the Split-Cath forces blood through the side holes (in and out), possibly diminishing clotting.

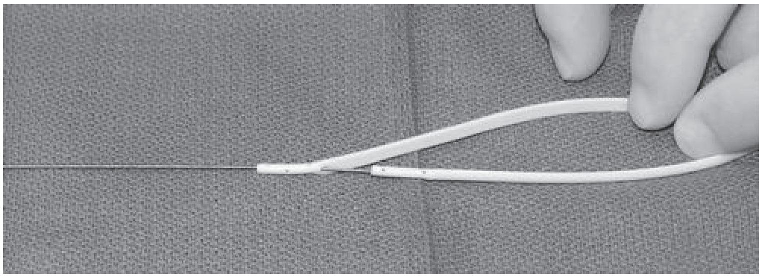


Also makes threading over a guidewire easier…

FIG. 14. Explanation of Question 3, continued.

Long-term functional survival of CVC is probably the most significant data regarding success of their use. K/DOQI Guideline 37 references studies indicating 1 year survival of CVC for dialysis of 30–65% (15). One problem with such studies is a lack of firm definitions for patency failure or catheter-related blood stream infection (CRBSI) to justify removal of the catheters, and most patients end studies like these with functional catheters. In the Trerotola study above (13), the Split Cath had slightly better 6 week survival than the Hickman catheter, as shown in the table below. Richard et al. performed a randomized study comparing the Split Cath, Opti-Flow and Tesio catheters in 113 placements in ESRD patients (17). Maximum (effective) blood flow rates were compared between the catheters immediately after placement, and 30 and 90 days after placement. Blood flow rate tended to be higher with the Split Cath but results were not significantly different. Failure-free survival of the catheters was analyzed with an average follow-up of 120 days. Although statistically not significant, the predicted lifespan appeared higher for the Split Cath and Tesio catheters than the Opti-Flow. Placement complications occurred only with Tesio and Opti-Flow catheters. These results are shown in the table below and in Fig. 18 (17).

Trerotola and Kraus also performed a randomized study comparing the Split Cath and Opti-Flow catheters in 132 placements in ESRD patients (18). Complications during placement were no different for the two catheters and ranged 15–17% (mostly, kinking). Opti-Flow



"Over the Guidewire" Weave Concept
Drs. Jack Work and Donald Schon

FIG. 15. Placement of split-tip catheter over a single guidewire.

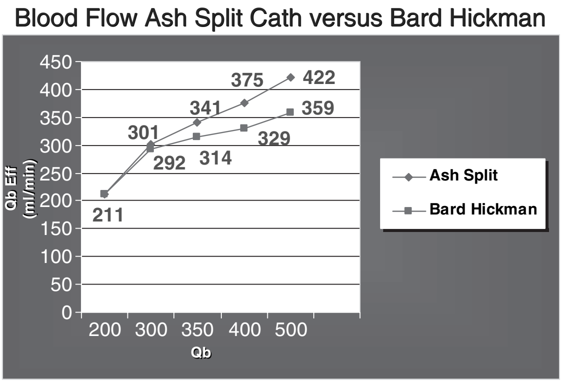


FIG. 16. Blood flow rate compared for Split Cath and Bard Hickman (13).

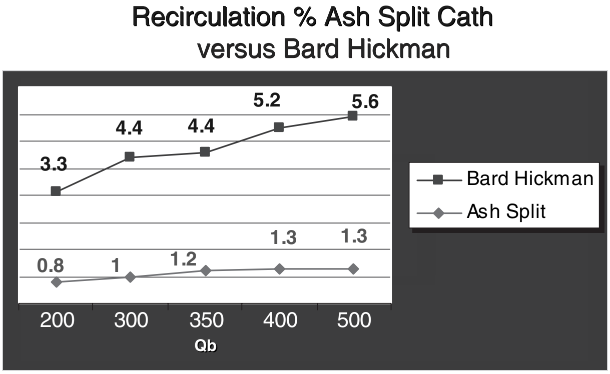


FIG. 17. Percentage recirculation of Split Cath versus Bard Hickman (13).

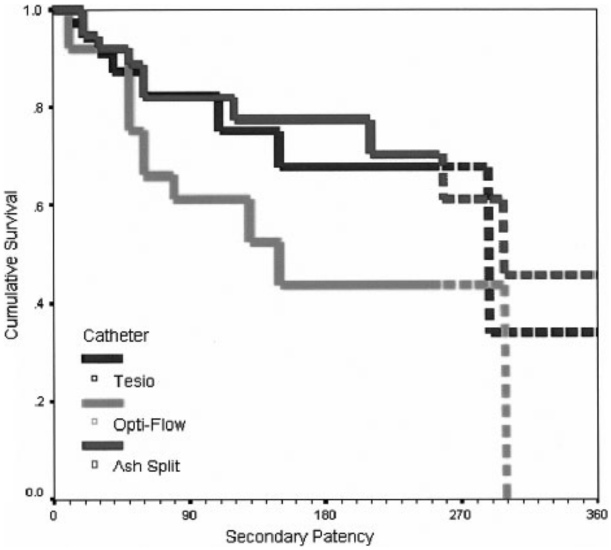


FIG. 18. Longevity of Tesio, Opti-Flow, and Split Cath catheters (17).

delivered significantly higher flow rates when tested at 1 month, but there was no significant difference in flow at 6 months. Recirculation was always less with the Split Cath catheter but not always significantly lower. The Split Cath had significantly longer half-life, partly due to lower infection rate but also due to some mechanical failures of the Opti-Flow. Postulating on reasons that the Split Cath might have lower infection rates, the authors suggested that the "self-cleaning" function of the Split Cath, with continuous flow through all side holes, may diminish fibrin sheath and therefore decrease opportunity for bacterial colonization.

