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ORIGINAL ARTICLE

Impact of needles in vascular access for hemodialysis

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ABSTRACT

This article reviews pragmatic aspects of cannulation practice and types of cannulation devices, as well as their impact in vascular access for hemodialysis. Hemodialysis treatment requires successful insertion of two needles for each dialysis treatment. The first needle is the arterial needle; it removes blood with toxin accumulation from the patient and delivers it to the dialysis machine. The second needle, called the venous needle, returns the purified blood from the dialyzer to the patient. Mechanical and hemodynamic trauma related to needle insertions will be discussed.

Keywords: Cannulation, Hemodialysis access, Metal needle, Needle trauma, Plastic cannula, Ultrasound

Introduction

As hemodialysis prescriptions are usually three times weekly (4 to 8 h), a fistula or graft for hemodialysis will be punctured twice each dialysis treatment or at least 312 times per year. To allow healing of the tissues damaged during each cannulation, optimal cannulation practice is required by rotation of the needle insertion sites each dialysis treatment. When the cannulation segments are short (<7 cm) (1-3), site rotation is compromised. Needle punctures cause injury to the skin and the vessel wall as well as to the vascular endothelium. Trauma to the vessel endothelium heals at a very slow pace, as evidenced by large needle marks that can be found in the intimae at different stages of healing of excised arteriovenous fistulas (AVF) (Fig. 1) (3, 4).

Definition of successful cannulation in hemodialysis access

Current definitions of successful use of an access refer to a two-needle cannulation for at least 2/3 of dialysis runs in a month (5), or the ability to insert two needles that can sustain adequate and uninterrupted dialysis treatment (one arterial needle and one venous needle) without miscannulation (insertion of more than one needle per arterial or venous site) (6). These definitions do not incorporate the amount of manipulation that may be required to place the needle in an optimal position inside the vessel lumen.

Point of care ultrasound for cannulation of hemodialysis access is becoming the standard of practice in Canada and worldwide (3, 7-9), but at this time its use is directed to cannulation of the new or complicated accesses, and not for routine cannulations (4, 7-11). When performing a "blind cannulation" (without ultrasound assistance) (8), the needle is assumed to be in optimal position if blood return can be observed pulsating in the needle tubing ("flush back") or if there is easy aspiration of blood into a syringe with normal saline and there is no resistance while flushing the saline back into the access. If the position of the needle is felt not to be optimal, the needle is "repositioned" by changing the direction of insertion of the needle tip, by changing the angle of penetration, or by flipping the needle inside the vessel lumen (11-13) until dialysis can be commenced at the prescribed blood flow (Qb). Needle repositioning is a well-known dialysis procedure and is done routinely "by feel" without ultrasound assistance (12-14).

In the past decade, great scientific attention has been directed to the effects of trauma to the endothelium to minimize activation of biochemical cascades responsible for neointimal hyperplasia (NIH) and thrombus formation that may lead to access failure (15-20). Needle manipulations must be performed with appropriate technique to prevent endothelium damage (12, 13).

Trauma associated with cannulation

Types of dialysis needles

There are two main types of needles commercially available: metal needles and plastic cannulae (Supercath Safety Clampcath) (Fig. 2).

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Fig. 1 - Histology sample of excised fistula placed inside out (endothelial side out) shows needle marks at various stages of healing.

