Short Paper

Comparative evaluation of straight and curved extension dialysis catheters for continuous renal replacement therapy in dogs with acute kidney injury

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10.22099/IJVR.2023.47626.6883

(Received 12 Jun 2023; revised version 1 Dec 2023; accepted 16 Dec 2023)

Abstract

Background: A patent dual-lumen dialysis catheter is one of the basic requirements for efficient extracorporeal (EC) therapy. **Aims:** The objective of this study was to measure the resistance to blood flow offered by straight and curved-extension dual-lumen dialysis catheters used for continuous renal replacement therapy (CRRT). **Methods:** Twenty dogs suffering from acute kidney injury (AKI) were subjected to CRRT. The dogs were allocated randomly to Group-I (curved extension catheter, n=12) or Group II (straight extension catheter, n=8), based on the type of dual-lumen catheter used in CRRT. The catheter outflow and inflow pressures were recorded at blood pump speeds of 50 ml/min and 99-100 ml/min. Data were tested for normality, and differences in mean inflow and outflow catheter resistances were evaluated for statistical significance using independent samples t-tests. **Results:** Straight extension catheters offered lower inflow resistance than curved extension catheters at both 50 ml/min (41.50 ± 5.84 mm Hg *vs.* 63.75 ± 6.88 mm Hg, P=0.03) and 99-100 ml/min (63.00 ± 8.11 mm Hg *vs.* 86.92 ± 7.02 mm Hg, P=0.04) blood flow rates. Straight extension catheters also offered lower outflow resistance than curved catheters at 99-100 ml/min blood flow rate (-94.12 ± 7.91 mm Hg *vs.* -128.25 ± 7.56 mm Hg, P=0.01; the negative signs only indicate the direction of blood flow). **Conclusion:** These findings suggest that straight-extension dual-lumen dialysis catheters perform better than the curved model in extracorporeal renal replacement therapy by considering their lower resistance to blood flow.

Key words: Acute kidney injury, Blood flow resistance, Dog, Continuous renal replacement therapy, Dialysis catheters

Introduction

Acute kidney injury (AKI) is generally characterized by an abrupt reduction in kidney function and/or reduced urine output. It is an ongoing process resulting in reduced functional mass (Mehta *et al.*, 2007; Porschen *et al.*, 2023) and may or may not lead to renal failure (Thoen and Kerl, 2011). Due to the dearth of renal-specific therapeutic agents, advancement in the management of AKI has been in the area of renal replacement therapy (RRT). Renal replacement therapies can effectively restore electrolyte, acid-base, and fluid balances. Moreover, RRT can help eliminate retained uremic toxins that prolongs the survival time and improves the potential for recovery (Segev *et al.*, 2013). Vascular access is one of the primary requirements for successful RRT (Chalhoub *et al.*, 2011), and its adequate patency facilitates management of the extracorporeal (EC) blood circuit (Tan *et al.*, 2002). Appropriate functioning of the catheter during continuous renal replacement therapy (CRRT) allows effective and adequate urea clearance. In animal practice, jugular vein access is the preferred location for small animals, and central venous catheters are the conventional method for vascular access (Chalhoub *et al.*, 2011). Clinicians may find it easier to select an appropriate catheter and prevent vascular access dysfunction by being aware of the facts regarding resistance to blood flow displayed by catheters with various designs. Data on blood flow resistance caused by various kinds of catheters during canine CRRT has not been reported before, as far as the authors are aware. Therefore, the purpose of this study was to compare the resistance offered by straight and curved-extension dual-lumen dialysis catheters in dogs undergoing CRRT.

Materials and Methods

Animal selection

This study was approved by the institutional animal care and use committee (DPV-M-13011-VMD). Written informed consent was obtained from each owner before conducting the procedures.

Clinical cases confirmed as suffering from AKI were classified based on the International Renal Interest Society's (IRIS) 2013 classification. The clinical signs documented in these dogs included anorexia, vomiting, melena, halitosis, oliguria, anuria, and oral ulceration. Blood gas analysis and serum electrolyte evaluation revealed metabolic acidosis, hyperkalemia, and hyperphosphatemia as major changes. Twenty dogs [Grade IV (blood creatinine 5.1-10.0 mg/dL) n=5; Grade V (blood creatinine >10.0 mg/dL), n=15] were subjected to CRRT and allocated randomly to Group-I (Curved extension catheter, n=12) and Group-II (straight extension catheter, n=8) based on the type of Quinton-Mohurkar dual-lumen catheter used in CRRT. There were 15 male dogs and 5 female dogs with an age range of 1 to 12 years. The dogs included 10 Labrador Retrievers, 3 German Shepherds, and 1 each of Doberman Pinscher, Chippiparai, Dalmatian, Rottweiler, Spitz, mixed-breed, and non-descript breeds.

