Acute Vascular Access: New Advances

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Dual lumen central venous hemodialysis catheters have become the preferred form of acute vascular access. Although they provide rapid angioaccess, these catheters are associated with a number of serious insertion complications. Furthermore, prolonged use can lead to late complications including infection and central venous stenosis. Recent advances in catheter construction as well as new techniques for line placement should reduce the incidence and severity of catheter-related problems.

Index Words: Acute dialysis; acute renal failure; catheters; subclavian vein.

Temporary hemodialysis angioaccess is frequently necessary in the treatment of patients with acute renal failure, chronic renal failure without a functioning arteriovenous fistula, or following certain toxic ingestions. Dual lumen central venous hemodialysis catheters have become the acute vascular access of choice. Although they are easily placed and provide excellent extracorporeal blood flows, these devices are associated with serious insertion and late complications. This article focuses on new advances which will improve catheter placement and management and likely reduce the incidence of catheter-related complications.

Complications of Acute Vascular Access

Insertion Complications

As summarized in Table 1, a wide variety of complications can occur during central venous cannulation. Although the incidence of specific complications varies with insertion site, the overall complication rate correlates best with physician experience. Inexperienced physicians have approximately twice as many complications and unsuccessful cannulations as more seasoned colleagues.[1]

Overinsertion of the guidewire or catheter frequently leads to atrial or, less commonly, ventricular arrhythmias.[2] The great majority of these rhythm disturbances are transient and hemodynamically insignificant and antiarrhythmic medications or cardioversion are very rarely needed.[3] Pneumothorax complicates from 1% to 10% of subclavian vein catheterizations, but fewer than 0.1% of internal jugular cannulations.[4,5] The risk is greater from the left side because the pleura and dome of the lung are higher than on the right. Clinically significant air embolism has been reported.[5]

Inadvertent femoral or carotid artery puncture occurs frequently, but bleeding can be controlled by direct pressure and rarely results in significant hematoma formation, even in patients with coagulopathies.[6] Subclavian artery punctures cannot be directly compressed, but bleeding often ceases spontaneously. Fewer than 1% of subclavian vein catheterizations result in serious hemorraghic complications.[4,5] Extreme caution must be exercised after accidental arterial puncture if heparin is administered within a few hours of the event. This should be avoided.

Frank perforation of vessels or adjacent structures can occur during catheter placement or as a delayed complication. Perforations often occur with multiple needle passes or forced guidewire or catheter advancement. The subclavian approach carries the greatest risk, presumably because of the tortuous course that the guidewire and catheter must negotiate. Perforation may result in hemothorax, pericardial tamponade, or injuries to adjacent structures such as the brachial plexus,[7] trachea,[8] and recurrent laryngeal nerve.[9]

Late Complications of Acute Vascular Access

Infection

Infection remains a major cause of catheter loss and morbidity and mortality. The major-

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Table 1. Complications of Central Venous Dialysis Catheter Placement

Insertion Complications	*Late Complications*
Arrhthymias	Infection
Arterial puncture	Thrombosis
Pneumothorax	Central vein stenosis
Hemothorax	Perforation
Vascular perforation	
Air embolism	

ity of infections result from migration of microorganisms from the patient's skin down the catheter.[10,11] Infection can also occur from contamination of the catheter connectors or infused solutions, as well as secondary colonization during bacteremia from a remote source. Infection can be localized to the exit site or tunnel, or may lead to sepsis.

Risk factors for catheter infection include prolonged cannulation,[4,11,12] breaks in sterile technique during insertion, and heavy bacterial colonization of the skin.[13] Tunneled silicone catheters with subcutaneous Dacron cuffs (DuPont Inc, Wilmington, DE) have much lower infection rates than standard central venous catheters.[14,15] Because of their proximity to the perineum, femoral venous catheters are believed to be prone to contamination, although an increased incidence of infection has not been well documented.

Several simple interventions, summarized in Table 2, may help prevent catheter infection. Chlorhexidine is superior to povidone-iodine solution for skin disinfection before catheter placement.[16] Subcutaneous silver-impregnated collagen cuffs,[17,18] attached during insertion, and antiseptic ointment,[19] applied to the exit site with dressing changes, appear to decrease infection rates. Dry gauze dressings, instead of occlusive coverings, also reduce the incidence of catheter infection.[13] Occlusive dressings are impermeable to water and may create a favorable environment for bacterial proliferation.