Randomized, Prospectively Controlled Studies of the Split Cath vs. Other Chronic CVC

Year	First author	Ref.	Duration of study	Catheter types, number	Function of catheters (ml/minute)	Survival of catheters
1999	Trerotola	(13)	6 weeks	Split Cath, 12	QbEff = 422 Recirc = 1.3%	92% at 6 weeks
				Hickman, 12	QbEff = 359 Recirc = 5.6%	62% at 6 weeks not needing urokinase
2001	Richard	(17)	120 days, mean	Split Cath, 38	QbEff = 338 at 90 days	Mean catheter survival 302 days Cath inf'n/100 days = 0.12
				Opti-Flow, 39	QbEff = 327at 90 days	Mean catheter survival 176 days Cath inf'n/100 days = 0.35
				Tesio, 36	QbEff = 297at 90 days	mean catheter survival 264 days Cath inf'n/100 days = 0.14
2002	Trerotola	(18)	100 days, mean	Split Cath, 64	QbEff = 363 at 6 months Recirc = 1.7 at 3 months	78% at 120 days Late cx/100 days = 0.22
				Opti-Flow, 68	QbEff = 366 at 6 months Recirc = 9.5 at 3 months	64% at 120 days Late cx/100 days = 0.43

In addition to these randomized studies there have been a number of observational studies on the success of the Split Cath, as shown in the following table:

Year	First author	Ref.	Duration of study	Catheter types, number	Function of catheters (ml/minute)	Survival of catheters
1998	Mankus	(12)	2 months	Split Cath, 10	Ave Qb = 295	–
				Hickman, 22	Ave Qb = 279	–
				Tesio, 17	Ave Qb = 300	–

Year	First author	Ref.	Duration of study	Catheter types, number	Function of catheters (ml/minute)	Survival of catheters
2000	Conz	(19)	4–8 months	Split Cath, 7	Ave Qb = 250	100%
2001	Conz	(20)	3 months	Split Cath, 5 geriatric patients	Ave Qb = 250 Recirc < 2%	100%
2001	Ewing	(21)	183 days	Split Cath, 118 Radiologic placement	URR near prescribed 66%	54% at 90 days
2002	Gallieni	(22)	260 days	Split Cath, 28	Ave Qb = 308 at 12 months	96% survival and primary patency
2003	Cetinkaya	(23)	360 days	Split Cath, 92	Thrombosis in 16%	Mean survival 289 days Cath infection = 0.82/1000 pt days
2004	Ash	(14)	240 days	Split Cath, 265	Over 300 ml//min	80% function at 1 year, 60% at 2 years

Mankus et al. published the first paper on the Split Cath and confirmed hydraulic function similar to both the Mahurkar (Hickman) and Tesio Twin catheters (12). Conz et al. demonstrated in a small number of patients with failure of fistula development and other geriatric patients that the Split Cath provides the prescribed blood flow (a relatively low 250 ml/min) over 3–8 months without failure or complication (19,20). Ewing et al. placed 118 Split Caths in ESRD patients who were awaiting fistula creation or had no other access possible (21). Flow rate was satisfactory according to unit prescriptions. The 3-month infection rate was 18.6% (2.4/1000 patient days), but only one-third of these catheters required removal. Gallieni et al. placed 28 Split Cath catheters in patients who were not candidates for surgical AV fistula or graft placement (22). Only one catheter failed during mean follow-up of 260 days, and there was a 96% primary patency rate. Cetinkaya placed 92 Split Caths in ESRD patients for whom it was planned as the permanent vascular access (23). Catheter related infection rate was 0.82 espisodes/1000 patient-days, and mean duration of catheter survival was 289 days.

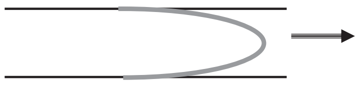
All of these prospective observational studies were performed in centers in which the Split Cath was a relatively new access device. Given this background, the results of use of the catheter for long term dialysis were satisfactory. In a prospective observational study in our own unit, complication survival for Split Cath catheters was 80% at 1 year and 60% for those catheters removed for complications (14).

There are many studies showing longevity for various types of catheters, but most are not randomized or comparative. The popularity and multiplicity of split-tip catheters, and the overall success of the Canaud/Tesio design would indicate that these catheters with two tips have flow rate and functional survival at least as long as any single body catheter. There are some disadvantages of split-tip catheters however:

- Limbs can go into different veins, especially when threading from the left side.
- Positioning is important, especially for split-tip catheters with a preformed angle between the tips (arterial lumen must be in right atrium).
- Care must be taken at the time of removal to grasp both lumens.
- Some catheters can survive so long that mechanical failures occur and removal is difficult.

