Contact Lens Drug Delivery

Graduate Student Math Modeling Camp 2019

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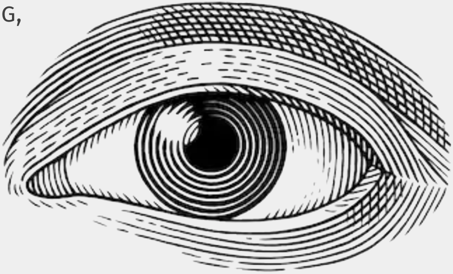
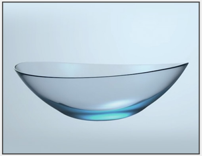
15 June, 2019



Motivation

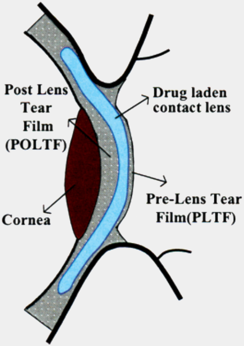
We investigate the effectiveness of delivering medication for ocular disorders via a drug-infused contact lens.



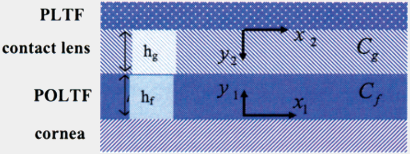
Such research can be helpful for treating Glaucoma, which leads to permanent blindness if not properly medicated.[1]

[1]Refer to: Prausnitz et al. (1998), Ciolino et al. (2009), Li et al. (2006), Ciolino et al (2014), Carvalho et al. (2015)

Anatomy of the Eye and Contact Lens Placement



(a) Diagram of a contact lens between tear film layers in the eye



(b) Simplified diagram of the contact lens system[2]

[2]Images taken from Li et al. (2006)

Starting Point

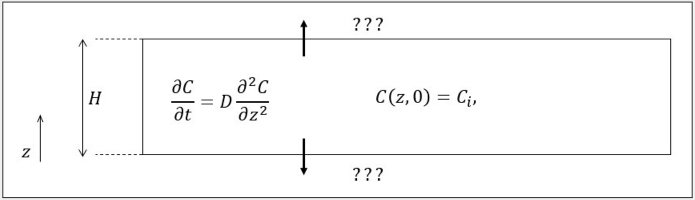


Figure 1: The starting point of our model – the drug concentration C diffuses out of the contact lens (thickness H) and into the PrLTF and PoLTF layers, according to some diffusion coefficient D.

System Diagram [almost] to Scale

Pre-Lens Tear Film Layer ↓

Contact Lens

Post-Lens Tear Film Layer ↑

CONSIDERATIONS AND ASSUMPTIONS: CONTACT LENS

Diffusion out of contact lens

- We assume uniform drug concentration in the contact lens.
- The drug diffuses into PrLTF and PoLTF in about .05 seconds.
- It takes about 2 hours for the drug to completely diffuse from the contact lens.

Time Scale: $\bar{t} = \frac{t_B}{t}$, where t_B is one blink cycle.

Length Scale: $\overline{W} = \frac{W}{H}$, where W is the lens width and $W \gg H$.

Concentration Scale: $\overline{C} = \frac{C}{C_{init}}$ in the contact lens.

CONSIDERATIONS AND ASSUMPTIONS: PRLTF

Water evaporates and replenishes in PrLTF

- Water evaporates from the PrLTF
- Drug concentration increases in PrLFT
- PrLTF fluid replenishes during blink

Length Scale: $\overline{h_{pre}} = \frac{h_{pre}}{H}$

Concentration Scale: $\overline{C_{pre}} = \frac{C_{pre}}{C_{init}}$ in the PrLTF

Considerations and Assumptions: PoLTF

Movement of fluid during blinks

- Both lateral and transverse movement
- Transverse movement squeezes out drugs in PoLTF