Table 2. Preventive Interventions Against Catheter Infection

- Chlorhexidine skin disinfection before catheter placement
- Application of silver-impregnated collagen cuff to subcutaneous portion of catheter at insertion
- Use of antiseptic-bonded catheters
- Application of antibiotic ointment to exit site at each dressing change
- Use of dry gauze dressing
- Limited duration of cannulation (<2 wk) for nonsilicone catheters

Table 3 summarizes the management of hemodialysis catheter infections. Although localized exit-site infections may respond to antimicrobial therapy alone,[20,21] extension into the tunnel or evidence of systemic infection necessitates catheter removal in addition to antibiotics. On occasion, cuffed silicone catheters can be salvaged by prolonged antimicrobial therapy; however, this approach should be reserved for carefully selected patients with limited access options who respond rapidly to treatment. Delayed removal of infected catheters may result in serious complications including suppurative central vein thrombophlebitis or metastatic infections, including endocarditis or osteomyelitis. Changing the catheter over a guide-wire once the temperature has been brought down by antibiotics may also be effective in eradicating infection.[22]

Thrombosis

Catheter thrombosis is a common complication of central venous cannulation. Table 4 summarizes the salient features of the different types of catheter thrombus. Intracatheter clot frequently disrupts catheter function by impairing extracorporeal flow.[23] Fibrin sleeve thrombi develop very frequently.[24] Usually clinically silent, they occasionally obstruct cath-

Table 3. Management of Catheter Infection

- Exit site
  - Appropriate antibiotics for 1-2 wk
  - Catheter removal if infection persists
- Tunnel infection
  - Catheter removal
  - Appropriate antibiotics for 1-2 wk
  - Surgical drainage of infected area, if necessary
- Catheter-associated bacteremia
  - Catheter removal
  - Appropriate antibiotics for 2-3 wk
  - Evaluate for suppurative thrombophlebitis or metastatic infection if poor response to antibiotics
- Silicone catheter sterilization
  - Prolonged antibiotic treatment (3-4 wk)
  - Changing the catheter over a guide wire (after resolution of fever with antibiotics)
  - Catheter removal unless rapid clinical response (resolution of fever and leukocytosis within 12-24 hr).

Table 4. Types of Catheter Thrombosis

- Intracatheter
  - Extremely common
  - Interferes with catheter function
- Fibrin sleeve
  - Exact incidence unknown, but likely extremely common
  - Frequently clinically silent
  - Infrequently interferes with catheter function
  - Potential nidus of infection
- Mural
  - Exact incidence unknown, but occurs less frequently than fibrin sleeve
  - Involves vessel wall, usually at point of insertion
  - More likely to be clinically significant
  - Potential nidus of infection
  - Can result in permanent vessel occlusion

eter ports and can serve as a nidus for infection. Mural thrombus occurs less frequently,[25,26] but can cause dramatic upper extremity edema. Pulmonary embolism appears to be a rare complication of catheter thrombosis.[27]

Table 5 summarizes the management of catheter thrombosis. Instillation of urokinase or streptokinase into the catheter lumens will reestablish patency in 90% to 95% of cases.[14] Forced injection should be avoided because of the risk of line rupture. Catheters with persistently compromised flow should be replaced or evaluated with a catheter venogram. If fibrin sleeve clot is found, a thrombolytic infusion may restore patency. Mural clot requires systemic anticoagulation and catheter removal. The vessel is often permanently occluded, although carefully directed thrombolytic infusions can sometimes reestablish patency, particularly if performed within a week of thrombus formation.[28]

Table 5. Management of Catheter Thrombosis

- Intracatheter
  - Intraluminal thrombolytics
    - Urokinase (5,000 U/mL)
    - Streptokinase (2,500 U/mL)
  - Avoid forced irrigation
- Fibrin sleeve
  - Catheter replacement if function impaired
  - Consider catheter venogram to document thrombus
  - Consider low dose thrombolytic infusion for up to 24 hr
    - Urokinase (5,000 U/lumen/hr)
    - Streptokinase (3,000 U/lumen/hr)
  - Consider catheter stripping
- Mural
  - Catheter removal
  - Anticoagulation
  - Consider directed infusion of thrombolytics
  - Surgical thrombectomy as last resort

