Study of lipid interactions with the surface and matrix of silicone hydrogel contact lenses

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Abstract

The aim of this dissertation was to advance understanding of the reciprocal interactions between tear-film lipids and silicone hydrogel (Si-Hy) materials used in soft contact lenses, and to develop tools that enable tracking these phenomena from the very first moments of contact through to their functional consequences. The work integrates three strands: the development of methods for visualizing lipid adhesion and transport (fluorescence confocal microscopy, including a Yokogawa spinning-disk unit), an in vivo assessment of how lens application affects the lipid layer thickness (LLT) of the tear film, and an evaluation—under near-physiological conditions—of how lipid deposits influence the equilibrium water content (EWC) of lens materials. The research was conducted within an industrial doctorate framework with a view to direct transfer of results and tools into the R&D practice of a contact lens manufacturer.

Methodologically, confocal imaging in reflective mode was first calibrated to provide a rapid, non-invasive characterization of lens surfaces. Fluorescently labeled cholesterol was then used to map deposition and diffusion within Si-Hy matrices. Finally, a spinning-disk confocal protocol with an expanded field of view and high temporal resolution was established, allowing registration of adhesion initiation on the timescale of minutes and tracking of diffusion fronts into the lens bulk. In parallel, a clinical LLT study (interferometric measurements using the IDRA device) was performed in adult participants, comparing pre-application values with measurements taken at 1, 3, and 5 minutes after application of four popular Si-Hy lenses. A separate in vitro module employed a purpose-built Contact Lens Incubator (CLI) that simulates blinking and ocular surface conditions (35 °C; artificial tear solution, ATS, with and without lipids), enabling multi-sample, reproducible assessment of EWC changes by gravimetric (thermogravimetric) measurement.

The findings corroborated Hypothesis I: the new confocal methodology captures the moment of lipid-adsorption initiation and differentiates deposition/transport mechanisms

between materials. The clinical study confirmed Hypothesis II: lens application induces statistically significant changes in LLT relative to baseline, with material dependence manifesting primarily in the kinetics of early changes (1–5 min); a five-minute window is often insufficient to assume a steady state. The in vitro module confirmed Hypothesis III: exposure to lipids in ATS leads to a significant reduction in EWC—on the order of several percentage points—consistently observed across tested materials, indicating lipid-induced dehydration of the polymer matrix and a potential secondary deterioration of wettability and pre-lens tear film stability. Collectively, the results provide an interpretative framework and a toolkit (including the CLI) for screening materials/coatings with enhanced resistance to lipid deposition and for designing care strategies aimed at controlling lipid load.