4. What happens to injections of lock solution equal to one catheter volume?

Fluid follows parabolic flow down the catheter lumen:



As a result 15–20% of the injected volume goes out the tip of the catheter immediately*

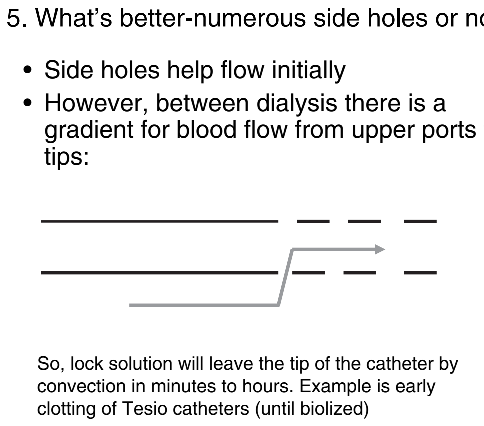
Fig. 19. Explanation of Question 4.

4. What Happens to Injections of Lock Solution at Catheter Volume?

The standard practice for locking a catheter after use is to infuse a volume of anticoagulant equal to the volume of the catheter. Several studies have demonstrated that patients receiving heparin catheter lock after dialysis are systemically anticoagulated, with PTT values over 200 seconds, even if the volume of lock infused is exactly the same as the catheter volume (24). When fluid flows through a catheter lumen at a reasonable flow rate, the flow is laminar and the profile of flow is parabolic. The fluid at the edges of the catheter remains stationary and most of the flow is through the center of the lumen (Fig. 19). The volume in which most of the fluid flows is therefore less than the catheter volume. Even in catheters without side holes, 15–20% of the fluid injected into a catheter exits the tip, when the injected volume equals the catheter fill volume (25). The only way to prevent systemic anticoagulation of the patient during catheter lock with heparin is to under-fill each catheter by 15–20%. This of course means that there is a lower concentration of heparin at the tip of the catheter than expected from the lock solution concentration.

5. What's Better—Numerous Side Holes or None?

This question has been raised among catheter designers for over 50 years. Side holes can improve flow of catheters in the short term, especially on the arterial side. However (Fig. 20), they allow a pathway for blood to



5. What's better-numerous side holes or none?

- Side holes help flow initially
- However, between dialysis there is a gradient for blood flow from upper ports to tips:

So, lock solution will leave the tip of the catheter by convection in minutes to hours. Example is early clotting of Tesio catheters (until biolized)

FIG. 20. Explanation of Question 5.

flow from the highest (most proximal) side hole through the catheter and out the tip. Although the pressure gradient is small between these two points, it takes only a fraction of an ml of blood to displace all of the lock solution from the end of the catheter and fill it with blood. Side holes in some catheters have rough edges, leading to adherence of clots (12). Tesio/Canaud catheters have six side holes in a spiral shape. It is not uncommon for these catheters to clot completely after placement, within hours. Removing the clot with forceful irrigation, using the catheter for dialysis and then re-locking the catheter with heparin usually results in a catheter that functions for a long time. Presumably this is because the catheter becomes "biolized" or protein-coated and is therefore more resistant to clotting.

Tal et al. performed a prospective study of Mahurkar type single-body catheter, comparing catheters with side holes to catheters without side holes (26). On removal, many of the catheters with side holes had adherent clots, while those without side holes had fewer adherent clots (Fig. 21). There was a slightly higher flow rate for catheters with side holes, though not a significant difference (Fig. 22). Surprisingly, there was a significantly higher rate incidence of CRBSI in the catheters with side holes versus those without (2.54/1000 catheter days versus 0.254/1000 catheter days). Catheters without side holes had a better overall survival rate (Fig. 23). The authors surmized that the clots adherent to the catheter tip served as a nidus for infection, after seeding from systemic bacteremia or lumen contamination. This study indicated that at least for the Mahurkar, side holes of a certain size and location may be detrimental rather than beneficial.

6. Why Does Blood Rise into Some IJ Catheters over Time, Displacing the Lock Solution?

Some patients arrive at the dialysis unit with blood visible in the catheter extension sets. The blood is seen to fill the catheter up to the point of the clamp on the extension set. How does this happen? (The answer relates to the difference in density of the lock solution and the density of blood Fig. 24). The density of blood with hematocrit of 35% is about 1.035 while the density of heparin is 1.000. If a patient with a right IJ CVC lies on their right shoulder, then there is a density gradient that will cause blood to enter the catheter and the lighter heparin to leave the catheter.