Central Vein Stenosis

Central vein stenosis develops in up to 50% of patients with subclavian hemodialysis lines.[29-31] This complication has tremendous clinical implications because subclavian vein stricture precludes fistula construction in the affected extremity. Catheter-induced vascular trauma appears to be a pathogenic factor because stenosis is associated with prolonged cannulation[31] and with stiff, nonsilicone catheters. Furthermore, strictures frequently occur at points of catheter-endothelial contact (Fig 1). Reduced vascular trauma may account for the low incidence of stenosis with relatively straight internal jugular catheters. Angioplasty often reestablishes vessel patency initially, but stenoses usually recur within several months.[32]

Perforation

Progressive vascular erosion can cause late perforation, especially with prolonged cannulation or rigid catheters. Improper catheter positioning or migration of the tip out of the proximal superior vena cava increases the risk of perforation. Repetitive catheter movement

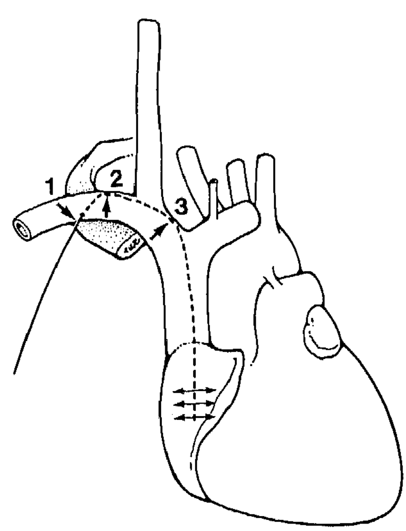

Figure 1. Potential points of catheter-endothelial contact for a right subclavian catheter. (Reprinted with permission.[46])

Table 6. Catheter Materials

Polyurethane
Sufficient rigidity at room temperature for insertion
Relatively low thrombogenicity
Inert to infusates
Polytetrafluoroethylene
More rigid and thrombogenic than polyurethane
Polyethylene
More rigid and thrombogenic than polyurethane
Polyvinylchloride
May leak chemical additives with infusions
Silicone elastomer
Extremely soft at body temperature
Very low thrombogenicity
Suitable for prolonged use
Requires peel-away sheath for percutaneous placement

may also be important. Late perforation may result in hemothorax or pericardial tamponade, which are often fatal because of delayed diagnosis.

Advances in Catheter Materials

Table 6 summarizes the features of commonly used catheter materials. Polymers, such as polyurethane, polyethylene, and polytetrafluoroethylene, are relatively rigid at room temperature but soften at body temperature. Catheters constructed of these materials are easily inserted percutaneously. Polyurethane appears more flexible and less thrombogenic than polyethylene and polytetetrafluroethylene.[33] Polyvinylchloride has excellent handling characteristics, but can leak chemical additives.

The development of silicone elastomer represents a significant advance. Softer, more flexible, and less thrombogenic than other polymers,[34] silicone catheters appear to cause less vascular trauma. They can be used for extended periods and can serve as permanent vascular access for patients in whom an arteriovenous fistula cannot be placed. Although placement is more difficult than with other polymers, silicone catheters can be inserted percutaneously with peel-away sheaths.[35]

Incorporation of antimicrobial substances in catheter material may prove to be another advance by improving resistance to infection.[36] Catheters with antiseptic substances such as chlorhexidine and silver sulfadiazine directly bonded to their surfaces are now available.

Advances in Catheter Design

Hemodialysis catheters consist of dual lumens arranged side-by-side or coaxially. To minimize recirculation of blood, the arterial ports are typically located 2 to 3 cm proximal to the venous port (Fig 2). These catheters reliably provide extracorporeal blood flows up to 300 mL/minute and may achieve flows up to 400 mL/minute, although high negative pressures may develop in the arterial limb at the higher flow rates.[37] Blood recirculation is usually less than 10%, even at maximal blood flows.[37,38] Central venous dialysis catheters are presently available in a wide variety of sizes and configurations (Fig 3).

