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Human Tear-Film Evaporation Rates from Infrared Ocular-Surface Cooling and Fluorescein Breakup

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Abstract

Purpose : Tear-film evaporation is critical for maintaining anterior-eye health and comfortable contact-lens wear. For the first time, we devise a quantitative method for ascertaining in-vivo tear evaporation rates (TERs) from simultaneous measurement of transient corneal surface cooling and fluorescein breakup.

Methods : Ocular surface temperature (OST) and tear-film stability by fluorescein areal breakup were assessed for 20 subjects following Li et al. [1]. OST was obtained using a high-resolution infrared camera [1]. The dynamic area fraction of breakup after fluorescein instillation was evaluated through image analysis [1]. To interpret the in-vivo data (i.e., extract TERs from OST measurements), we developed a transient 1D heat-transfer model. The analysis accounts for evaporative cooling of the tear film, convective and radiative heat loss to the environment, and heat supply to the corneal surface by conduction from the anterior chamber. Based on the work of Peng et al [2], we propose that tear evaporation through black spots is close to that of pure water, whereas tear evaporation over the remainder of the cornea is through a lipid covering. Consequently, the area of black spots increases as tear breakup proceeds yielding locally-elevated TERs. The overall corneal TER is the area-weighted sum of evaporation through the lipid-free area and through the lipid-covered area.

Results : Figure 1 graphs dynamic OST for three human subjects (filled symbols). Shaded regions correspond to no tear-film breakup, with TERs that are 80-90% of that measured for pure water. In all cases, shaded regions overestimate OSTs. Solid lines account for

increased tear evaporation through black-spot regions giving increased cooling of the eye. Reductions in evaporation rates through the lipid-covered regions are listed for each subject. They range from 62 to 95% reductions compared to that of pure water.

Conclusions : We developed a new procedure to extract human TERs from transient OST measurements. We establish that tear-film breakup must be accounted for when interpreting OST data. Our measured aqueous TERs through lipid layers range from to g/cm^2/s (i.e., 62 to 95% that of pure water).

[1] Li W, Graham AD, Selvin S, Lin MC. Optom Vis Sci. 2015;92:248-56.
[2] Peng C-C, Cerretani C, Bowers S, Shahsavarani, Lin MC, Radke CJ. Ind Eng Chem Res. 2014;53:18130-9.

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