In-vitro Validation of Catheter Recirculation Measured by Thermal Dilution

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Abstract—**Introduction: Increasing numbers of end-stage renal disease patients are becoming dependent on hemodialysis catheters (HCs) for chronic hemodialysis access. Recirculation measurement is considered as useful to check for inadequate catheter blood flow and blood clots at the catheter tip. HCs normally have the outflow tip extending approximately 2 to 3 cm beyond the inflow tip to prevent blood recirculation (R) during dialysis. The purpose of this study is to assess the accuracy of recirculation measurements based on the thermal dilution technique.**

Methods: R was measured in-vitro with a blood temperature monitor (BTM, Fresenius Medical Care, Germany) using temperature sensors placed on the arterial and venous segment of the extracorporeal blood line. Hereby R was physically prevented by placing a flexible hose over the venous outflow tip of the catheter.

Results: Recirculation with standard lumens of well-functioning catheters is normally negligible. However, thermal dilution techniques applied to dual lumen catheters always result in positive R values which increase with decreasing blood flow. As arterial and venous catheter lumens are in direct contact, temperature boli which are injected in the venous lumen are partly transferred through the catheter wall to the arterial lumen.

Conclusion: BTM thermodilution measurements with non-recirculating dual lumen catheters always yield positive recirculation results. Furthermore the displayed R value is dependent on extracorporeal blood flow and decreases with increasing flow.

Keywords— **Recirculation, catheter, access, hemodialysis.**

I. Introduction

In acute renal failure, percutaneous dual lumen hemodialysis catheters (HCs) have become the standard for temporary access because they can be used in virtually any patient. They are easily inserted at the bedside, and - unlike fistulas - are suitable for immediate use following insertion. Several types of catheters are available for clinical use, including short peripheral catheters, peripherally inserted central venous catheters, non-tunneled central venous catheters used for short term application, and tunneled central venous catheters used for long term application or as "desperate access". In clinical practice, however, catheter malfunction is still a major problem associated with the use of these catheters, leading to infection and/or insufficient blood flow rates [1]. It is obvious that the development of new catheter designs aiming at an optimization of hydraulic flow properties is mandatory to enhance the quality of catheter based hemodialysis treatments [2]. Despite of this development, inadequate delivery of blood flow is still a matter of complaint from clinicians. In this context, catheter malfunction is often defined as the inability to deliver a high and stable blood flow or recirculation values above 5% [3,4].

Recirculation is defined as the fraction of cleared extracorporeal blood flow that returns to the inlet of the arterial blood line without systemic equilibration [5]. Assuming that blood flow in the vena cava superior is above 2000-3000 ml/min and that the arterial catheter tip of a well-functioning catheter is placed near the right atrium, one can expect mean recirculation values close to zero. However, as recirculation in well-functioning catheters is expected to be around zero, the origin of measured in-vivo recirculation values between 1-5% is still unclear [6]. The purpose of this study is to evaluate factors influencing the degree of recirculation measured with the thermal dilution technique.

II. Results

Recirculation measurements were performed with a blood temperature monitor (BTM, Fresenius Medical Care, Germany). The BTM is a plug-in module that can be implemented into the 4008 and 5008 series of Fresenius dialysis machines. The best description of the device can be found in a publication of D. Schneditz and coworkers [5]. Two sensors which hold the blood lines at 1,5m distance from the Luer-Lock connectors of the catheter record the temperature of arterial and venous blood tube. The precision of the temperature measurement is better than 0,1°C for blood flows above 120 ml/min. During recirculation measurements, a thermal bolus is automatically produced by decreasing or increasing the dialysate temperature by 2.5-3°C for a period of 3-5 minutes. The whole procedure is fully automated, so a manual injection of cool saline is not necessary. The hemodialyzer serves as a very good heat exchanger, and thus the temperature bolus on the dialysate side is nearly completely transferred to the venous blood side of the extracorporeal circuit. The fraction of cool venous blood re-entering the arterial blood line is measured, and the amount of recirculation is calculated according to equation (1). Hereby ΔT_{art} and ΔT_{ven} represent the arterial

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and venous temperature changes of the blood lines monitored by the sensor heads of the BTM.