Recent advances in catheter design include curved catheter shafts (Fig 4), which may reduce catheter kinking, especially for tunnelled internal jugular lines. In addition, nontunnelled curved internal jugular catheters are better tolerated because they are more easily secured, allow free head and neck movement, and can be hidden under clothing.

Another design modification may improve catheter patency by reversing the traditional arrangement of the arterial and venous ports.[39] With this design, venous outflow, directed along the catheter shaft instead of radially, is proximal to arterial inflow (Fig 5). The flow of blood past the arterial port hopefully will prevent thrombus development or dislodge adherent clot. A major advantage of this device is its ease of percutaneous insertion through a relatively small peel-away sheath. This makes it suitable for repeated but separate insertion in the same vein for different periods of temporary hemodialysis. Unfortu-

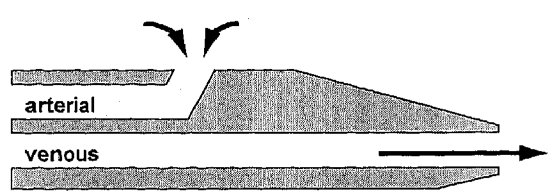

Figure 2. Typical hemodialysis catheter tip with the separation of the proximal arterial and distal venous ports.

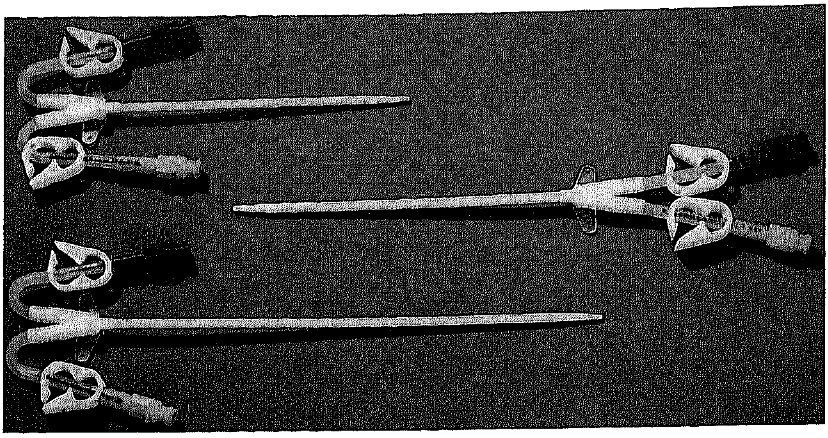

Figure 3. An array of available hemodialysis catheters.

nately, this design results in recirculation rates exceeding 20%.[35] Further clinical evaluation will be needed to determine whether this design improves catheter patency sufficiently to outweigh the reduction in dialysis efficiency. If so, it may make subclavian cannulation unnecessary in the future.

Advances in Catheter Insertion Techniques

Despite low infection rates and reduced vascular trauma, the use of silicone dialysis catheters remains somewhat limited by the technical challenges of line placement. Fortunately, the development of peel-away sheaths has eliminated the need for surgical insertion. Providing a rigid exterior cover during insertion, these sheaths can be gradually peeled away while catheter position is maintained.[31]

In the past, central venous cannulation was guided solely by available anatomic landmarks. Distortion of these landmarks by obesity, trauma, surgery, or radiation greatly increased the difficulty and risk of catheter placement. In addition, vascular abnormalities such as venous stenosis or variant vessel position could not be detected.

The development of handheld ultrasound devices capable of imaging internal jugular, subclavian, and femoral veins has greatly facilitated dialysis catheter insertion. These devices can establish venous patency before cannulation (Fig 6). Once the vein is located, the introducer needle is inserted under direct visualization. This technique reduces the number of passes required for successful cannulation.[40] More precise determination of vessel and needle position during catheter placement will reduce the incidence of insertion complications and may decrease late complications by minimizing initial vascular trauma.

