Measurement of aqueous outflow volume rate using photoacoustic microscopy

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Purpose

Glaucoma is a leading cause of irreversible blindness worldwide despite new medications and newer surgeries, such as microinvasive glaucoma surgeries (MIGS). Currently the outcome of MIGS targeting Schlemm's canal (SC) is unpredictable in part due to a long-existing gap in knowledge on the outflow resistance within the vasculature distal to the inner wall of SC in the Trabecular Meshwork (TM). In our previous studies, we demonstrated measuring the 3D structure and deformations of distal aqueous drainage vasculature and its surrounding sclera during intraocular pressure regulation with photoacoustic microscopy (PAM). In this study, we upgraded our system with flow velocity imaging capability. Along with the 3D structural information, we investigated the feasibility to access the volume flow rate through distal aqueous humor outflow vasculature.

Methods

The flow measurement was validated using imaging phantoms and human globes ex vivo. The phantoms were porcine gel blocks including tunnels with varied diameters. Human globes went through full circumferential ab externo trabeculotomies so that the aqueous outflow resistance in the distal vasculature was isolated from those at the levels of TM and SC. Both the imaging phantoms and the globes were perfused with 6 μm microspheres at varied flow rates. Images were taken by an optical resolution PAM system with a laser repetition rate of 6.2 kHz, corresponding to an interscan time of 40 μs between the B-mode images at the vascular cross-sections.

Results

Fig. 1(a) shows consistent flow velocities measurements within phantom lumens with varied diameters. In addition, the measurement is able to reliably differentiate flow velocities at a difference of 0.5 mm/s ($n=10$, $p<0.01$). Fig. 1(b-d) shows that our system can detect the perfusion flow rate changes within distal aqueous outflow vasculature in a human globe as well as the laminar flow patterns. The volume flow rate at a branching anatomy shows promising preliminary result that we can have relatively constant volume flow rate measurements along a closed system.

Conclusions

Our imaging system shows reliable flow velocity measurement and promise in quantifying volume flow rate through the distal vasculature. Our immediate future work is to study the interactions between the volume flow rate within the vasculature and the deformation of surrounding sclera during intraocular pressure regulation.