

Original Article

Exit of catheter lock solutions from double lumen acute haemodialysis catheters—an *in vitro* study*

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Abstract

Background. Double lumen dialysis catheters are routinely heparin or citrate 'locked' to maintain patency. Heparin lock-related bleeding episodes and antibiotic lock-related toxicity have been reported. The aim of this study is to quantify the amount of leak during 'lock' procedures and to compare leakage for different double lumen dialysis catheters.

Methods. In an experimental, *in vitro* study at a University research laboratory, five different double lumen dialysis catheters were tested using three different lock volumes.

Results. Using the catheter flush volume, leak ratios for Flexxicon II 15 cm and 20 cm catheters were greater than that seen in the Arrow 16 cm catheter ($P < 0.05$). Using 20% less than the catheter flush volume, the Flexxicon II™ 20 cm catheter had greater leak than the Duo-flow 15 and 20 cm catheters and Arrow 16 cm catheter ($P < 0.05$). The Flexxicon II™ 15 cm catheter had greater leak than the Duo-flow 15 cm and Duo-flow 20 cm catheters with 20% less locking volume ($P < 0.05$). Using 20% greater than the catheter flush volume, the Duo-flow 20 cm catheter had significantly less leak ratio than the Flexxicon II™ 20 cm catheter ($P < 0.05$). There were no other significant differences in leak ratios between the catheters.

Conclusion. All double lumen dialysis catheters we tested have a substantial amount of leak even when the catheter 'lock' volumes were used, and leak ratio increases significantly with 20% overfill. There is a leak even when using 20% less 'lock' volume. The amount of leak can be clinically important and may

explain the reports of bleeding episodes after heparin lock and antibiotic toxicity after antibiotic and anticoagulant combination lock. Some devices have lower leak ratios than others, likely related to catheter design.

Keywords: complications; dialysis catheter; heparin; heparin leak

Introduction

Short-term percutaneous dual lumen dialysis catheters are frequently used in critically ill patients with acute or chronic renal failure for haemodialysis. A high concentration of heparin or other anticoagulant solution is routinely used to fill and 'lock' the catheter to maintain patency after the haemodialysis session. According to Poiseuille's law, the concentration of locking solution will be higher in the middle of the lumen compared to the periphery of the lumen [1]. Because a clotting and biofilm layer that leads to infection initially occurs at the catheter wall, it has been suggested that catheters be overfilled by 20% to achieve appropriate concentrations of drugs at the tip and wall of the catheter. However, the exit of the drug into the bloodstream may cause systemic adverse effects. Although we lock each lumen of the catheter with a volume of heparin equivalent to the volume of the lumen, we have long suspected that using these volumes causes systemic anticoagulation, based upon anecdotal observations of unexplained elevations of aPTT or generalized oozing of blood from surgical or puncture sites. This complication may be particularly detrimental for post-operative patients. Application of Poiseuille's law predicts overspill of the locked volume even with catheter locking volumes [1].

Density differences as a cause of locking solution leakage has been reported [2]. Fluid exchange

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occurs between plasma and locking solution if the density of locking solution is greater than plasma [1].

Several authors have confirmed the risk of heparin lock-related bleeding when using indwelling haemodialysis catheters. Significant increases in the aPTT values, measured after heparin lock in patients with cuffed tunneled catheters, have been observed [3,4]. Systemic anticoagulation and life threatening bleeding in children with haemodialysis catheters have been reported in four patients [5]. In a randomized clinical study comparing trisodium citrate vs heparin as the catheter-locking solution, major bleeding episodes were significantly more likely in patients with heparin-locked catheters [6]. Significant early and late leakage from the catheter occurs after performing a catheter lock [7].

The aim of this *in vitro* study was to evaluate if leakage occurred, and to compare the amount of leakage in temporary dialysis catheters of different sizes and from various manufacturers. We also evaluated the effect on leakage when using 20% less or 20% greater volume than the manufacturer stated catheter volume.

Materials and methods

Five different double lumen haemodialysis catheters were used: (i) Vas-cath® Flexxicon II™ (Bard Access Systems Inc., Salt Lake City, Utah) 15 cm with an arterial and venous lumen volume of 1.2 ml each; (ii) Vas-cath® Flexxicon II™ 20 cm with an arterial and venous lumen volume of 1.4 ml each; (iii) Arrow Blue FlexTip 16 cm catheter (Arrow International, Inc., Reading, PA, USA) with an arterial lumen of 1.3 ml and venous lumen volume of 1.4 ml; (iv) Medcomp Duo-flow 20 cm catheter (Medcomp, Harleyville, PA, USA) with arterial lumen of 1.1 ml and venous lumen of 1.4 ml and (v) Medcomp Duo-flow 15 cm catheter with an arterial lumen of 1.2 ml and venous lumen of 1.1 ml.