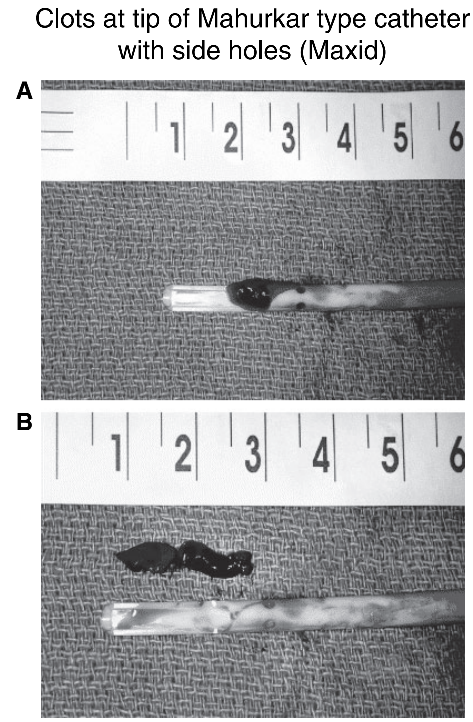


FIG. 21. Clots on Maxid catheter side holes after catheter removal (26).

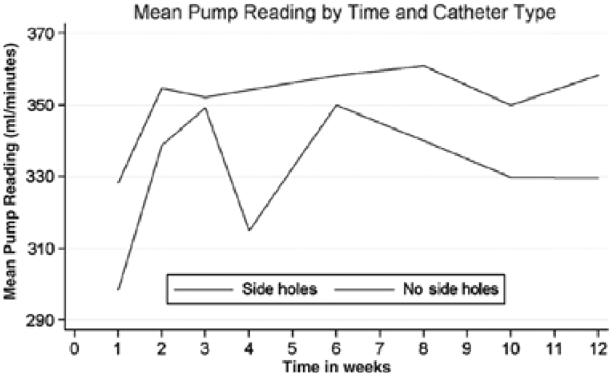


FIG. 22. Flow rates for Maxid catheters with and without side holes (26).

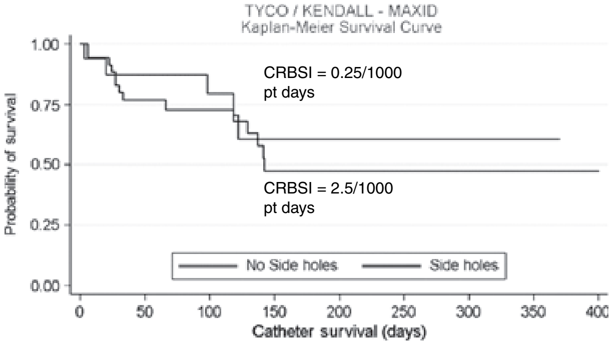


FIG. 23. CRBSI incidence for Maxid catheters with and without side holes (26).

6. Why does blood rise into IJ catheters over time, displacing the lock solution?

- Density of blood is 1.035 at hematocrit of 34%.
- Density of heparin is 1.000
- If patient with right IJ lies down on right side, the more dense fluid (blood) goes down and lighter fluid up:

Effect is reversed when lock is more dense than blood, such as with 23% citrate or 25% NaCl (specific gravity 1.10) . This fluid slowly falls from catheter with patient upright*

FIG. 24. Explanation of Question 6.

Filling with blood is more pronounced for heparin-locked femoral vein catheters with the tip pointed upward. For lock solutions with density greater than blood, such as 23% citrate or 25% saline, the catheter fills with blood when the patient is upright, This effect can easily be shown in the laboratory, where even very small differences in density between the lock solution and the fluid outside the catheter will cause the lock solution to leave the catheter and blood to enter the catheter (27).

7. How Can a Small Kink (or Stenosis) Decrease Flow so Much?

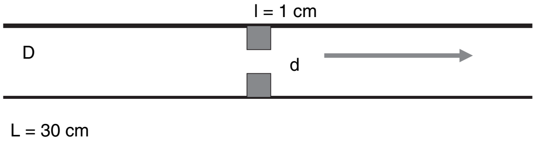
We all know that a small kink in a catheter can limit blood flow so badly that dialysis is not possible, even if the kink incompletely blocks the lumen as shown in Fig. 25. Similarly, a short segment of stenosis within a graft or fistula can decrease flow dramatically. The large effect of a short kink or stenosis on flow is due to the fourth-power relationship between hydraulic resistance and diameter of the lumen (see point 2 above). Figure 7 is a depiction of a hypothetical flow pathway with a diameter *D* and length of 30 cm as proposed by Keller (28). A stenotic area has a length of 1 cm long and diameter *d*. The flow path and stenosis are in series. The pressure drop (Δp) is proportional to the length and diameter of each segment and the flow rate (Q). Thus a 50% stenosis, with $d = 0.5D$ over a length of 1 cm results in a twofold increase in the term ($L/D^4 + l/d^4$). Put another way, at the same pressure drop, this 50% stenosis creates a 50% decrease in flow rate. A 30% "residual" stenosis decreases the flow in this model by 20%. This is the acceptable residual stenosis for angiographic procedures for grafts and fistulas. It is also an almost imperceptible kink in a catheter (per K/DOQI).