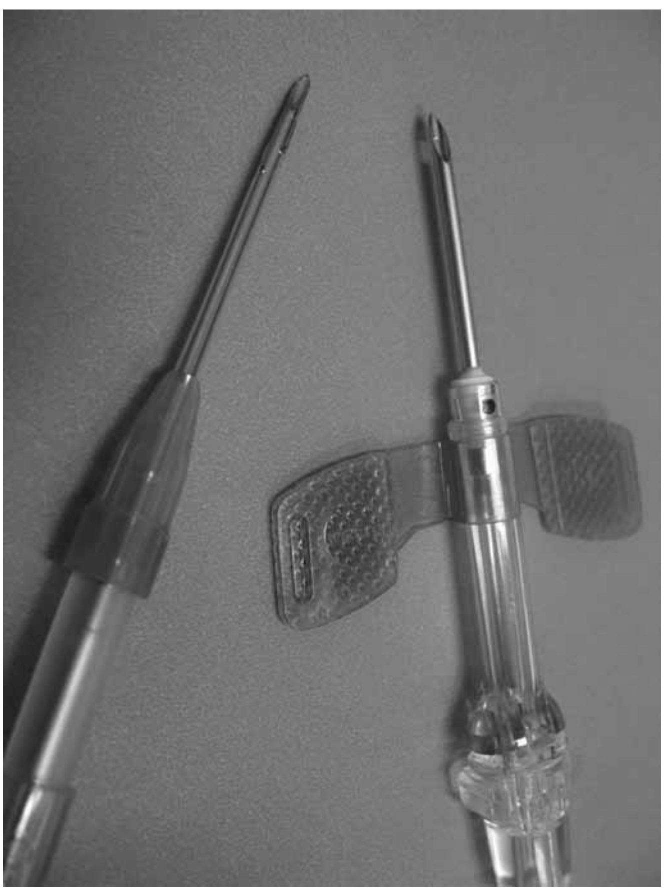

Fig. 2 - 15 g metal needle with back eye (right) and 17 g plastic cannula with metal needle guide (left).

Metal standard needles are usually 15 g in caliber and 1” long though a number of calibers are available. The bevel of metal needles has a sharp “V”-shaped pointed tip that provides a cutting function for easy penetration through skin layers and the vessel wall. It has a hole at the tip, and some needles have another hole at the back of the needle close to the tip commonly known as “back eye”, to help obtain steady blood supply during dialysis.

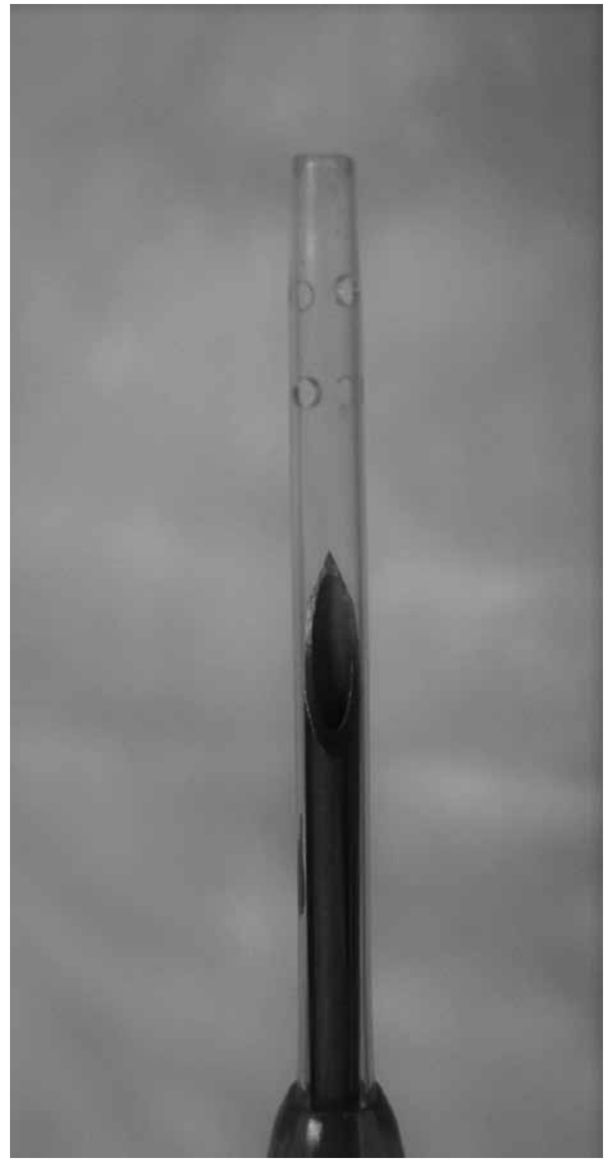

Fig. 3 - Plastic cannula with metal needle guide retracted. Note the four side holes within 5 mm from the tip.