Each catheter was flushed and locked with distilled water. The tip of the catheter was immersed into a test tube containing 50 ml distilled water. The tip of the catheter was positioned at a depth of 10 cm to mimic central venous pressure of approximately 6–8 mmHg. After positioning, each catheter lumen was filled and locked with a 5% dextrose solution, using the volumes indicated on the catheter by the manufacturer. Injection time was 2 s for each port. The catheter was removed within 5 s and the solution in the test tube stirred with a magnetic stirrer, and then a sample of 2 ml was obtained from the test tube to measure dextrose concentration in the test vessel. The procedure was repeated three times on each catheter for reproducibility. The same experiment was then performed using 20% greater and 20% less dextrose volume than catheter volume. All procedures were performed by the first two authors using a standardized method.



Fig. 1. *In vitro* model used to test the catheters.

The leak volume was calculated with the following formula:

$$\frac{1}{50 \text{ (mg/ml)}} \times \left[\text{Measured glucose (mg/ml)} \times (\text{Volume of free water [50 ml]} + \text{injected volume}) \right]$$

Leak ratio (%) calculated with the following formula:

$$\frac{\text{Leak volume} \times 100}{\text{Injected volume}}$$

We compared leak ratios instead of leak volumes because catheters have different sizes and filling volumes.

In the second part of the experiment, a methylene blue solution was injected in the volumes as noted earlier, to allow observation of leak pattern of the individual catheters (Figure 1). Photographs were taken during the injection process using a 10.1 megapixel Nikon D80 digital camera, and the leak patterns of the catheters were analysed qualitatively.

Statistical analysis

The data were analysed using Sigma Stat (SPSS, version xv, 1997). The data are expressed as mean \pm 1 SD. Data were analysed for normality and then one-way analysis of variance (ANOVA) was used to compare data. Alpha was set at ≤ 0.05 for statistical significance.

Table 1. Catheter leak volumes with each catheter

Flush volume	Catheters leak volumes (ml ± SD)				
	Flexxicon II™ 15 cm	Flexxicon II™ 20 cm	Duo-flow 15 cm	Duo-flow 20 cm	Arrow 16 cm
Catheter volume (CV) (ml) (A/V lumens)	1.2/1.2	1.4/1.4	1.2/1.1	1.1/1.4	1.3/1.4
Flush with CV	0.71 ± 0.02	0.85 ± 0.06	0.46 ± 0.16	0.54 ± 0.08	0.49 ± 0.2
20% < CV	0.33 ± 0.06	0.48 ± 0.03	0.16 ± 0.01	0.12 ± 0.05	0.18 ± 0.05
20% > CV	1.18 ± 0.02	1.43 ± 0.02	0.99 ± 0.03	0.96 ± 0.08	1.08 ± 0.07

A/V, Arterial and venous.

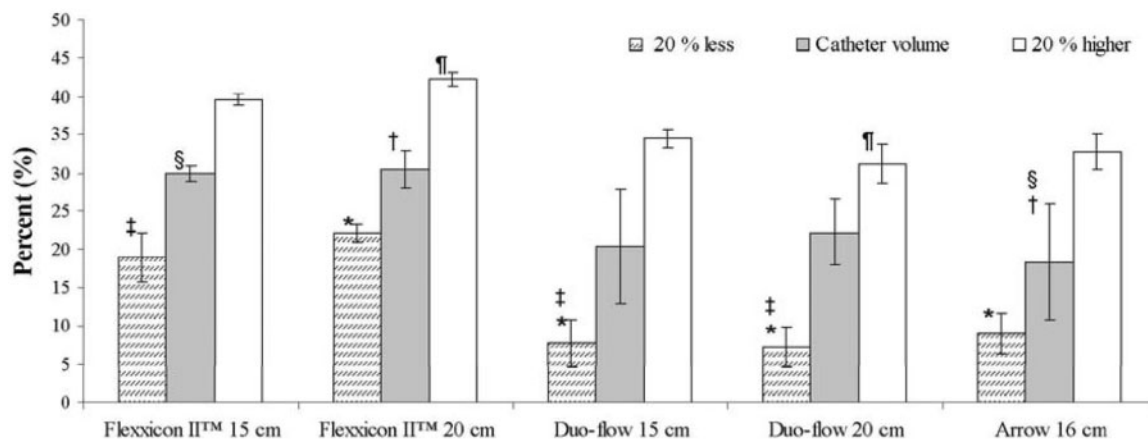


Fig. 2. Leak ratios with three different catheter locking volumes. * $P < 0.05$ compared to Flexxicon II 20 cm catheter; † $P < 0.05$ compared to Flexxicon II 20 cm catheter; ‡ $P < 0.05$ compared to Flexxicon II 15 cm catheter; § $P < 0.05$ compared to Flexxicon II 15 cm catheter; ¶ $P < 0.05$ compared to Flexxicon II 20 cm catheter.

