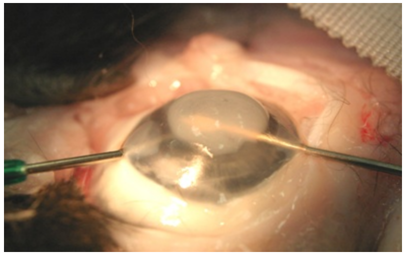
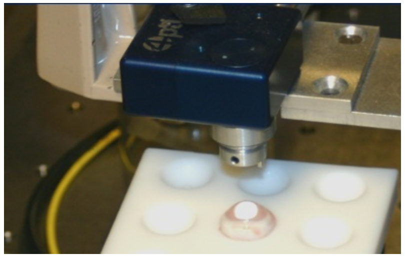
M. Frentz, N. Schrage, F. Spöler, M. Först, H. Kurz

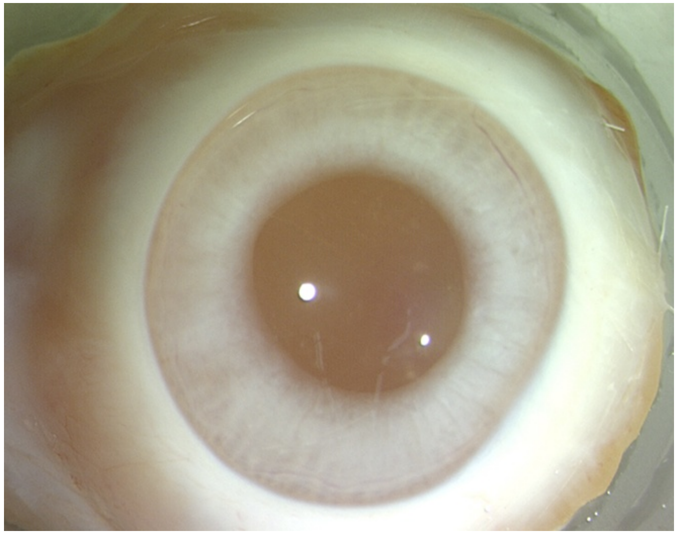
Dynamic analysis of hydrofluoric acid penetration and decontamination on the eye by means of optical coherence tomography

Motivation

Chemical eye burns cause approximately one forth of all traumatic ocular injuries. To improve the efficiency in the emergency treatment of such injuries the penetration and the effects of decontamination within tissue have to be qualified and quantified. Conventional methods like intraocular pH measurements (shown in the upper right image) only give limited insight into the mechanism of chemical trauma. With its ability to non-destructively generate cross sectional images of tissue morphology at high speed with micrometer scale resolution optical coherence tomography (OCT) offers large potentials to close this analytical gap. The probe of the OCT setup is shown on the lower right image.







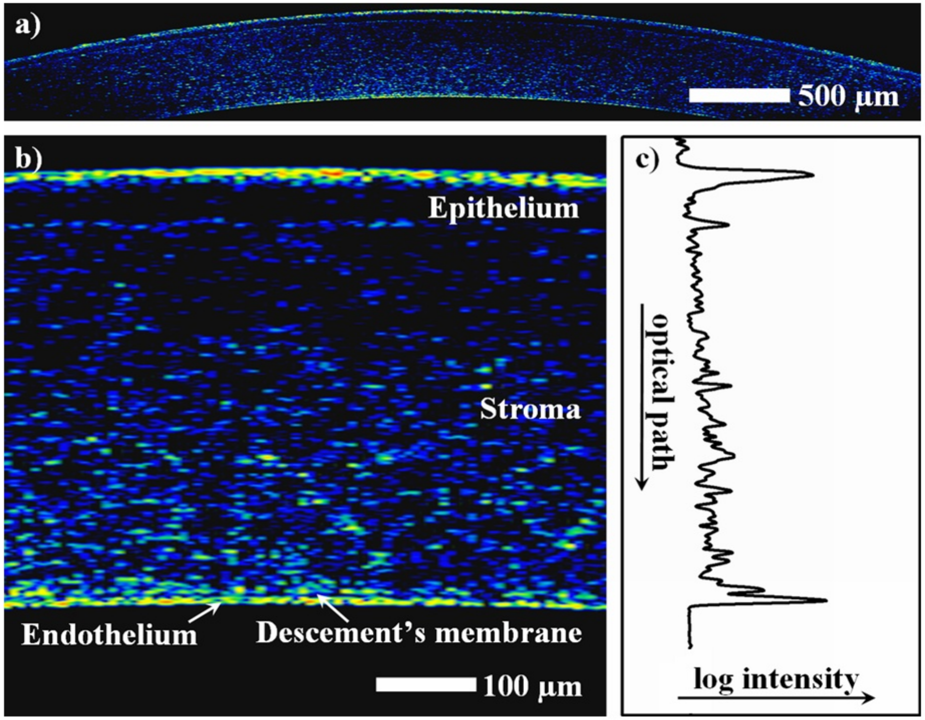
Acute ex vivo eye irritation test (EVEIT)