CRRT procedure

An 11.5 Fr × 13.5 cm Quinton-Mohurkar dual-lumen dialysis straight catheter (with straight and curved extension) was placed into the left jugular vein (Figs. 1a-d) of dogs by the Seldinger technique (Davenport, 2004) using a J-guide wire and venodilator under local anesthesia (lidocaine 2%). No sedatives were given during the study period. The catheter was advanced down the vein until the tip was located close to the level of the right atrium. Each vascath lumen of the catheter was heparin-locked (ampule 5000 units in 5 ml) to prevent clotting. Heparin locking solution was aspirated before use. The catheter placement was confirmed by digital radiography in each patient. The catheter was secured, by stay sutures and the cutaneous site was treated with povidone-iodine, followed by a protective bandage during the CRRT and an adhesive elastic bandage on termination of the treatment.

Following the stabilization of blood flow after 1 min of the patient being attached to the circuit, the catheter outflow (Ro) and inflow (Ri) pressures (resistance) were measured at a blood flow speed (QB) of 50 ml/min. The blood flow rate was kept at 50 ml/min for the first measurements of the pressure before increasing to 99-100 ml/min for the next 5 min. The Prisma machine (Gambro Prismaflex, Gambro Lundia AB, SE-22010, Lund, Sweden) with in-built pressure transducers was used to record the outflow and inflow pressures. At least five readings were taken at each blood flow over the course of the therapy, and an average of the readings was utilized for analysis. On the first day of therapy, all patients had their catheters examined. Each patient was given access to the catheter's proximal lumen. From 8 to 22 h were spent on the therapy.

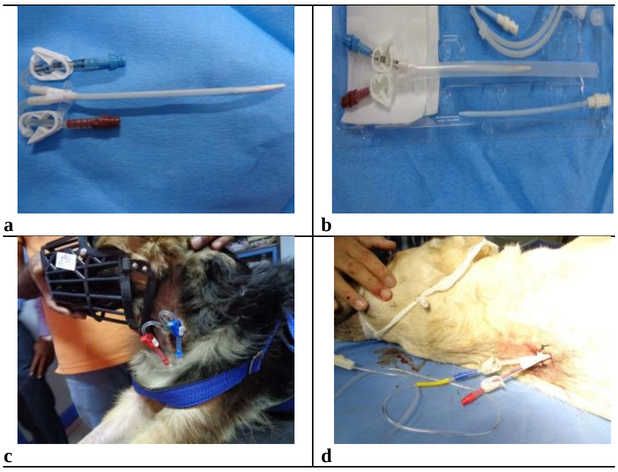


Fig. 1: Quinton-Mohurkar catheter placement by Seldinger technique for continuous renal replacement therapy. (**a**) Curved catheter, (**b**) Straight catheter, (**c**) Curved catheter placement by Seldinger technique, and (**d**) Straight catheter placement by Seldinger technique

Selection of treatment mode

In this investigation, a postdialyzer setup with continuous venovenous hemodiafiltration (CVVHDF) as the treatment modality was employed. Anticoagulation: A 500-ml solution containing 5000 units of heparin and 0.9% normal saline was used to prime the PrismaFlex CRRT circuit. This makes it easier for heparin to attach to the filter membrane, which is important to keep the membrane from clotting. The Louisiana State University heparin work sheet was used to monitor patients during CRRT (Acierno, 2011).