$$R = \frac{\Delta T_{art}}{\Delta T_{ven}} \quad (1)$$

All experiments were carried out using a commercially available device for renal replacement therapy (FMC 4008, Fresenius Medical Care AG, Germany) which was equipped with the BTM device. Effective extracorporeal blood flow was measured with an ultrasound Doppler monitor (HD01, Transonic Inc., USA). A 20-liter water bath at a constant temperature of 37°C simulated the patient. During all measurements the dialysis machine was set to standard hemodialysis treatment without ultrafiltration. Room temperature was 22-23°C. HCs were connected to the ends of the blood lines and immersed in the water bath. The venous catheter tip was equipped with a 4 meter flexible hose, and the venous return flow went through a second 20-liter water bath at a temperature of 37°C before re-entering the first bath (Figure 1). This was done to assume full equilibration of the venous thermal bolus.

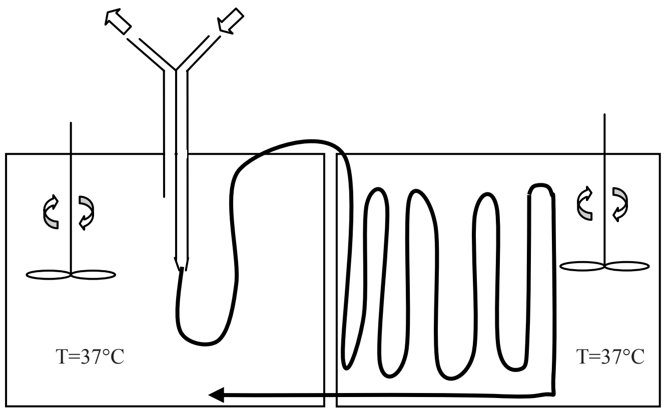

Fig. 1: Experimental set-up

The absence of R was checked in a first series of experiments without dual lumen catheters. Hereby the arterial and venous Luer-Lock connectors were directly placed in the water bath at a distance of 2 cm, with the venous Luer connected to the flexible 4m hose. R values were 0,5±0,3 and thus negligible.

After HC connection, 15 repeated R measurements were performed. Time delay between measurements was 5 min. Figure 2 shows measured R ± standard deviation (SD) as function of effective extracorporeal blood flow QB for a straight 12.5French Soft-Cell dual lumen catheter with 19cm insertion length (Bard Access Systems, USA). It is evident from the reported data that even in absence of recirculation the displayed values of the BTM are positive. The interpretation of this result suggests that a temperature transfer within the HC housing causes a systematic error. As arterial and venous catheter lumens are in direct contact, temperature boli which are injected into the venous lumen are partly transferred through the catheter wall to the arterial lumen. This is especially evident for blood flows below 200ml/min.

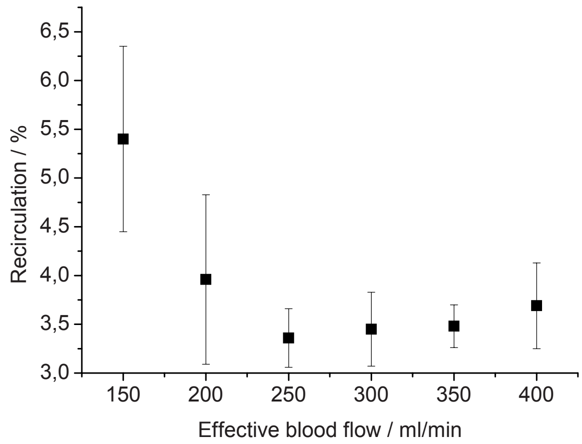

Fig. 2: Mean R±SD as function of effective blood flow.

III. Conclusions

Catheter recirculation occurs if blood returning from the venous lumen re-enters the arterial lumen without passage of the systemic circulation. It is widely accepted that the assessment of catheter recirculation helps to identify HCs with in- or outflow problems. Our study shows that even in absence of recirculation, measured R is 3-5% for a blood flow above 200 ml/min. It follows that BTM thermodilution measurements with dual lumen catheters include effects caused by a temperature transfer between the arterial and venous catheter lumen. However, a BTM based recirculation of more than 5% with a minimum blood flow of 200 ml/min will still be significant for real catheter recirculation.

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