Length Scale: $\overline{h_{post}} = \frac{h_{post}}{H}$

Concentration Scale: $\overline{C_{post}} = \frac{C_{post}}{C_{init}}$ in PoLTF

Diffusion out of the Contact Lens

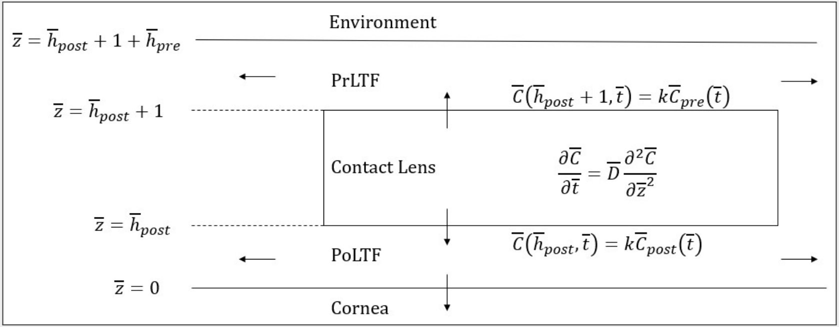


Figure 2: The contact lens concentration $\overline{C}$ shown in the z-coordinate axis. Direction of flow is indicated by arrows.

Diffusion Coefficient: $\overline{D} = \frac{t_B}{H^2} D$

BEHAVIOR IN THE PRE-LENS TEAR FILM

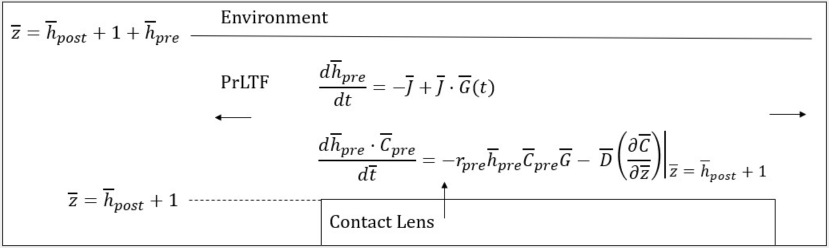


Figure 3: The contact lens concentration $\overline{C}$ shown in the *z*-coordinate axis. Direction of flow is indicated by arrows.

Evaporation: $\overline{J}$, taken to be a small constant.
Blink action: $\overline{G}(t)$, narrow repeating Gaussian to model influx of fluid from blink.
Loss Proportion: r_{pre} is the drug lost during blink compression.

Behavior in the Post-Lens Tear Film

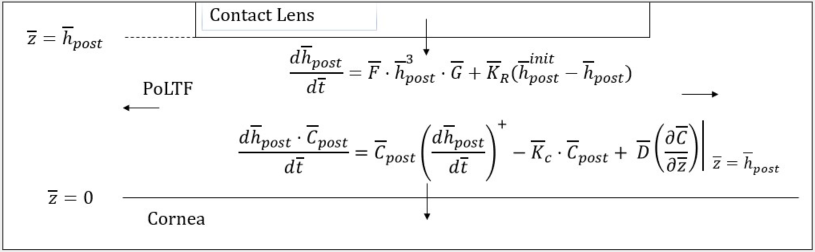


Figure 4: The contact lens concentration $\overline{C}$ shown in the z-coordinate axis. Direction of flow is indicated by arrows.

Partition Coefficient: $\overline{K_c} = \frac{K_c t_B}{H}$ at the PoLTF-cornea boundary, where t_B is the time of one blink cycle.