8. Where Should the CVC Tip Be Placed—SVC or Right Atrium?

The instructions for placement of most CVC for dialysis state that the tip of the catheter should be placed "at the junction of the superior vena cava and right atrium" as shown in Fig. 26. These instructions are actually not very clear. If the venous tip is at this junction, then the arterial tip will be about 3 cm above this junction. If the arterial limb is at the junction, the venous tip will extend into the atrium by about 3 cm. Within the superior vena cava the arterial lumen may lie against the wall, obstructing some side holes and partially obstructing the tip. Common experience has indicated that having the arterial lumen reach the atrium creates much better flow of blood into the catheter. On a fluoroscopic image of the heart, the junction of the superior vena cava is not at the top of the right atrial shadow but is approximately one-third of the distance from top to bottom of the right atrium (Fig. 27) (5). The tip of the catheter rises several centimeters when the patient stands, due to downward movement of the diaphragm and the right chest wall. This makes placing the catheter tip into the center of the atrium in the supine patient even more important.

To make placement even more complicated, there are lots of places that a CVC can end up that are not in the right atrium or SVC (29). The normal venous anatomy in the upper chest is remarkably complicated (Fig. 28). During placement of an IJ catheter the guidewire can enter a number of veins including the azygous, hemiazygous, internal mammary, subclavian, and others. This is especially common in the presence of central stenosis, when the azygous veins can become large enough to accomodate the entire catheter (Fig. 29). Surprisingly, catheters can work in positions like these (5).

7. How can a little kink (or stenosis) decrease flow so much?



$$(\Delta p)^{total} = 8Q/\pi\mu \ (\ L/D^4 \ + \ l/d^4 \ )$$

Two fold increase =(30/1 + 1/0.03)

$d^4 = 0.03$, $d = 0.5$ (i.e. a kink occluding 50% of the lumen, or in a fistula, 50% "residual stenosis")*

FIG. 25. Explanation of Question 7.

8. Where should the tips of the CVC be placed?

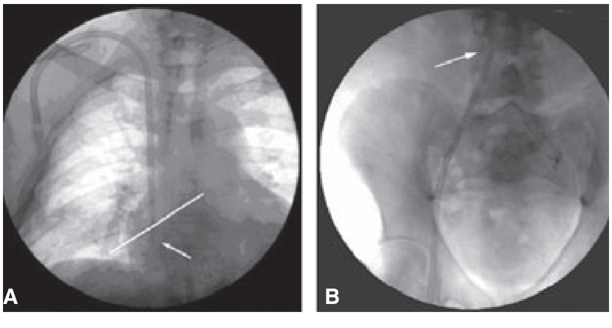


FIG. 26. Proper location of tips of CVC for dialysis, from IJ and femoral approach (5).

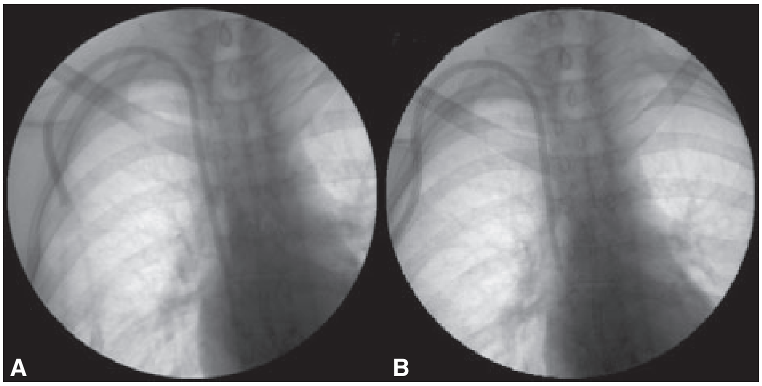


Fig. 27. Change in tip location from supine (left) to standing (right) (5).

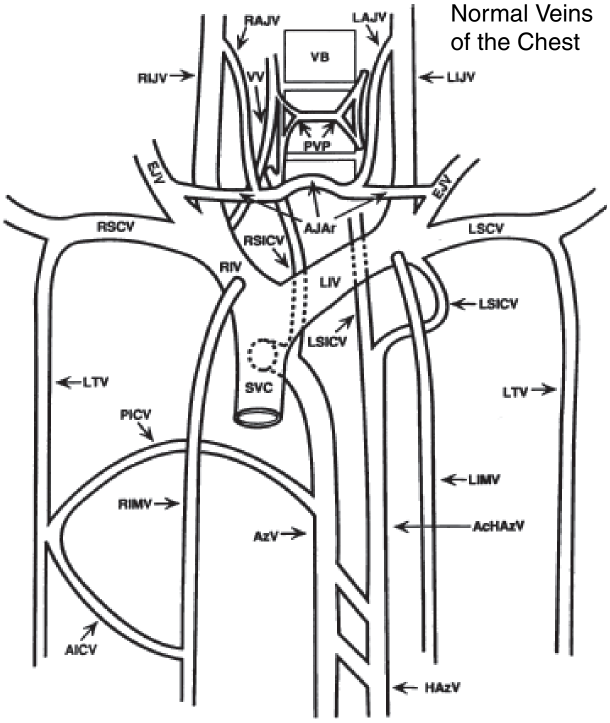


Fig. 28. Major and minor normal veins of the chest (29).

Fig. 29. CVC for dialysis inserted through innominate and hemiazygous veins (5).

