HPGuar Provides a Synthetic Glycocalyx for Superior Tissue Lubrication

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Statement of Purpose: Excellent in-the-eye lubricity has been reported for new products containing hydroxypropyl guar galactomannan (HPGG). Although reported to be superior to all previous "artificial tear" preparations, the interfacial mechanism/s associated with the demonstrated reduction of tissue-on-tissue coefficient of friction values to less than 0.1 have not been previously documented.

Methods: This study (Rodgers 2010) utilized a reciprocating tissue-on-tissue friction test series, employing glutaraldehyde-preserved bovine pericardium at varying stiffnesses to monitor friction coefficients over time periods of seconds to hours at laboratory conditions of 20°C and 50%RH with lubricious HPGG and comparison formulations at different concentrations in distilled water, buffer, physiologic saline, and calcium chloride solutions at pH's ranging from 3-11. Selected conditions were repeated with freshly harvested paraformaldehyde-preserved pig pericardium, which has reduced self-fluorescence compared to the commercial glutaraldehyde-preserved bovine product. The experiments with pig pericardium and Texas-Red-labeled HPGG confirmed frictional data with unlabeled HPGG and allowed inspection of the lubricated surfaces by confocal microscopy. All test tissues and formulations were characterized by contact angle methods and multiple attenuated internal reflection infrared (MAIR-IR) spectroscopy for component identification, surface tension values, lubricant substantivity, and transferability to and from surface-modified germanium substrata having either hydrophilic, high-surface-energy or hydrophobic low-surface-energy properties. Urea was added to a subset of test formulations to examine potential hydrogen-bonding versus hydrophobic-bonding mechanisms for lubricant retention. Light microscopy, scanning electron microscopy, and quantitative surface profilometry were used to assess surface texture and friction-induced surface damage to articulated tissue specimens.

Results: Articulated, reciprocating tissue-on-tissue couples displayed an approximate frictional (drag) resistance of approximately 30 grams-force when lubricated with saline solution (Unisol 4) alone. This value decreased to as low as 10 grams-force when test HPGG formulations were instilled to displace the saline. As the reciprocating action continued over a 60-second period, HPGG polymer components gelled and attached to the tissues, shifting the frictional regime from liquid lubrication to boundary lubrication. Under different experimental conditions, frictional reductions associated with this shift in lubrication regime indicated that formulation ingredients could differentially adsorb/absorb at the tissue interfaces, but only the HPGG significantly reduced boundary friction in all cases. Using criteria of degree of tissue-on-tissue friction reduction and resistance to elution during water rinsing, 0.2% (approx.) HPGG concentrations in formulations with no surfactant additives showed stronger dilatant features, and higher substantivity than most other formulations tested. Based on confocal microscopy calibration of the labeled HPGG, it was observed that the 0.2% HPGG formulation became a more highly concentrated gel (0.7% w/v) at the interface. No significant influences of different diluents (e.g. distilled water; physiologic saline; calcium chloride solution) on lubricity were detected. High or low pH affected lubricity in this test model, but only during the first 10 minutes of exposure. Experiments with urea indicated that the HPGG gel interacted with the tissue substratum via hydrogen bonding.

Conclusions: The combined data demonstrated the best lubricity results during articulation of tissue-bound HPGG gel-structured water-on-water interfaces (similar to ice-on-ice low-friction couples). HPGG gels formed synthetic glycocalyxes via hydrogen-bonding overlayers (Figure 1) and diminished tissue friction-induced superficial damage without interpenetration of the HPGG into the tissue surface. The greatest lubricity was associated with superficial 0.7% w/v HPGG gel layers that spontaneously formed from an initially applied 0.2% concentration on both articulating surfaces. Higher starting concentrations of HPGG caused further gelation, stiffened the overlayers and promoted easier mechanical detachment, which limited longevity of the lubricant effect.

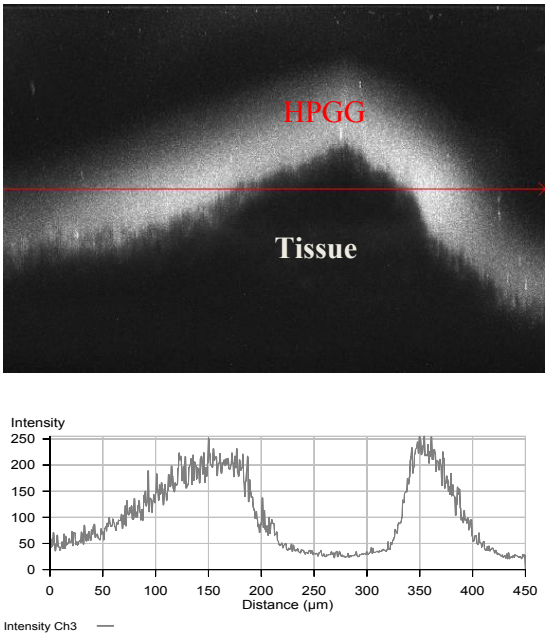

Figure 1. Confocal microscopy image of a superficial gel layer (0.7% w/v HPGG) that does not penetrate the tissue.

Reference: Rodgers LF [Springer LF], M.S. Thesis, State University of New York at Buffalo, 2010.