Results I

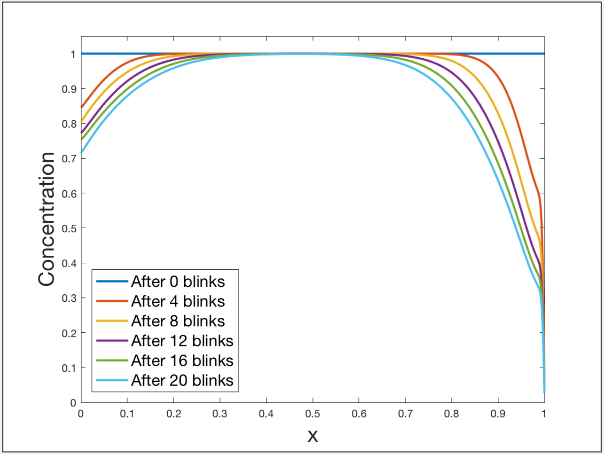


Figure 5: Concentration of drug in the CL over 20 blink cycles.

Results II

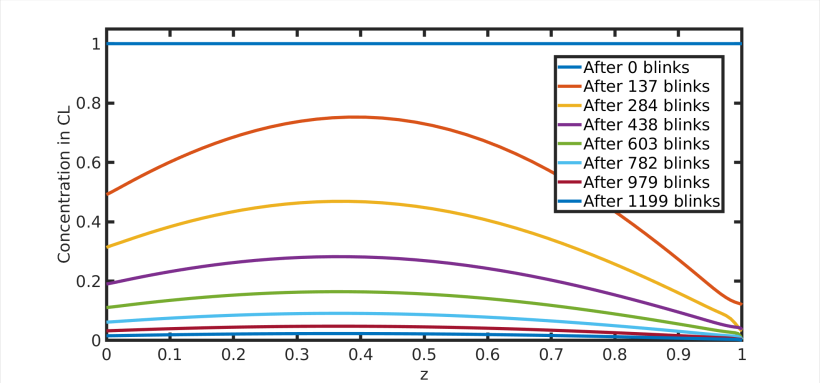


Figure 6: Drug concentration in the CL from the PrLTF to the PoLTF.

Results III

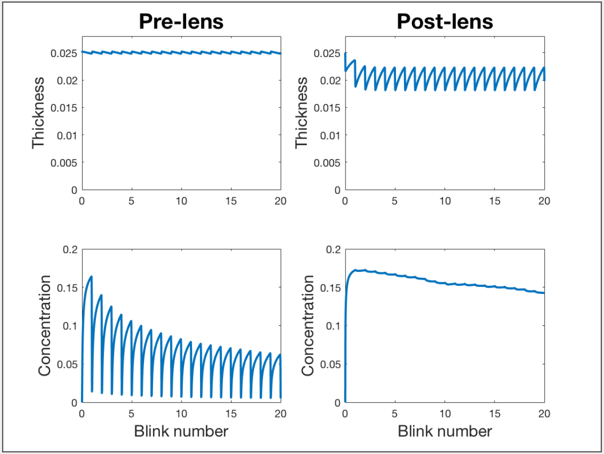


Figure 7: Dynamics of the PrLTF and PoLTF thickness and concentration over time.

Results IV

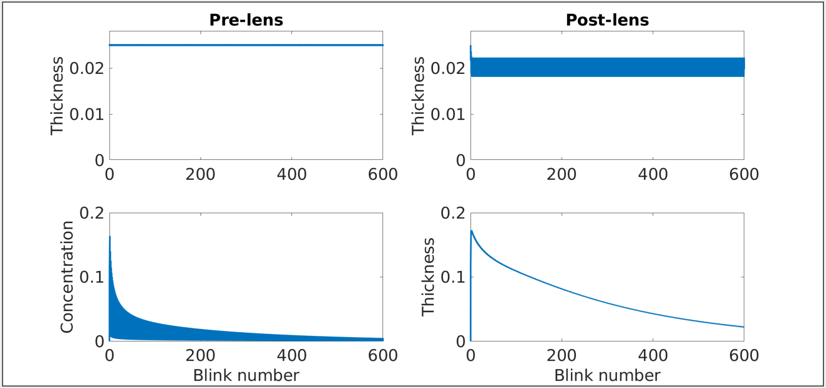


Figure 8: Dynamics of the PrLTF and PoLTF thickness and concentration at long times.