Plastic cannulae combine a plastic cannula and a metal-introducing needle. The plastic cannula fits snugly over the metal needle, leaving only the 17 g sharp tip exposed. The metal-introducing needle punctures through the skin and top wall of the fistula or graft, guiding the plastic cannula into the lumen of the access. Once the plastic cannula is inside the lumen, the metal-needle introducer guide is retracted leaving the plastic cannula in situ. The thin-walled, soft plastic cannula has a 16 g dull round tip that minimizes vessel wall injury (Fig. 3). Plastic cannulae have four lateral round holes close to the tip to help maintain steady blood flow during dialysis. While the body of the tip of the introducing needle is 17 g, the blunt tip of the cannula is 16 g and the body is 15 g. Plastic cannulae are generally used for the first two weeks of

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cannulation of new fistulae. Their use may be extended beyond this time if it is felt that the arteriovenous (AV) access is still maturing, if it is fragile, or when there is an increased risk of a needle infiltration due to restlessness of the patient. The primary reason to transition plastic cannulae to metal needles is cost. Plastic cannulae are more expensive than metal needles. The long-term benefit of the use of plastic cannulae in the development of access cannulation-related complications is currently being studied in some dialysis units in Canada.

Effect of mechanical trauma: needle injury

During the initial period of cannulation of an AV access (first 4-6 weeks of use), complications related to needle injury may occur, for example: blood extravasation at the cannulation site, back wall needle infiltration, and hematoma formation (21-23). These problems are not uncommon and can have a severe impact in the delivery of dialysis. They result in delay or loss of dialysis treatment, or may require resting of the fistula and/or the insertion of a hemodialysis catheter to provide treatment until the hematoma resolves. In more severe cases, they may cause compression of the fistula lumen with flow obstruction, thrombosis, and permanent access loss (2, 24, 25).

Complications such as aneurysmal dilatations and stenotic lesions may develop progressively over weeks to months at needle insertion sites. If the needle insertion sites are not effectively rotated, overuse of the same areas for cannulation may cause damage of the skin and the elastic lamina of the vessel wall, resulting in aneurysmal formations that vary in size (23, 26, 27). Stenotic lesions can decrease and/or obstruct the blood flow requiring diagnostic interventional procedures to maintain or re-establish patency (23, 26). Aneurysmal areas are not only unsightly, they can enlarge to a size that requires surgical repair or radiological wall stent placement which, in turn, reduces the area along the fistula that is available for cannulation (28). Grossly enlarged aneurysms can rupture spontaneously and can be the cause of exsanguination and death when emergency intervention is not available (14, 26, 29, 30). Interventions not only add burden of illness to this population, they also burden health systems due the costs associated with the delivery of these services (31-34).

Effect of hemodynamic trauma: hoop and shear stress

Increased blood flow alters shear stress. During hemodialysis, blood-flow disturbances are increased at needle cannulation sites. Blood is pulled through the arterial needle with a negative pressure and pushed through the venous needle with a positive pressure (approx -250 mmHg to 250 mmHg) at blood pump speeds of 250-400 mL/min using a 15 g to 17 g needle or plastic cannula. Laminar blood flow is disturbed at needle sites for the duration of the dialysis treatment usually a period of 4-8 hours. The intimal layer of the vessel wall may respond by activating biochemical cascades known to contribute to the development of neointimal proliferation and NIH, factors known to lead to stenotic lesions and subsequently access thrombosis (16, 20, 35).

Effect of mechanical trauma: angioplasty

It has been demonstrated that endothelial damage occurs during balloon angioplasties performed to improve or restore patency of an AV access. Recurrence of lesions at angioplasty sites is, in many instances, aggressive and hard to treat (25, 36-40). Studies of NIH have mainly focused on learning the natural history, genetic and molecular component of this lesion, and in the development of pharmaceutical products and interventions to prevent or treat them (15, 18, 37, 41-44).

To date, little attention has been given to the effect of needle injury during cannulation or to the hemodynamic effect of blood-flow disturbances at cannulation sites during hemodialysis.