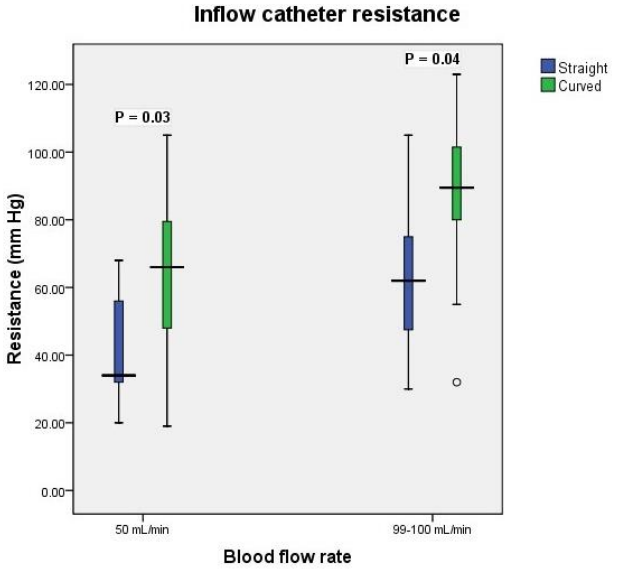
Statistical analysis

Data were analyzed using SPSS Statistics 17.0 software (SPSS Inc., Chicago, IL). The Shapiro-Wilk and Kolmogorov-Smirnov tests were used to evaluate normality. As the data were normally distributed (P>0.05), differences in inflow and outflow resistance between straight and curved extension catheters at the two specified blood flow rates were evaluated for statistical significance by an independent samples t-test. Differences with P-values less than 0.05 were considered to be statistically significant. Results are presented as mean ± standard error (mean±SE).

Results

The mean inflow resistance offered by straight extension catheters was lower than the resistance offered by curved extension catheters at 50 ml/min (41.50 ± 5.84 mm Hg *vs.* 63.75 ± 6.88 mm Hg, P=0.03) and 99-100 ml/min (63.00 ± 8.11 mm Hg *vs.* 86.92 ± 7.02 mm Hg, P=0.04) blood flow rates (Fig. 2a). Straight extension catheters also offered lower outflow resistance than curved extension catheters at 99-100 ml/min blood flow rate (-94.12 ± 7.91 mm Hg *vs.* -128.25 ± 7.56 mm Hg, P=0.01; the negative signs only indicate the direction of blood flow). A similar numerical trend was observed at 50 ml/min blood flow rate (-69.00 ± 6.68 mm Hg *vs.* -82.08 ± 6.78 mm Hg, P=0.21), however, the difference was not statistically significant (Fig. 2b). The inflow and outflow resistances for both catheters showed a consistent rise when the blood flow rate was increased from 50 ml/min to 99-100 ml/min.

a



b

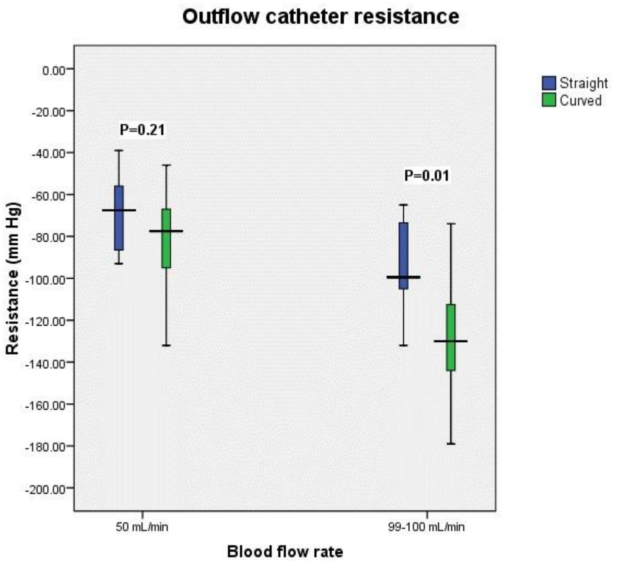


Fig. 2: Box and whisker plots showing inflow catheter resistance (**a**), and outflow catheter resistance (**b**) offered by straight and curved catheters. Within each blood flow rate, P<0.05 indicate a significant difference in mean resistance between the two groups. By convention, inflow catheter resistance is expressed as positive and outflow catheter resistance is expressed as negative. The positive and negative signs only indicate the direction of blood flow and not the actual measurements

Discussion

Continuous renal replacement therapy is commonly used in critically ill human patients with acute kidney injury (Ronco *et al*., 2001; Kim *et al*., 2011; Tandukar and Palevsky, 2019). However, due to a lack of facility and expertise, CRRT is not widely used in small animal practice. The efficacy of CRRT depends on the continuous patency of the extracorporeal circuit (EC). Patented vascular access is a major prerequisite for successful treatment delivery and adequacy. Clot formation in the catheter, however, remains as a major concern that reduces CRRT adequacy and access lifespan that results in frequent circuit breakdowns. Moreover, a continuously patent catheter allows for smooth and efficient patient management. Prolongation of a continuously patent EC is of central importance and is usually accomplished by anticoagulation. An increase in systemic/circuit anticoagulation dose is a common response to frequent EC clotting. However, this methodology leads to an increased risk of bleeding and ignores the factors related to inadequate vascular access that may be of similar importance in the pathogenesis of circuit clotting (Tan *et al*., 2002).