Experiments were performed using the acute EVEIT. This model has been proven to react very similar to living eye tissue concerning the behavior during chemical eye burn. In this study, enucleated white rabbit eyes were used. Rabbit heads were obtained from abattoir and kept cool until enucleation of the eyes. The globes were stored at 4°C in a humid atmosphere to ensure preservation of the corneal epithelium. Only clear corneas without any epithelial defects were processed. All measurements were performed within 12 hours after animal death.

Optical coherence tomography (OCT)

OCT imaging admits non-contact visualization of the corneal epithelium and stroma. Within the study presented here, a customized ultrahigh resolution OCT systems with an axial resolution of 3 µm is used which additionally allows for the imaging of further corneal structures. By this non-invasive imaging approach also dynamic processes which are not accessible by histology can be observed.

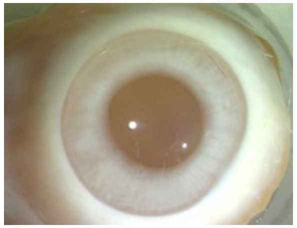
A characteristic high resolution OCT image of an untreated rabbit cornea ex vivo is shown in (a) using a logarithmic false color scale. The magnification of the central section (600 µm × 600 µm) is given in (b). Here, epithelial and endothelial layer, the stroma and, allusively the stromal fibers are distinguishable. The Descement's membrane is imaged as low scattering band. To determine layer thicknesses A-scans as shown in (c) are used. Here, the boundary of the different layers are illustrated by peaks in signal intensity, whereas the Descement's membrane is represented by a noticeable drop of the OCT signal.