Doppler velocities and blood-flow patterns at needle sites

Doppler velocities at needle sites

Venous needle disturbances have been studied with laser Doppler velocimetry using a one-dimensional He-Ne Dantec Laser Doppler System in preclinical arteriovenous graft (AVG) models. With this method, turbulence measurement obtained at venous needle sites increased 5-6 times from baseline at 400 mL/min (45).

The jet flow disturbance at needle sites has also been studied using bovine carotid endothelial cells cultured in the inner surface of a compliant tube. The results of this *ex-vivo* experiment showed loss of endothelial integrity and a decreased production of nitric oxide (NO) at needle turbulence sites. The authors concluded that the jet flow effect at needle sites may contribute to the activation of the cascade responsible for neointimal hyperplasia in hemodialysis vascular access (46-49).

The impact of repetitive blood-flow disturbances at needle sites in the clinical setting has not been reported to date, perhaps due to the practical aspects of obtaining the measurements during hemodialysis treatment and/or the availability of portable equipment that can take these measurements at the bedside.

Preliminary clinical observations: Doppler velocity studies at needle entry sites were done in 10 prevalent hemodialysis patients (5 dialyzed using metal needles and 5 with plastic cannulae). With the use of a portable ultrasound unit (SonoSite S-Cath US system; Sonosite Canada, Toronto, Ontario), and the transducer in longitudinal position, mean velocity measurements were obtained at the venous at 2 cm and 4 cm upstream from the needle tip, at baseline and with Qb of 200, 300 and 400 mL/min. Mean results of this evaluation were consistent with preclinical data, velocity was higher at 4 cm compared to 2 cm from the needle tip, and increased 2-4 times from baseline to a Qb of 400 mL/min. (Tab. I). Increase was directly proportional to the increase in Qb. Velocities differed with the two types of needle designs and there was a trend to lower velocities with plastic cannulae. Figures 4 and 5 show images of mean velocity measurements done at 2 cm and 4 cm, respectively, from the needle tip with a plastic cannula.

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TABLE I - Doppler velocities expressed in cm/s taken at 2 cm and 4 cm from the needle tip at baseline and with pump speeds from 200 to 400 mL/min, with metal needle and plastic cannula

Type of needle	Bevel	Qb mL/min	at 2 cm (cm/s) mean ± SD	at 2 cm (cm/s) mean ± SD
Metal needle	Up	0	38 ± 7	
Metal needle	Up	200	50 ± 10	96 ± 4
Metal needle	Up	300	63 ± 11	104 ± 16
Metal needle	Up	400	75 ± 7	172 ± 8
Plastic cannula	N/A	0	46 ± 5	
Plastic cannula	N/A	200	58 ± 16	84 ± 24
Plastic cannula	N/A	300	72 ± 8	126 ± 17
Plastic cannula	N/A	400	87 ± 13	144 ± 12

Qb = blood flow; N/A = not applicable.

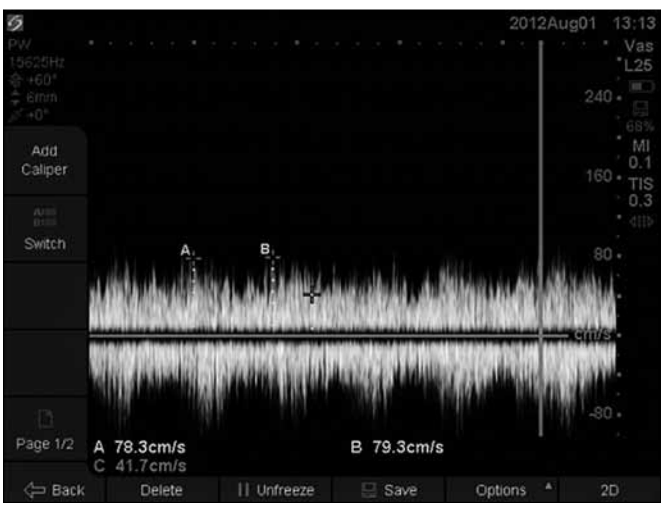

Fig. 4 - Ultrasound image for a mean velocity Doppler measurement at 2 cm from the needle tip at 200 mL/min blood flow (Qb).