Results V

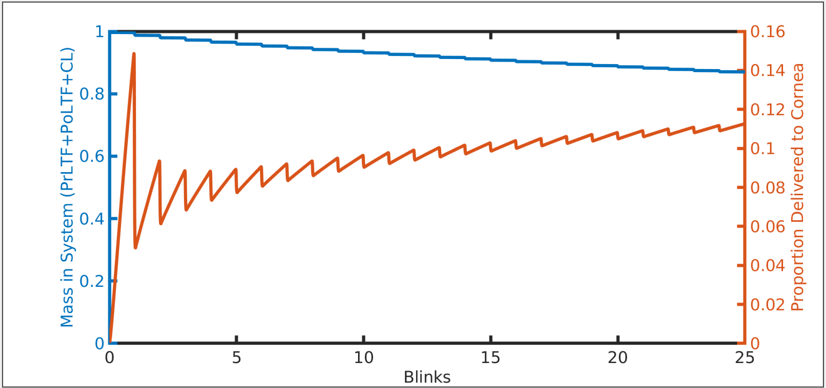


Figure 9: Tracking the mass of the drug in the system over the first 25 blink cycles.

Results VI

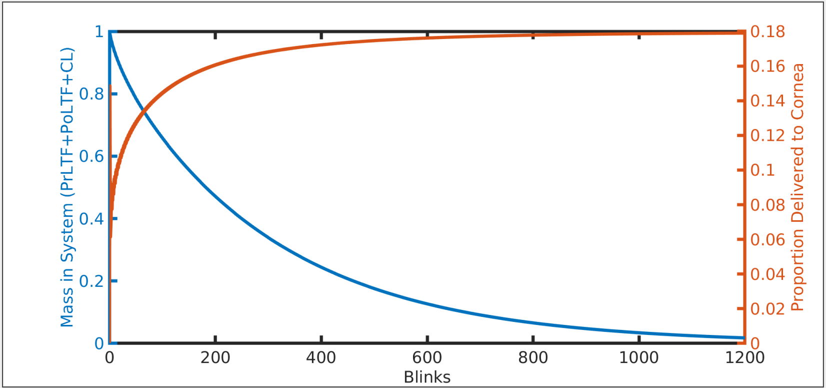


Figure 10: Mass of the drug tracked over time.

Results VII

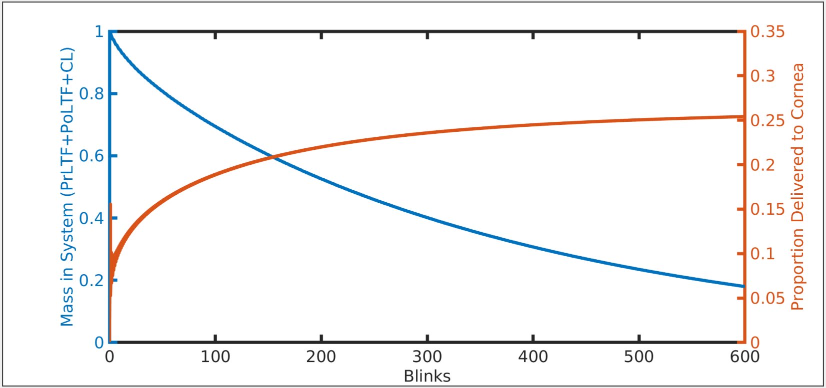


Figure 11: Mass of the drug tracked over time, but with lower force on PoLTF.

Conclusions

- Simple model: PDE for CL, ODEs for PrLTF and PoLTF
- Capture main dynamics, compare relative importance
- Numerical solutions confirm predictions, suggest escape routes of drug
- CL drug delivery to cornea is better than eye drops, but 80 % still flushed out by blinks

Future Work:

- Use analytic solution to diffusion in CL in full problem
- Model lateral movement of CL due to blink, turn ODEs $\rightarrow$ PDEs for PrLTF, PoLTF
- Replace blink function with delta function; restart simulation each blink

References I

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Questions?