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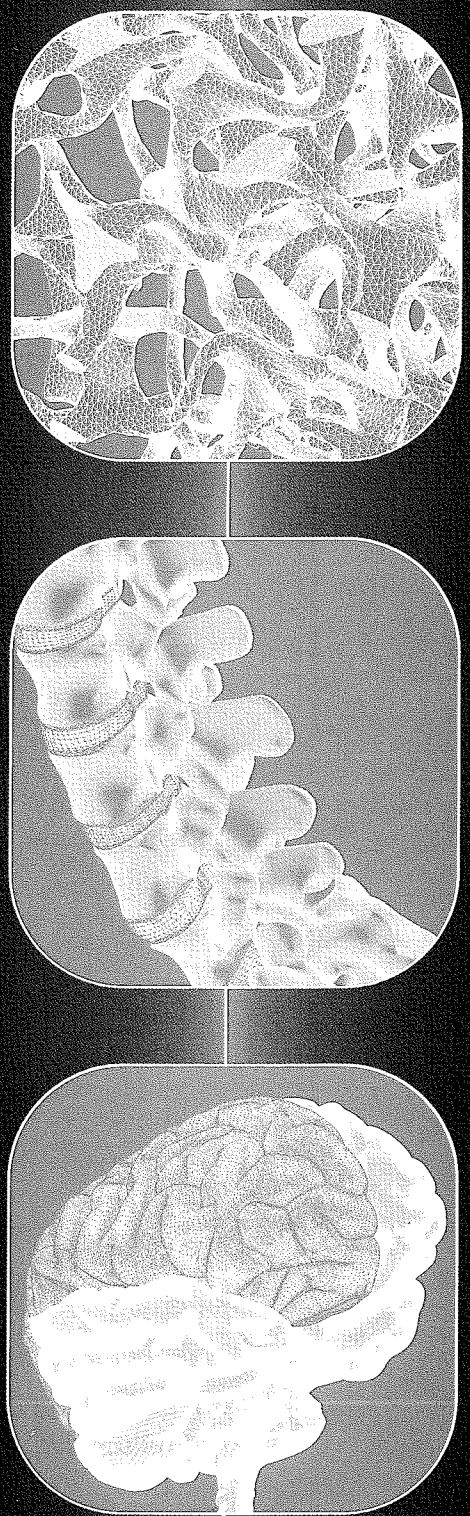

Computer Methods in Biomechanics and Biomedical Engineering

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Using a Doppler wire to measure intravascular flow

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1. Introduction

There is a medical need to continuously monitor the flow of blood towards organs, for instance in the situation of sceptic shock in the intensive care unit. Commercially available Doppler flow wire systems allow assessment of instantaneous peak flow velocity (IPV) in a sample volume. However, for blood flow measurements, assessment of mean flow velocity (averaged over the vessel cross section) is more appealing. Jenni *et al.* recently developed a method for simultaneous calculation of the mean flow velocity and the cross-sectional area with a Doppler flow wire in coronaries, making use of the fact that the Doppler beam widens with distance Jenni *et al.* (2000). The long term purpose of our investigation is to expand the applicability of this method in larger blood vessels. In this study, we report intermediate results focused on the processing of Doppler audio data obtained from a commercially available Doppler flow wire system (FloMap, Volcano Therapeutics, Inc., Rancho Cardova, CA, USA) for assessment of flow characterising parameters. Tests were performed in an *in vitro* setup.

2. Materials and methods

2.1 Assessing flow with a Doppler wire

The first step in the method of Jenni *et al.* (2000) consists of detecting the point where the ultrasonic beam completely intersects the vessel. This point is searched through sampling of the Doppler signal with increasing range gate (n) and is reached if the following equation based on the moments (M) of the spectral analysis of the returned Doppler signal, is satisfied for the first time.

$$\frac{M_{0,n+2}}{M_{0,n+1}} \cong \frac{M_{0,n+1}}{M_{0,n}}$$

The cross-sectional area can then be calculated from knowledge of position n and the angle of the beam. Secondly the mean flow velocity (at point n) is calculated as

$$V_m = \frac{c}{2f_s}\frac{M_1,n}{M_0,n}$$

(c is the speed of sound in the medium, f_s is the emitted frequency).