In our study, catheters showed different blood flow resistances against the specified blood flow rates, which is in congruence with Tan *et al*. (2002) who reported that dual-lumen catheters offer variable resistances to blood flow under standard *ex-vivo* conditions. Straight extension catheters offered lower resistance as compared to curved extension catheters and proved to be a better choice for CRRT. Higher blood flow resistance may result in access pressure alarms indicating a failure to maintain EC blood flow. In a human study, catheter dysfunction, either due to infectious or noninfectious complications, led to increased mortality in the affected population (Miller *et al*., 2016). However, such studies are lacking in veterinary medicine. Moreover, catheter function decreases with time since thrombosis or stenosis develops gradually (Chalhoub *et al*., 2011).

Acute kidney injury cases in small animals are often hemodynamically unstable as a result of fluid, electrolyte, and acid-base imbalance (Bloom and Labato, 2011). In these animals that receive renal replacement treatment, catheter dysfunction is a significant problem. Numerous hemodynamic parameters encourage thrombosis and blood flow stagnation. These elements include vascular remodeling as a result of damage, restenosis brought on by surgical manipulation, vessel shear strain, and pressure (Walsh and Mclachlan, 2006). By altering expression at the cellular level, vascular endothelial cells can detect and react to pressure changes imposed on them, particularly oscillatory pressure fluctuations (Walsh and Mclachlan, 2006). Moreover, this response may be aggravated by the high resistance offered by the dual-lumen catheters causing oscillatory pressure changes that perpetuate the endothelial pathological response. Therefore, a vicious cycle sets in, which corrodes the adequacy of CRRT (Tan *et al*., 2002). These factors are usually unavoidable; however, the type and design of catheters chosen can be manipulated and might help reduce several stressors impairing blood flow. This notion appears to be supported by the present study, which demonstrates that catheter performance measured as inflow and outflow resistance to blood during CRRT varies according to the design of the catheter. Further studies are required to investigate the endothelial changes associated with the use of different catheters during CRRT in dogs.

The present study has some limitations that should be considered while interpreting or applying its findings. Since a completely randomized design was followed for the allocation of the patients to the two study groups (curved and straight extension catheters), there was an unequal sample size in the two groups. A strength of this approach, though, is that it minimizes selection bias. Another limitation of the study was the use of a single-length catheter in all dogs due to the non-availability of different-length catheters. However, the study involved small and medium-sized dogs, and catheters were inserted in the middle to lower third of the jugular vein to ensure that the catheter tip was close to the level of the right atrium. Nevertheless, the findings should be interpreted with caution, considering the potential confounding effect of catheter length in dogs with different sizes. The impact on comparison between the straight and curved extension catheter groups is likely minimal, though, because the dogs were allocated randomly to the two groups. The small sample size of this study is also a limitation, and, therefore, the findings need to be confirmed in further studies involving larger populations of AKI-affected dogs undergoing CRRT. Finally, catheters were placed in the left jugular vein of all of the dogs used in this study due to the attending clinicians' preference for the left side. Although catheter placement on the same side in all the dogs minimizes confounding, the selection of the left side limits the potential extrapolation of results to a general canine population in which the right jugular vein is catheterized more often than the left jugular vein. Further studies involving more optimal placement of the catheters are required to confirm the preliminary findings of this study.

In conclusion, the results of the current study indicate that straight-extension Quinton-Mohurkar dialysis catheters offer lower outflow and inflow resistance than the curved extension model in dogs undergoing CRRT. Further studies are required to confirm these findings in a larger population.

Acknowledgements

The authors are thankful to the dog owners for their cooperation and the supporting staff members for their assistance.

Conflict of interest

The authors declare that they have no competing interests.

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