Biomimetic Engineered Corneal Surface on Silicone Hydrogel Contact Lens

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Statement of Purpose: In biological tissue, biomolecules are highly complex and are organized to express unique functions. They are responsive to the surrounding environment and capable of adapting to changing local conditions. It is clear that elucidating the process by which these complex molecular structures are derived and artificially reproducing it will be useful for creating materials. In particular, medical devices contacting living tissue need to have properties at the surface similar to those in living tissue. Biomimetic concepts for material design are predicated on the idea of reproducing the chemical and mechanical characteristics of biomolecules with artificial compounds.

The cornea of the eye is transparent to light, wet with tears, exposed to the air, and in mechanical contact with the eyelids. The anatomy on the surface of the cornea plays an important role in maintaining a wettable surface, mechanical strength, and dynamic lubricity. On the corneal surface, a soft hydrogel-like matrix called the glycocalyx containing a complex matrix of glycosaminoglycan provides the necessary wettability and lubricity by the aqueous medium and covers the collagen rich layers beneath which provide the mechanical strength and optical properties of the cornea (Figure 1).

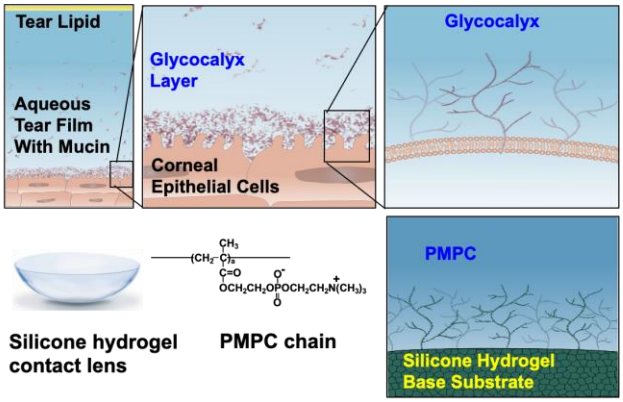

Figure 1. Illustration of biomimetic engineered surface.

We have researched a biomimetic material design to form an artificial corneal structure on the surface of a silicone hydrogel material. A phospholipid polymer, poly(2-methacryloylethyl phosphorylcholine) (PMPC) was applied to create a biomimetic surface on the contact lens[1]. The PMPC layer shows super-hydrophilicity, a low elastic modulus and high lubricity similar to those of the natural soft tissue. Therefore, we created a unique surface through biomimetic engineering that can be applied to an ophthalmic medical device.

Methods: The reactive PMPC was used for surface modification of silicone hydrogel contact lens[2,3]. The interface of the PMPC-modified contact lens was observed by an environmental scanning electron microscope, atomic force microscope (AFM), scanning transmission electron microscope (STEM). Also, the surface modulus was determined by AFM. All evaluations were done under 100% humidity or in water.

Results: It was confirmed that the surface of the silicone hydrogel contact lens was covered with a PMPC layer. The PMPC layer was hydrated and swollen similar to a natural corneal surface (Figure 2).

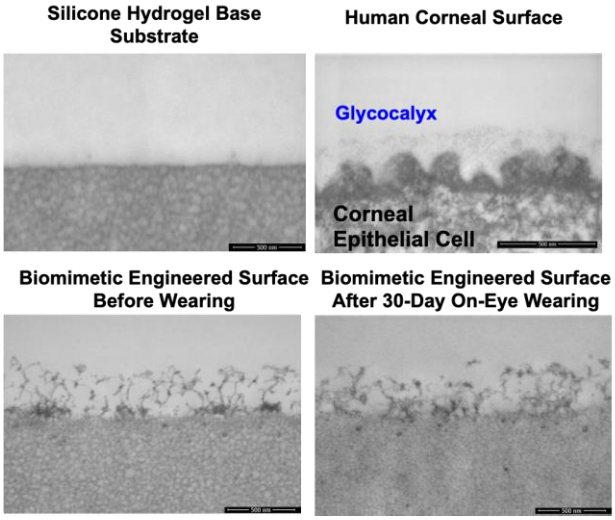

Figure 2. STEM image of biomimetic engineered surface.

In the natural eye system, surface wetting and lubricity is dominant by the characteristics of the hydrated glycocalyx, which binds to the corneal tissue surface and functions at the tear-contact interface. A glycocalyx-like structure of PMPC was strongly immobilized to the silicone hydrogel substrate. Such a soft PMPC-modified surface like a natural cornea exhibited robustness and could not be removed by mechanical rubbing, surfactant cleaning, or high temperature treatment such as autoclave sterilization. Even after 30 days of daily wear on eye, after almost a million blinks, 30 cycles of cleaning by finger rubbing and over-night soaking in surfactant-containing lens care solutions, the PMPC layer remained without change in the morphology on the contact lens surface.

Conclusions: Comparing the properties of the biomimetic engineered cornea surface with that of natural cornea, it became clear that the mechanical properties are similar in the living environment and that they exhibit low modulus and frictional properties comparable to natural tissues. These results showed the validity of material creation by biomimetic methods. These analytical methodologies may contribute to future development of novel biomimetic engineered medical devices.

References: (1) Ishihara K. J Biomed Mater Res. 2019:105A;933-943 (2) Shi X. et al. Colloid Surf B. Biointerface. 2021;199:111539, (3) Ishihara K. et al. ACS Omega. 2021:6;7058-7967.