Pressure Profile Analysis at Hemodialysis Needle: a New Method for Early Detection of Vascular Access Stenoses

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I. Introduction

HEMODIALYSIS vascular access complications, such as thromboses due to flow limiting stenosis, are a major cause of morbidity and mortality in chronic renal failure patients [1, 2]. The Kidney Disease Outcomes Quality Initiative (K/DOQI) clinical practice guidelines define a stenosis significant at 50 % diameter reduction, accompanied by a hemodynamic or clinical abnormality [1]. Since, flow limitation and pressure drop rise appear only at a diameter reduction above 70%, the current vascular access surveillance techniques (flow measurements and static-access pressure measurements) are unable to detect early stenosis (<50% diameter reduction) and cannot further reduce the incidence of vascular access failure due to thrombosis [3, 4]. To overcome the inability to predict early stage stenoses and the low sensitivity of current tests, a new, non-invasive method based on pressure profile analysis (PPA) was studied. Therefore, an in vitro model of a radio-cephalic arterio-venous fistula was built.

II. Material and Methods

A vascular access model (VAM) was integrated in a closed circuit shown in Figure 1. A blood mimicking fluid flows from the reservoir in a windkessel by a pulsatile pump. From the windkessel, the fluid is distributed over the VAM and over a draining tube with a resistance representing the blood flow towards the body. In the VAM, the compliant artery with an internal diameter of 4 mm was connected by an end-to-side anastomosis of 60 degrees with the compliant draining vein of 7 mm diameter.

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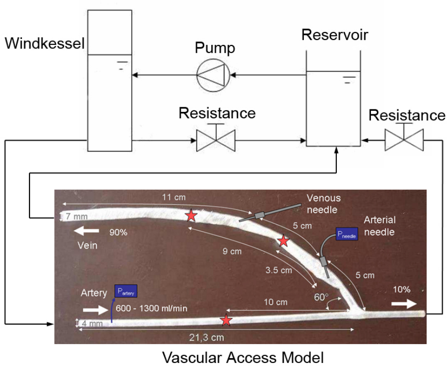

Figure 1. Experimental Setup (stenosis location: $\star$)

As during hemodialysis, two 15G needles were introduced. The arterial needle was inserted against the direction of flow 5 cm downstream the anastomosis, and the venous needle was inserted along the flow and 5 cm more distal (Figure 1). Both needles were punctured for 1 cm by an angle of approximately 30 degrees. The introduced stenoses were made of rigid tubes and had 1 cm of length. A stenosis of 50% diameter reduction was created on three different places: (I) 10 cm before the anastomosis ('proximal artery (PA) stenosis'); (II) between the two needles ('distal vein (DV) stenosis'); (III) 3 cm downstream the needles ('proximal vein (PV) stenosis').

For each case, the initial boundary conditions were set, before introducing the stenosis. The flow towards the VAM was established using both changeable resistances. The flow in the artery was divided into 90% towards the draining vein and 10% towards the distal artery. The inlet pressure profile was measured in the proximal part of the artery and changed by adjusting the air level in the windkessel to establish a profile with a pulse pressure (PP), maximum minus minimum, around 40 mmHg.

Starting from the reference situation described above (no stenoses, 90% venous flow and 10% distal artery flow), position of the stenosis, arterial blood flow (500-1300 ml/min) and heart rate (60; 75 and 90 beats/min) were varied. The pressure at the proximal part of the artery (PAP) and at the arterial needle (ANP) were measured using fluid filled pressure transducers. The used PP's were averaged out for at least 6 cycles. A dimensionless factor, '%-Pulse Pressure' (%PP) was defined as:

$$\%PP = \frac{ANP}{PAP} \times 100$$

The PPA is performed by comparing the %PP measured in different cases.

ANOVA analysis was performed to obtain a statistical ground to evaluate the PPA-method. A post-hoc (Bonferroni) test finishes the statistical discussion.

III. Results

Arterial blood flow rate versus %PP is shown in Figure 2. The %PP decreases with increasing blood flow and increases with increasing heart rate. In the control model (no stenosis), %PP was 20.26 ± 4.55. PA-stenosis significantly decreased %PP to 7.69 ± 2.08 ($P<0.001$), while presence of DV-stenosis (36.20 ± 2.12) and PV-stenosis (32.38 ± 2.17) lead to significantly higher values of %PP ($P<0.001$). The post-hoc analysis shows that a stenosis can be located upstream versus downstream the needle ($P<0.001$). It is even possible to distinguish

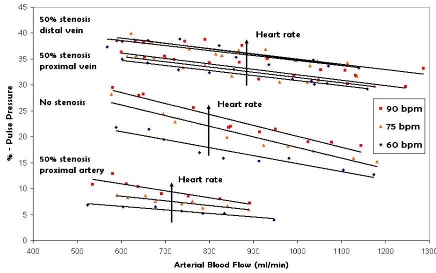

Figure 2. %-PP vs. arterial bloodflow

between the distal and the proximal vein stenosis ($P<0.001$).

IV. Conclusion

Out of these experimental *in-vitro* findings, it can be concluded that a 50% stenosis, for the tested range of heart rate and arterial blood flow rate, can be detected and located by pressure profile analysis at the arterial needle. Those experimental results open the way to a clinical long term study to fully validate this new low-cost and non-invasive method.

Acknowledgments

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References

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