2.2 The in vitro

set-up

Pulsatile flow (with flow rates 180–430 ml/min.) was created in silicon rubber tubes of 3–4 mm diameter. The fluid under study was water with scatterers (Optison, GE Healthcare) in suspension. A flow wire ($f_s = 12$ MHz) was connected to the FloMap console, and positioned under visual inspection and with qualitative investigation of the spectrogram seen on the FloMap. Reference flow was measured with a Transonic flow probe around the vessel. The method of Jenni *et al.* (2000) requires advanced processing of Doppler spectra. As spectra cannot be exported on commercially available systems, it is mandatory to sample and process data with dedicated equipment. For the available FloMap system, this entailed sampling of the Doppler audio signal. We also sampled the IPV generated by the FloMap system. All data were digitally stored for off-line analysis.

3. Results and discussion

Dedicated software has been developed in Matlab for the generation and processing of Doppler spectra. The IPV generated by the FloMap system appeared very sensitive to noise (figure 1B). Since correct delineation of peak velocity is important, we developed an alternative and novel method for calculation of IPV. For a given instant in time, the IPV can be found using the cumulative distribution of the present velocities in the calculated spectrogram plotted as function of the velocities

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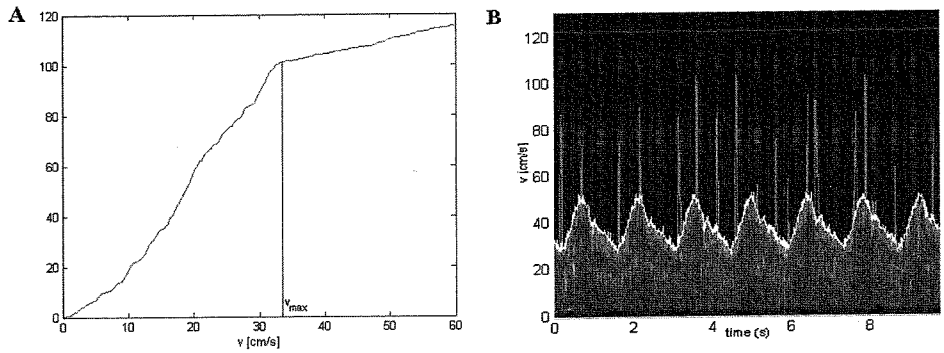

Figure 1. A. Determination of the velocity vmax for the spectrogram at t = 0. B. Spectrogram of received Doppler signal with IPV calculated with new method (white) and IPV calculated by FloMap (light grey). Available in colour online.

(figure 1A). The IPV is detected by searching the velocity corresponding with the maximum slope change in the cumulative distribution (v_{max}). For the example in figure 1A, the cumulative distribution of velocities present in the spectrogram at $t = 0$ is displayed. Velocities higher than 33 cm/s contribute significantly less to the cumulative distribution, leading to a significant decrease of the slope of the distribution curve for velocity values higher than 33 cm/s. This velocity is considered as the IPV at that instant. The procedure is repeated for all time steps, yielding the IPV displayed in yellow on figure 1B. It is visually appreciated that the new method yields IPV's less susceptible to noise than the algorithm embedded within the FloMap.

The next step will be the actual computation of volumetric flow using the method of Jenni *et al.* (2000) and comparison of the results with the reference values. Nevertheless, even if these *in vitro* experiments demonstrate feasibility of the methodology, ultimate validation will require further *in vivo* (animal) experiments where all aspects, specific to the *in vivo* situation, are present.

References

Jenni, *et al.* "*In vitro* validation of volumetric blood flow measurement using doppler flow wire", *Ultrasound Med. Biol.*, 26, pp. 1301–1310, 2000.