Results

The leak volumes for all catheters at all filling volumes are shown in Table 1. There are some significant differences in leak ratios (Figure 2).

Using the catheter flush volume, the average leak volume was 0.61 ± 0.18 ml. Compared to the Flexxicon II™ 15 and 20 cm catheters there was significantly less leakage with the Arrow 16 cm catheter ($P < 0.05$). There were no other statistically significant differences between the catheters when catheter locking volumes were used.

Using a lock volume 20% less than the catheter flush volume, both Flexxicon II™ 15 and 20 cm catheters had a significantly higher leakage ratio than Arrow 16 cm, Duo-flow 15 cm and Duo-flow 20 cm catheters ($P < 0.05$). There were no other significant differences between the catheters with this volume.

Using a catheter lock volume 20% greater than catheter flush volume, the Duo-flow 20 cm catheter had significantly less leak ratio than the Flexxicon II™ 20 cm catheter ($P < 0.05$). There were no other significant differences between the catheters.

Most of the leakage occurred from the most proximal holes of catheters and only a small amount

occurred from the holes closest to the most proximal hole corresponding to that catheter port (Figure 3).

Discussion

This *in vitro* study showed that all of the tested double lumen temporary dialysis catheters had leakage using either the catheter volumes or even using 20% less than the catheter volume. Overfilling the catheters by 20%, which could easily happen in a clinical situation, resulted in significant increases in leak volume.

Double lumen dialysis catheters are filled with heparin or citrate at the end of each dialysis session to prevent catheter clotting. We tested five different double lumen dialysis catheters currently in use in our intensive care unit. When the catheter volume was used, all catheters leaked volumes that ranged from 0.46 to 0.85 ml, corresponding to an 18–30% leakage of injected volume, depending upon the size and manufacturer of the catheter. For this study, we used 5% dextrose rather than heparin as the 'lock' solution for ease of measurement, as there is significant difficulty in measuring heparin levels with accuracy in such a small volume.



Fig. 3. Leak pattern demonstrated with methylene blue injection. Leak from the proximal side hole.

Clinically, we use a heparin concentration of 5000 U/ml to lock these catheters. The volume of leakage we have observed in this study correlates to inadvertent intravenous administration of 2300–4250 U of heparin with each locking procedure. This amount may double when 10 000 U/ml of heparin is used. Leakage of lock solution begins when ~80% of the lock solution is injected. When the catheter filling volume is injected, the mean concentration at the tip of the catheter is ~90% of the locking solution's concentration [1]. Dialysis catheters may also be filled with higher volumes than the catheter volumes using diluted heparin solutions to prevent clotting [8]. Polaschegg and Shah recommended 20% overfill of the catheter with the locking solution to achieve full strength [1]. The present work suggests that leakage of catheter lock solution increases significantly with 20% overfill of locking solution. One should consider possible unwanted systemic effects of locking solution, especially when overfill volume is used.

Prior to our work, it was reported that instillation of the catheter filling volume results in an overspill of ~17–20% [1]. There is significant methodological variation between that work and ours, as the catheter used by those investigators was a long-term tunneled catheter without side holes. Our short-term catheters, on the other hand, were conically shaped and have side

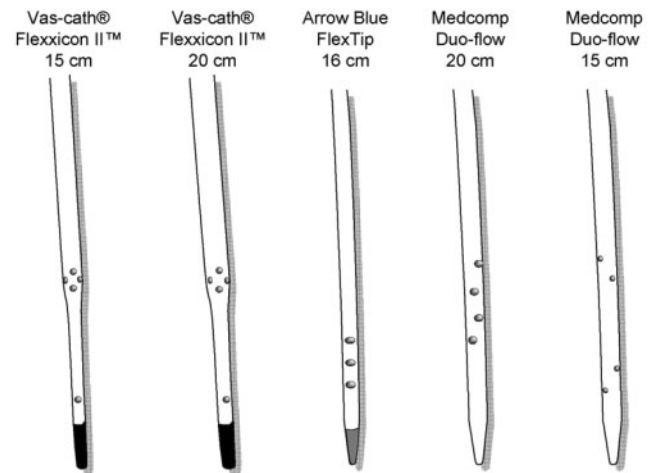


Fig. 4. The tip designs of the catheters that authors have used.