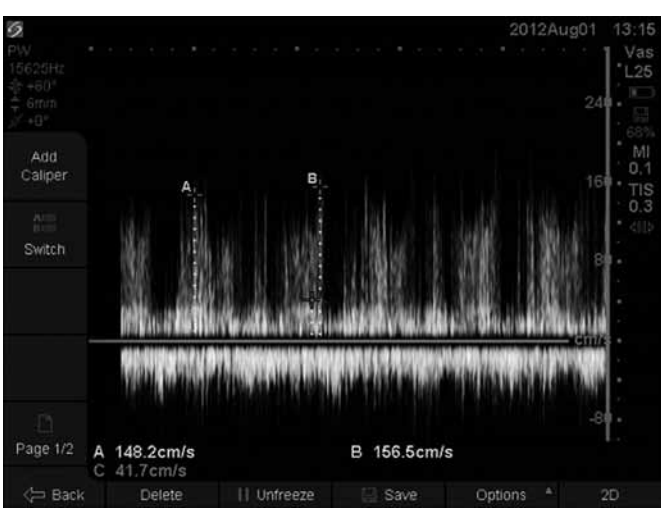

Fig. 5 - Ultrasound image for a mean velocity Doppler measurement at 4 cm from the needle tip at 400 mL/min.

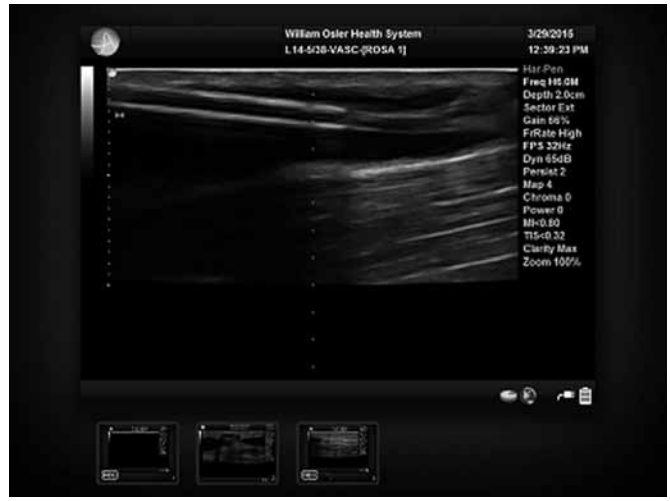

Fig. 6 - Ultrasound image of the jet flow effect inside the vessel lumen. The flow directed to the center of the vessel lumen shows as two white parallel bands beyond the tip of the plastic cannula.

Flow image patterns at needle sites

Observations of flow images at venous cannulation sites show very distinct patterns with the two types of needle designs. Images obtained with metal needles showed that the jet flow effect appeared to be a solid stream projected towards the vessel wall. In contrast, the image appeared diffuse extending from the side holes to the tip of the cannula, towards the center of the vessel lumen. In both types of needles, the blood-flow pattern became wider upstream; this may represent a higher level of turbulence consistent with higher velocities obtained at a distance of 4 cm compared to 2 cm from the needle tip in the Doppler studies mentioned above. An ultrasound image of blood-flow pattern from a plastic cannula inside the vessel lumen at a venous access site is shown in Figure 6.

A study comparing the hemodynamic effects of these two types of needles in the development of complications at cannulation sites is underway in Canada.

Summary and conclusions

Optimal cannulation practice is necessary for prolonging survival in vascular access for hemodialysis. The importance of the effect of needle trauma during cannulation or needle repositioning and the effect of hemodynamic trauma at needle cannulation sites during dialysis treatment cannot be overstated.

The definition of successful cannulation needs to incorporate the amount of needle repositioning required to place the needle to obtain adequate blood flow: "successful cannulation is the insertion of a dialysis needle through the skin into the vessel lumen **in one single stroke,** without the need to reposition the needle to obtain adequate flows for hemodialysis treatment".

The use of ultrasound at the bedside is recommended when available. Partnership between hemodialysis vascular clinical groups and Industry is helping develop ultrasound

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technology that is hand-held, user-friendly, and easy to learn. Field evaluation of this equipment is taking place in some Canadian dialysis units.

Disclosures

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