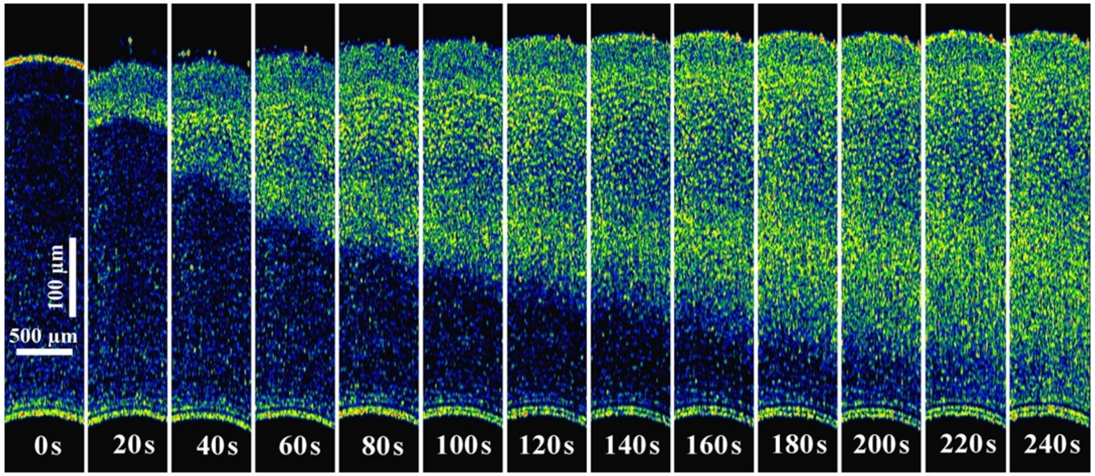


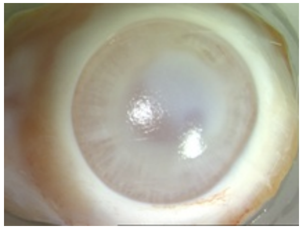
Dynamic analysis of hydrofluoric acid penetration

The microstructure of tissue determines its scattering cross section and therefore the OCT signal amplitude. In reverse, the change of tissue appearance in OCT images caused by interaction with a corrosive can be ascribed to structural changes as a result of chemical interaction. This is demonstrated in the central figure below, where a time series data set of a rabbit cornea ex vivo is shown which underwent superficial exposure to 25 µl hydrofluoric acid 2.5% (HF). The corresponding cross sectional image of the cornea before HF application is given on the leftmost image. Time steps given within the following pictures refer to zero time delay, when the acid is applied onto the cornea. The tissue damage induced by the corrosive is delineated with high contrast indicated by a significant increase in OCT signal intensity compared to the image taken prior to the application of the chemical. The penetration velocity of the corrosive is decreasing with time. Full penetration of the cornea is completed within 240 s.

Photographic images of the eye globes prior and after HF treatment are given on the left and right hand side respectively.