9. Which Is Really Better—Splitsheath or Over-the-Wire Placement

Placement of split tipped chronic catheters such as the Split Cath has been greatly simplified by the use of the "over-the-wire" technique, somewhat similar to the methods used for placing "acute" dialysis catheters as shown in Fig. 30 (30). Like the splitsheath technique, this placement procedure must be performed with ultrasound guidance and certainly should be performed with fluoroscopy. In this technique a guidewire is placed as usual and dilated as usual. The outside end of the guidewire is threaded through the venous end of the catheter. The wire is then made to exit from a side hole of the venous limb and then directed through the arterial end of the catheter and advanced to the outside connector (Fig. 4). A hemostat is placed on the outside end of the wire and the catheter is advanced over the wire until the tip is at the skin surface. For catheters like the Cannon catheter which are advanced into the vein and then tunneled outward to the skin, the placement is directly along the line of the guidewire and the guidewire can be held relatively constant in position. For catheters like the Split Cath the catheter is first tunneled from a skin exit site to the primary incision, the guidewire placed through the catheter and the catheter advanced in an arcuate manner along the guidewire and into the vein while the guidewire is intermittently retracted. When the catheter forms an acute arc over the primary incision (over the internal jugular vein) pushing the arc downward completes the insertion. Some companies supply a stiffening catheter within the dialysis catheter, for the purpose of threading over the guidewire. This decreases friction as the catheter is advanced over the wire, but also makes the catheter somewhat stiffer especially when bent to enter the primary incision.

9. Which method is better for CVC placement-Splitsheath or Over-the-wire?

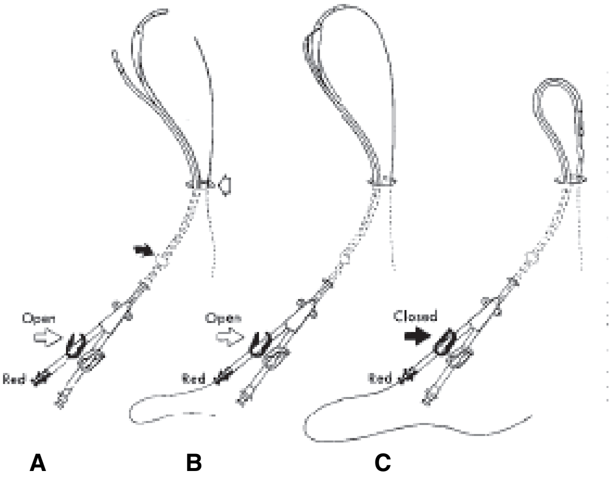


FIG. 30. Method of over-the-wire placement for CVC for dialysis tunneled inward (30).

Using the "over-the-guidewire" technique for chronic and acute split catheters has several advantages versus using the splitsheath:

- The procedure is somewhat simpler and avoids having to learn how to grasp the ends of the catheter to insert them into the sheath, and how to split and remove the sheath from around the catheter.
- There is less blood loss and generally a lower risk of air entry to the vein versus the splitsheath (even if the sheath is "pinched" after the dilator is removed).
- There is less bleeding around the catheter after placement, as the vein entry hole is the size of the catheter, not the size of the larger splitsheath.
- The technique is suitable for any vein, including femoral veins where the pressure of the blood and the bend of the inguinal vein can make use of the splitsheath problematic.

For chronic catheters there are some problems of placement which are specific to the over-the-wire technique:

- If the catheter is advanced slowly, then excessive bleeding can still occur as blood exits through the arterial lumen around the guidewire [this can be minimized by closing the arterial clamp over the guidewire, as suggested by Patel (30)].
- As blood exits slowly through the arterial lumen it can clot, causing flow problems during the first dialysis treatment.
- If the central venous pressure is very low, then air can enter the venous system during placement through the arterial lumen and around the guidewire, as this lumen remains open during the placement.
- The guidewire cannot be held in constant position while the catheter is advanced; rather the catheter is usually advanced and then the guidewire retracted. If the guidewire is clamped within the arterial extension set then the guidewire always moves into the patient as the catheter is advanced.
- When placing catheters that have been tunneled under the skin from exit site to primary incision, the catheter becomes sharply arcuate just above the skin as it follows the guidewire out of the primary incision and then back into the vein. This last portion of the catheter must be compressed under the skin through the primary incision. At this time it is impossible to retract the guidewire or prevent it from advancing further into the vena cava or into the right atrium.
- The guidewire is always bent at the point of arcuate bend of the previously tunneled catheter. This bend in the guidewire and the passage of the guidewire through several holes at the end of the catheter means that there is resistance during removal of the guidewire from the catheter. During guidewire removal some guidewires have fractured, with the outer spiral winding separating from the inner wire. Careful traction of both the spiral winding and internal wire usually allows the guidewire to be removed intact. The tip of the catheter can be displaced during guidewire removal.
- The placement procedure is made easier by a Teflon-coated wire such as the Glidewire (Boston Scientific, Natick, MA). This guidewire costs about \$80. The long (150 cm) length of the guidewire makes the control of the end of the wire during catheter placement of the catheter more difficult, and the outer coating of this Glidewire can still occasionally fracture from the internal wire if significant force is needed in removal of the guidewire.
- Chronic CVC which can be placed over a single guidewire must have a relatively small tip for both arterial and venous lumens, and must have side holes properly placed to allow exit of the wire from the medial side of the venous lumen to enter into the arterial lumen. The Split Cath has small tips to make the procedure relatively easy. The Dura-Flow catheter has a hole placed on the outside of the arterial lumen to receive the guidewire, assuring that the catheter follows on one side of the guidewire and making placement easier in spite of the large lumen sizes. Placing catheters with no side holes requires two guidewires, one for each lumen.

