APPLICABILITY OF STRESS-BASED AND STRAIN-BASED HEMOLYSIS MODELS FOR SHORT-TERM STRESS PEAKS IN ROTARY BLOOD PUMPS: AN EXPERIMENTAL STUDY IN MICROCHANNELS

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Introduction

In the development process of blood-carrying medical devices, such as rotary blood pumps (RBPs), it is important to predict hemolysis - flow-induced damage to red blood cells (RBCs) - at an early development stage. Several models exist that predict the index of hemolysis (IH) based on the flow field obtained from computational fluid dynamics (CFD) simulations [1]. Commonly used stress-based models with a scalar shear stress (SSS) formulation, like the power-law model, have unclear validity, especially for complex flows [2,3]. Alternatively, strain-based models estimate hemolysis from local velocity gradients affecting RBC deformation. These models have been investigated in fewer studies than stress-based models [1,2].
This study compares the experimentally measured IH of three microchannels to the IH predictions of these models using CFD simulations.

Methods

We conducted experiments with human whole blood in three microchannels, each representing a different flow scenario typical for critical regions of RBPs (figure 1).

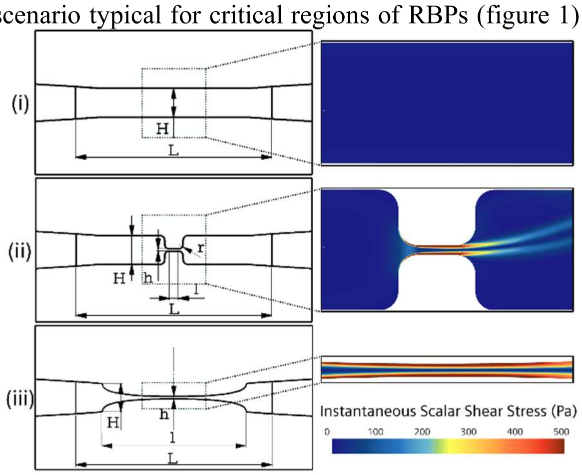

Figure 1: Left: The three channels investigated. Right: CFD SSS field. (i): Reference (ii): Sudden (iii): Smooth.

Hemolysis was measured after circulating the blood up to 1200 times through the channels. Using CFD simulations and virtual massless particles, we traced trajectories and used the velocity gradient along the trajectories as input for the hemolysis models. Two stress-based models with different SSS formulations ([2] and [4]), and one strain-based model were used [5].

Results

Experiments showed for all three microchannels low and statistically not significantly deviating hemolysis values. The CFD simulations determined SSS of up to 1500 Pa, with high-stress exposure times in the range of milliseconds. Stress-based models overestimated hemolysis by up to three orders of magnitude and differed significantly across microchannels. The strain-based model predicted low and approximately equal hemolysis for all channels, agreeing with experimental observations (see table 1).

Method	IH in %		
	Reference	Sudden	Smooth
Exp.	5.0e-2	5.3e-2	4.1e-2
Stress 1	6.25e-3	7.2e-1	1.49
Stress 2	7.77e-2	76.49	16.44
Strain	1.93e-3	1.69e-3	1.79e-3

Table 1: Hemolysis results from 1200 pass-throughs with experiments (Exp.), two stress-based models (Stress 1: [4], Stress 2: [2]), and the strain-based model (Strain [5]).

Discussion

The results suggest that for short-term stress exposure (< 5 ms) the stress-based hemolysis models are not suitable. The strain-based model, which considers the time-dependent red blood cells' deformation, is more appropriate in our flow scenario. This implies a similar relationship for RBPs, where such flow scenarios are typical for the high-stress areas.

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