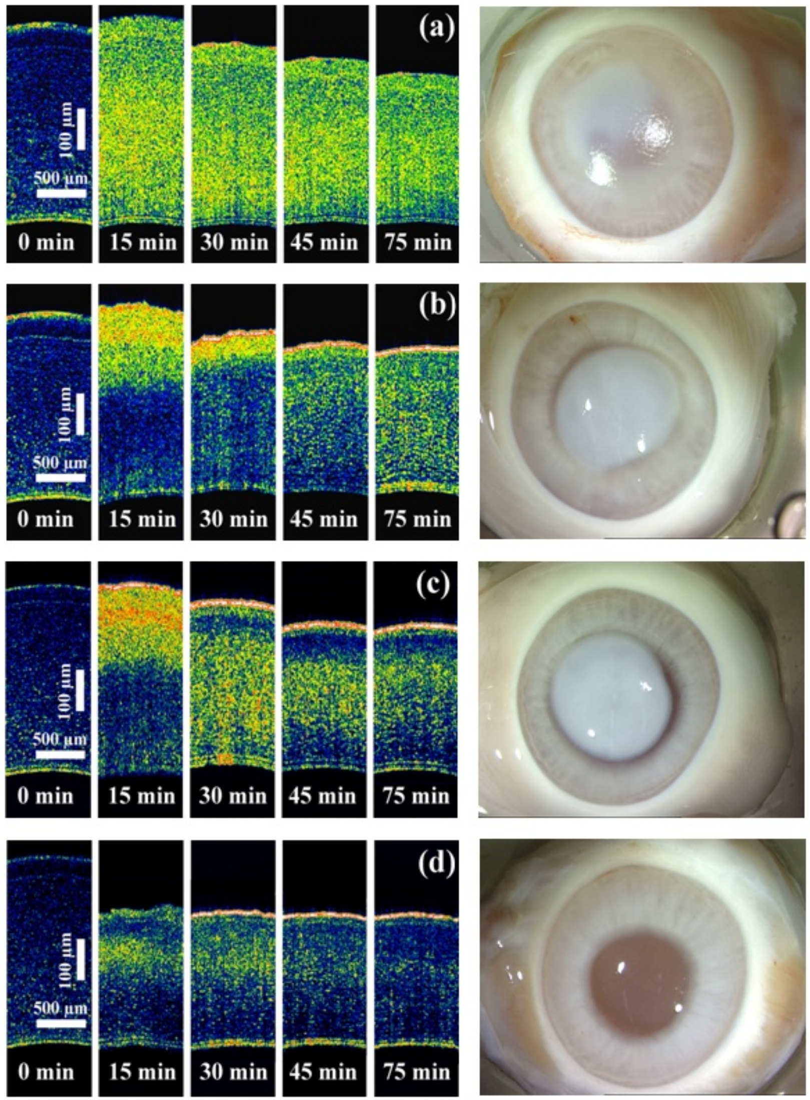




Analysis of decontamination after hydrofluoric acid (HF) burn

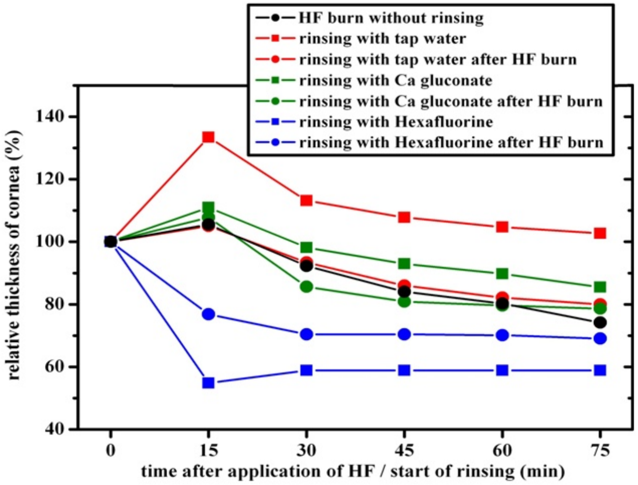
Severe eye burns with HF are rare but extremely hazardous. HF penetrates readily within the cornea due to the penetration power of the undissociated molecule. The major toxic effect of HF is ascribed to the fluoride anion, in addition the acidic character has to be considered. Decontamination of HF is recommended officially with water and calcium gluconate solution. In addition, successful use of Hexafluorine®, a hyperosmolar antidot for HF is described in the literature.

OCT image sequences to evaluate the efficiency of different rinsing solutions after eye burn caused by hydrofluoric acid are shown. Eyes were burnt by a filter paper soaked with 25 µl HF (2,5%) onto the cornea for 20 s. Rinsing was started 5 s after the filter paper was removed and maintained for 15 min. For reference no rinsing was applied in (a). The outcomes after rinsing with tap water (b), calcium gluconate 1% (c) and Hexafluorine® (d) are shown together with the visual outcomes (photographs) after the rinsing period.



Analysis of corneal thickness changes

The figure summarizes the observed changes in corneal thicknesses for different treatment conditions. Effects of rinsing without preliminary treatment with HF are also given. In case of HF burn the cornea is strongly dehydrated with and without rinsing therapy. Without prior application of HF a significant swelling could be observed for water rinsing, which abated within 60 minutes after rinsing was stopped. For calcium gluconate a minor effect on corneal thickness was observed whereas Hexafluorine® showed shrinkage of the cornea with about 40% loss of thickness.



Conclusion

In summary, the use of OCT as an additional diagnostic tool within the EVEIT system is capable to essentially enhance the information available by this ex vivo animal model. The direct access to the diffusion process by means of OCT measurements during exposure is a favorable instrument to give exact definitions of the possible damage at different intervention time points and allows for the quantification of therapy strategies with new substances like Hexafluorine® and comparison to established rinsing solutions like calcium gluconate and water with a reduced number of tests. The hyperosmolar rinsing of the HF burnt eye with Hexafluorine® is effective in physical inversion of water flow characteristics and chemical neutralization of H^+ and F^- ions being visible in the Hexafluorine® rinsed cornea remaining clear for 75 min post burn.