These problems and risks of "over-the-wire" placement can be minimized by some logical steps. First, using an ultrasound machine the patient can be positioned so that the jugular vein is moderately distended but not overly distended, before placing the first needle into the vein. This assures only a modest central venous pressure, which minimizes blood loss through the catheter during advancement of the catheter over the guidewire, and also minimizes the risk of air entering the vena cava. Using fluoroscopy or cardiac monitoring it is possible to advance the tip of the guidewire past the heart and into the inferior vena cava (in most cases). This means that advancing the wire during catheter placement has less risk. Creating a wider than usual primary incision over the jugular vein means that there is a less sharply arcuate bend in this part of the catheter as it is compressed under the skin. Using a Teflon-coated wire such as the Glidewire, which has greater flexibility and resiliency means that there is less tendency for the wire to bend or kink at the primary incision during placement.

In spite of some potential problems, the over-the-guidewire technique has moderate safety advantages over splitsheath placement techniques for chronic CVC for dialysis. Training is easier for the procedure, though there is still need to learn in the proper force and direction for and "feel" of advancing the catheter into the IJ vein. Further, anyone placing catheters using the over-the-wire technique must also be skilled in use of the splitsheath as in some patients advancement of the catheter over the guidewire is not possible. This is especially true in patients who have had previous chronic or acute catheters in the IJ, and have scarring of the vein wall (30).

Both the splitsheath and guidewire placements can be performed in the ICU, with ultrasonic and fluoroscopic guidance. This means that soft dual-tipped chronic CVC can be placed for treatment of patients with acute renal failure with little more risk and difficulty than acute dialysis catheters. The use of a chronic tunneled and cuffed CVC for patients with acute renal failure provides advantages of increased blood flow, more stable blood flow, less venous irritation and much greater duration of use, versus acute catheters. Patients with soft chronic catheters in the femoral location may walk or sit when desired, and all patients with IJ catheters can walk or sit when needed. Most importantly, the fact that only one catheter is needed for the course of acute renal failure means that there is significantly less vein trauma as opposed to the usual course of changing the acute catheter every 5 days or so. If the patient recovers in other ways but still has renal failure, the chronic CVC is already in place for beginning chronic dialysis therapy.

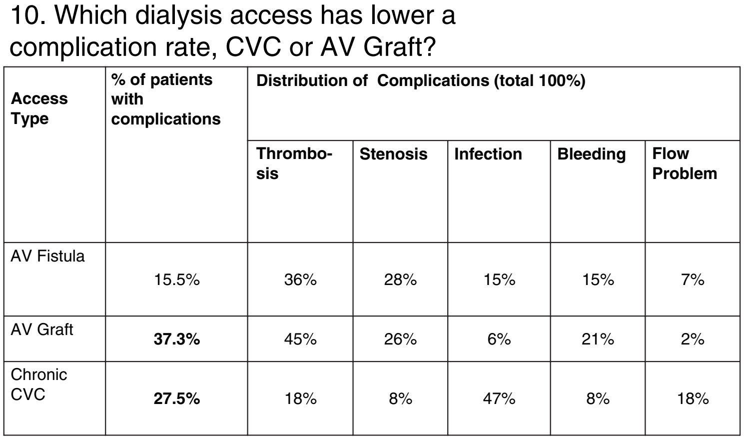
10. Which Dialysis Access Has a Lower Complication Rate—Chronic CVC or AV Graft?

Regarding the incidence of complications with various types of access devices, there is no doubt that the AV fistula is the safest and most effective access for chronic dialysis. However, there is reason to question whether grafts have fewer or more complications than CVCs. There have actually been few studies comparing the overall complications of these three types of dialysis access over time. A prospective, multi-center study of vascular access was performed and recently reported by the Research Board of the European Dialysis and Transplant Nurses Association/European Renal Care Association. The study followed the incidence of complications of AV fistulas, AV grafts and chronic CVC for dialysis in 1380 ESRD patients in Europe for a 1-year period (31). At the start of the study 77% of patients had an AV fistula, 10% had an AV graft, and 13% had a chronic CVC for dialysis. As expected, AV fistulas had the lowest incidence of complications, 15.5% in 1 year (Fig. 31). The overall complication rate for AV grafts was 37.3% over the year: chronic CVC for dialysis had a complication rate of 27.5%. Of types of complications, infection was higher for CVC and thrombosis higher for AV grafts as in the following table. The "major" conclusion of the study was that AV fistulas are the preferred access for chronic dialysis. However, a second conclusion is that serious complication rates are similar for chronic CVC for dialysis and AV grafts. Note however that the incidence of infection of catheters in this study is much lower than the average published for CVC (3/1000 patient-days, or 9% of catheters per month).