New Considerations in Catheter Insertion Site Selection

The clinical features of the femoral, subclavian, and internal jugular approaches are summarized in Table 7. Alternative approaches, such as translumbar cannulation of

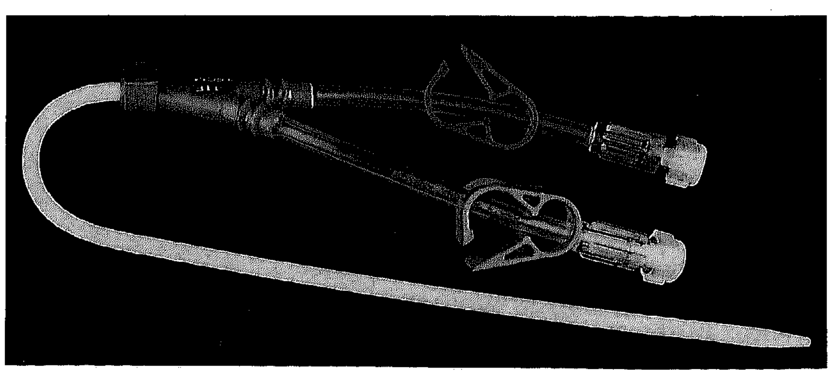

Figure 4. A hemodialysis catheter with a curved shaft.

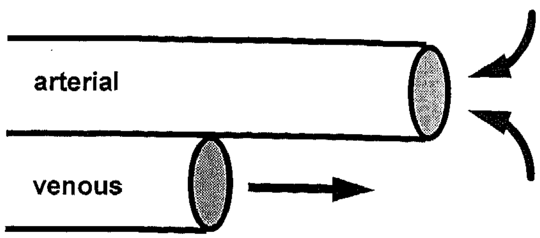

Figure 5. Modified hemodialysis catheter tip with distal arterial and proximal venous ports. Note that the venous outflow is directed along the catheter shaft.

the inferior vena cava,[41] may be attempted in selected patients without other access sites.

The femoral vein is the preferred approach for unstable patients because it can be rapidly and safely cannulated. Femoral venous catheters are probably unsuitable for high efficiency hemodialysis because of increased recirculation and negative arterial circuit pressures at high extracorporeal blood flows.[37] Because they easily kink, femoral venous catheters are generally removed after dialysis unless the patient is restricted to bedrest. Flexible silicone catheters, which are less likely to kink,

Table 7. Acute Hemodialysis Catheter Insertion Sites

Insertion Site	*Advantages*	*Disadvantages*
Femoral	Ease of insertion Low risk for insertion complications	Patient discomfort Limited patient mobility ? Increased risk of infection
Subclavian	Patient comfort Extended functional life	Technical expertise required for insertion High risk for serious insertion complications Risk for subclavian stenosis
Internal Jugular	Extended functional life Decreased risk for serious insertion complications	Technical expertise required for insertion

may allow the use of this approach in selected ambulatory patients,[42] although the risks of infection, thrombosis, and bleeding with prolonged femoral cannulation remain to be determined.