holes through which a large portion of the catheter lock solution escapes, primarily from the most proximal side hole [4]. Locking solution is presumably forced out of the side holes because of the increased resistance to flow at the tip of the catheter secondary to its conical shape. This leak pattern—leakage through the proximal-most port—was observed in all catheters. The tips designs of the catheters we have used are illustrated in Figure 4. All catheters had sharply tapered tips for ease of placement. Flexxicon catheters had more leak ratios than the other catheters. The most striking difference in design of Flexxicon catheters from the others is at the tip of the catheter: the distal end of the Flexxicon catheters is significantly longer compared to the other designs. This longer tapering creates a more narrowed lumen. The resistance of the catheters to flow increases exponentially as luminal circumference decreases. Thus the Flexxicon catheters likely have a more significant leakage because of increased flow resistance secondary to long narrowed tips. This principle should be considered in the catheter design process.

Our results may explain the study of five children and adolescents, all with previously normal coagulation panels, who developed inadvertent systemic anticoagulation and bleeding complications when a high concentration of heparin was used to lock their dialysis catheters [5]. Insufficient aspiration of heparin locked into the catheter, inaccuracy of the internal volume indicated on the catheter, giving a larger volume than the actual catheter volumes during the heparin lock procedure due to human error and 'leaching' of heparin into the patient during the intradialytic period, are noted as possible reasons for haemorrhagic complications after heparin locking of a dialysis catheter [5]. The National Kidney Foundation guidelines do not give any options on how to prevent catheter thrombosis [9]. A very significant increase of the aPTT values has been noted 10 min after the injection of a heparin containing solution into the

catheter lumens [8]. In this study, the patient-to-control ratio of aPTT was 3.58 ± 0.61 .

Consistent with our results, Agharazii [7] quantified the amount of leakage from double lumen dialysis catheters in an *in vitro* study [7]. Using two different haemodialysis catheters, the catheter leak was estimated to be 0.59 ± 0.03 ml just after simulated heparin lock with the catheter volume. The leak increased 5, 15 and 30 min after the simulated heparin locking. There was no significant difference between catheters. These results are consistent with our findings. We compared five different double lumen dialysis catheters with three different volumes and found an average leak volume of 0.61 ± 0.18 ml.

Inadvertent systemic heparinization can be devastating in surgical patients. Our *in vitro* study demonstrated that filling and locking the dialysis catheter lumen with the volume of the catheter results in considerable leakage outside the catheter, and the quantity of leakage may differ with different brands of dialysis catheters. Moreover, if the volume of heparin used for locking is greater than the catheter volume, the leak increases significantly and this may result in a dangerous situation for surgical patients. Measurable plasma concentrations of gentamycin were reported with the use of gentamycin-citrate catheter lock solution and 10% of those patients developed aminoglycoside-related ototoxicity when using 0.2 ml overfill of the catheter volume [10].

It has previously been shown in an *in vitro* study that increase amount of bathing times for the catheter increases the amount of leakage [7]. While locking our catheters, we used an injection time of 2 s to mimic our clinical practice. Injection time can affect leakage through the catheter. To the best of our knowledge the most optimal injection time of lock solution is unknown. Additionally, in this study, we evaluated for immediate catheter leakage after locking, which is the time most of the leakage occurs.

The use of trisodium citrate as a catheter lock solution may be more appropriate than heparin, because any trisodium citrate that leaks into the circulation will bind to calcium and will be inactivated [6]. Thus, sodium citrate may be the agent of choice for patients at high risk of bleeding. It was recently shown that 1000 U/ml heparin lock solution may be as effective as 10 000 U/ml heparin lock solution [11]. Using low concentration heparin lock solution may

help prevent bleeding complications in high-risk patients.

Although the optimal volume and concentration of locking solutions used for each type of haemodialysis catheter remains to be determined, we recommend that double lumen dialysis catheters not be 'locked' with more than the catheter volume. A 20% overfill may increase leak ratio significantly and should be avoided. In patients at high risk of bleeding, the provider must weigh the beneficial effects of maintaining catheter patency with heparin against the risk of potential bleeding.

Conflict of interest statement. None declared.

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