Future Trends

The advent of successful chronic CVC for dialysis has been a great advance for patients with ESRD, those beginning hemodialysis and for many who remain on dialysis for many years. It has been 15 years since the PermCath was introduced. Chronic CVC for dialysis allow dialytic support of patients for many months if needed. Though access by AV fistula should always be investigated and attempted in most patients, the chronic CVC for dialysis serves as a workable alternative to AV grafts and suitable access to allow time for fistula maturation with or without intervention.

In spite of the advances, chronic CVC still have significant problems and limitations. For each of these prob-



10. Which dialysis access has lower a complication rate, CVC or AV Graft?

Access Type	**% of patients with complications**	**Distribution of Complications (total 100%)**				
		Thrombosis	**Stenosis**	**Infection**	**Bleeding**	**Flow Problem**
AV Fistula	15.5%	36%	28%	15%	15%	7%
AV Graft	**37.3%**	45%	26%	6%	21%	2%
Chronic CVC	**27.5%**	18%	8%	47%	8%	18%

FIG. 31. Incidence of complications in 1 year in 1380 patients with AV fistula. AV graft, and catheter and distribution of main complications per type of vascular access (from Research Board of the EDTN/ERCA, 9).

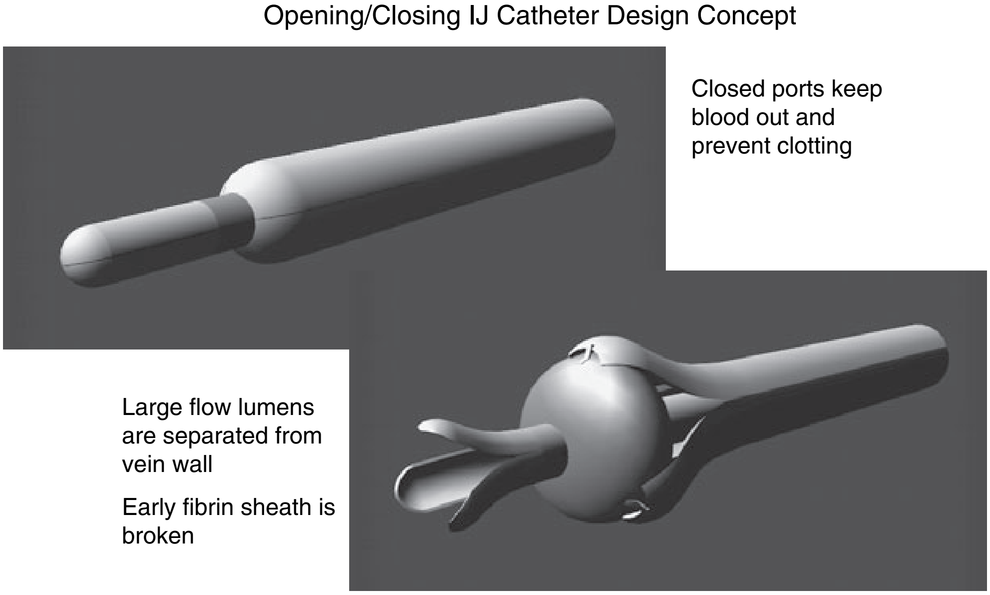


FIG. 32. Stylized concept of CVC for dialysis with active opening and closing of tips.

lems, there will someday exist a solution which will advance the technology and benefits of chronic CVC for dialysis:

- *Catheter-related infections*: Catheter materials, chemical impregnation methods or catheter locks will be found to kill bacteria in the biofilm layers both on the outside and inside of chronic CVC for dialysis, in order to decrease this most common complication of the catheters. The antibacterial effect of materials must remain for many months rather than a week or so (as with acute catheters).
- *Catheter clotting*: Catheters which open and close at the tip would allow the catheter to retain anticoagulant and to avoid blood clotting within the ports. A futuristic design is shown in Fig. 32.
- *Catheter fibrous sheathing*: Catheter material, chemical impregnations, shapes or blood flow patterns must be found to prevent the growth of fibrous sheaths around the catheter bodies, which leads eventually to loss of flow. Some degree of sheath probably forms on every chronic catheter placed in the vena cava, and limits eventual flow of many. Catheters that expand when used may allow the early fibrous sheath to be repeatedly opened around the catheter.
- *Central venous stenosis*: Methods to distribute or diminish "wear" on the vena cava must be evolved to avoid this serious and still frequent complication. Avoiding use of acute dialysis catheters diminishes the frequency of central venous stenosis.
- *External component bulk*: Patients bandage and keep dry the hubs, extension tubings, clamps and connectors, but many also complain about the general bulk of the catheters components on their bodies. Moreover, the preclusion of showering is a real bother to many patients. Subcutaneous ports were proposed as one solution (LifeSite, BioLink) but clearly are not the answer for most long-term patients. Eventually more radical skin-level "connectology" will be applied.
- *External component breakage*: More durable yet still light-weight components are possible. Simplifying the entire catheter design to limit the size and number of glued connections is a partial solution.

With a few more improvements, chronic CVC for dialysis could become a painless, effective and safe long-term access for the majority of dialysis patients and perfectly acceptable as an alternative to AV grafts.

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