# The Effect of Surfactant Treatments on the Mechanical and Delamination Behavior of Human Stratum Corneum


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**Statement of Purpose:**

The stratum corneum (SC), the outermost layer of the skin, is the first level of mechanical protection for the body and the initial layer through which mechanical stimuli must pass to reach underlying tissue. The SC is also subject to variable conditions including changes in local temperature and humidity as well as potentially damaging acute and chronic chemical exposure. This exposure can be induced by surfactants (e.g. soaps) or use of skin-adherent technologies (e.g. transdermal drug patches) and influences the structure and mechanical properties of SC. Induced SC changes using specific treatments enable better understanding of the relationship between tissue structure and mechanical properties. We present mechanics-based techniques to study both the in-plane and the out-of-plane mechanical behavior of human SC tissue as a function of temperature, hydration, and chemical treatment.

**Methods:**

To probe the mechanical behavior of SC as a function of treatment, several test methodologies were employed. A fracture-mechanics-based cantilever-beam method was used to reproducibly determine energy release rates (G), quantified in units of J/m$^2$, to measure SC cohesive energy, as a function of hydration, temperature, and chemical conditioning. In addition to out-of-plane measurements, in-plane cyclic tensile and dynamic mechanical tests have been performed to examine the influence of pH and surfactant treatments on mechanical properties including SC viscoelastic properties. Simple rheological modeling of the tissue also yields insight into the underlying processes and the time scales at which they occur. Dynamic mechanical analysis (DMA) studies were focused at low strains (<1%) to observe the effect of temperature and frequency on the mechanical properties of surfactant treated SC.

**Results / Discussion:**

The delamination energy for debonding of cells within the SC was found to be sensitive to tissue moisture content and to test temperature. For untreated SC delamination energies were measured in the range of 1 to 8 J/m$^2$ depending on test temperature. SC conditioned at 100% RH yielded debond energies that decreased with increasing temperature while ~ 45% RH conditioned specimens exhibited more constant values of 2 – 4 J/m$^2$. Lipid-extracted specimens exhibited higher delamination energies of ~ 12 J/m$^2$ with values decreasing to ~ 4 J/m$^2$ with increasing test temperature. Additional SC was treated with pH-buffered solutions (pH 4.2, 6.7, 9.9) and selected surfactant solutions (1%, 10% wt/wt sodium dodecyl sulfate (SDS)) for comparison to untreated controls. While statistically significant differences were observed, the SC was found to be resistant to large changes in delamination energy with pH and 1% wt/wt SDS treatments with values in the range 4.2 – 5.1 J/m$^2$ compared to control values of 4.4 J/m$^2$. More substantially elevated values were observed for SC treated with a 10% wt/wt SDS solution (6.6 J/m$^2$) and a chloroform-methanol extraction (11.2 J/m$^2$). These data indicate that SC is highly sensitive to the presence intercellular lipid content and conditioning which can influence the lipid properties.

For cyclic tensile testing SC modulus was observed to increase from ~ 50 MPa to ~ 85 MPa with increasing surfactant pH from pH 7 to pH 10.3. DMA tests run on similarly treated SC at 1 Hz with a 3°C /min. temperature ramp from -50°C – 150°C indicated suppression of melting temperature of SC free water near 0°C with increased pH. These data suggest that increasing pH affects the distribution of free and bound water in the SC in which proportionally more free water is present with increasing surfactant pH [1]. A secondary transition is observed in the vicinity of 45 – 50°C which may be attributed to the onset of melting of SC lipids [1]. With increasing surfactant pH these transition temperatures are observed to increase. In contrast, at higher temperatures (~65°C – 80°C) at which transitions associated with the melting of intercellular lipid lamellae are know to occur, these transitions are observed to decrease with increasing pH. Similar trends are observed between 80 – 90°C, likely linked to dissociation of lipids covalently bound to the corneocyte protein envelope. Curiously, these two higher temperature trends are contrary to other studies possibly related to the use of the DMA technique to observe these transitions [2]. The increased moduli with increasing pH seen in cyclic tensile tests suggest that the effect of these treatments on the corneocyte keratin has a more pronounced effect on SC mechanical properties than changes in SC lipid conformational behavior.

**Conclusions:**

SC mechanical properties have been explored as a function of various treatments. The methods employed help quantify mechanical properties of SC, which can be utilized to better understand the relation between tissue structure and properties.

**References:**


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