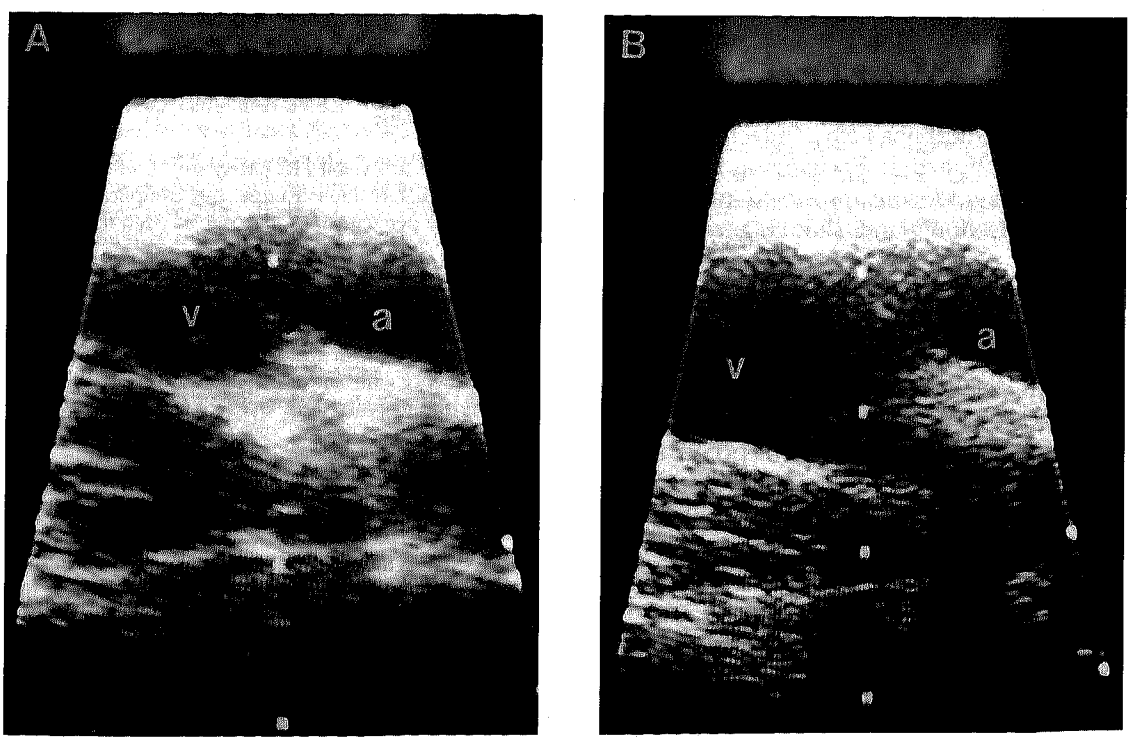

Figure 6. (A) Ultrasound image of the femoral vein (v) and artery (a). (B) Note the venous distension after the patient performs the Valsalva maneuver.

The internal jugular vein has become the preferred approach for ambulatory patients because of the high incidence of serious insertion complications and central vein stenosis with subclavian cannulation. Ultrasound guided insertion reduces the technical difficulties posed by poorly defined anatomic landmarks, small internal jugular vein diameter, and variable vessel location. As discussed above, curved catheters have improved patient acceptance.

Advances in Catheter Maintenance

Infection

The high incidence of infection with prolonged cannulation and frequency of asymptomatic catheter colonization[13] have lead to the practice of routinely changing functioning nonsilicone dialysis catheters. To minimize the risk of insertion complications, some clinicians simply exchange catheters over a guidewire. Tunneled silicone catheters with Dacron cuffs are not routinely changed because of their extremely low rate of infection.

Recent evidence suggests that catheter changes do not reduce the incidence of infection, but do increase the risk of insertion complications.[43] Therefore, central venous hemodialysis catheters should only be changed for clinical indications such as infection, thrombosis, or malfunction. Exchanging such catheters over a guidewire appears to increase the risk of infection[43] and should generally be avoided.

Thrombosis

Catheter stripping, a new technique of mechanical clot removal, can salvage silicone dialysis catheters with poor function caused by fibrin sleeve thrombus. In this procedure, a snare is advanced from the femoral vein up the inferior vena cava to the occluded line. The snare is closed around the distal portion of the catheter and then pulls away the adherent clot. Pulmonary embolism has not been reported as a consequence of this maneuver.

The role of oral anticoagulants in preventing catheter thrombosis remains unknown. Despite anecdotal reports of the beneficial effects of warfarin and aspirin on catheter patency,[44] neither agent has been systematically evaluated. In view of well-documented risks of iatrogenic bleeding, these agents cannot be recommended at present.

Central Vein Stenosis

Despite encouraging initial results, the majority of subclavian vein stenoses appear to recur rapidly after successful angioplasty. Although repeated angioplasty procedures may be acceptable treatment for some patients, intravascular wall stents appear to offer some benefit for lesions refractory to angioplasty because of elastic recoil.[45] The precise role of angioplasty and such stents remains under investigation.

Conclusions

Although central venous catheters provide excellent acute vascular access, their use may lead to serious late complications, particularly subclavian vein stenosis. It is hoped that increasing recognition of these late complications, in combination with advances in catheter design, placement techniques, and insertion site selection, will lead to improved catheter function and decreased complication rates.

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