BLOOD DAMAGE POTENTIAL OF RESISTANCE CLAMPS IN IN-VITRO TEST LOOPS

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Introduction

Resistance clamps are important in regulating flow and pressure in in-vitro test loops for blood pumps. However, the narrow cross section introduced by these clamps may contribute to elevated shear stresses. To date, the sole effect of resistance clamps on the in-vitro hemocompatibility assessment of blood pumps has been unclear. The aim of this study was to investigate the hemolytic potential of adjustable resistance clamps at various clinically relevant operating conditions. Computational fluid dynamics (CFD) simulations were performed to understand the flow dynamics and interrelation between this in-vitro hemolytic action and the energy dissipated through the clamps.

Methods

A hydraulic-pneumatic setup was developed consisting of two reservoirs connected by a tubing (Figure 1). Alternating blood flow between the reservoirs was facilitated by controlled pneumatic pressures, while an adjustable resistance clamp (R1/R2 in Figure 1) regulates the flow. Utilizing heparinized bovine blood, hemolysis assessment was conducted under 3 operating conditions with R1: low (7.5L/min at 30mmHg), medium (5L/min at 60mmHg), and high (1.5L/min at 90mmHg) resistances. The influence of sudden (R1) versus gradual (R2) contraction/expansion of tubing was evaluated under medium resistance conditions. Experiments were also conducted to investigate the hemolytic potential of the test loop without a resistance clamp. Further, silicon castings were created to replicate the resistance profiles of the 3 operating conditions, followed by 3D reconstruction. Unsteady RANS simulations were performed in the reconstructed replicas. Hydraulic quantities were computed to calculate the global hydraulic losses together with power-law-based NIH calculation. Further, the interrelation between global hydraulic energy dissipation, in-silico, and in-vitro NIH was evaluated through Pearson correlation coefficients.

Results

The hemolysis contributed by the test loop without clamps was similar to the static control group, with delta fHb of 0.285mg/dl/h. Nine experiments with R1 conducted for 3 operating conditions revealed no significant difference in delta fHb (1.15±0.13mg/dl/h, $p>0.81$). The NIH increased with increasing resistance: high 14.4mg/100L, medium 4.99mg/100L, and low 2.57mg/100L. Comparative analysis of two-resistance clamps (R1&R2) across five experiments revealed no significant difference in delta fHb and NIH ($p=0.55$). The pressure drop computed in-silico was in good agreement with the in-vitro results ($r=0.999$, RMSE<8.7mmHg). A strong correlation was observed between the numerically computed global hydraulic energy dissipation and both in-silico NIH ($r=0.9$) and in-vitro calculated NIH ($r=0.95$).

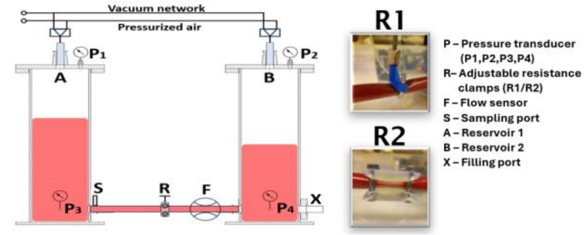

Figure 1: Schematic diagram of the in-vitro test loop (left) and the resistance clamps (R1, R2) (right).

Discussion

Adjustable resistance clamps substantially affect hemolysis outcomes in in-vitro investigations of blood pumps regardless of the investigated shapes or profiles. Clamps with medium resistance are responsible for up to 81% of NIH observed in third-generation blood pumps operated at main operating point [1]. Low/high resistance settings contribute <47% of NIH measured with these blood pumps at off-design conditions. CFD provided a comprehensive understanding of the flow dynamics within the resistance profiles. Consistent with previous studies [2], the strong correlation between the dissipative losses and both in-silico and in-vitro NIH reflects that the dissipated energy may partially be converted into hemolysis. These findings on the hemolytic potential of adjustable resistance clamps may further improve the understanding of in-vitro hemolysis assessments of blood pumps at various operating points.

References

1. Escher et al, IEEE Trans Biomed Eng, 69(8), 2022
2. Escher et al, Adv. Theory Simul, 5,2200117, 2022

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