Investigating the influence of relative humidity on expression microwrinkles

The quest for efficient anti-wrinkle treatments has mainly focused on biochemical approaches aiming to mitigate or slow down the effects of both intrinsic and extrinsic ageing. However, the biophysical principles that govern the formation and evolution of wrinkles remain to be elucidated. Georges Limbert shares the findings of a study his computational biophysics group conducted with US researchers (Ramos-e-Silva and da Silva Carneiro, 2007; Assaf et al, 2010), the frictional response of the skin is highly dependent on wrinkle characteristics.

Manifestations of skin ageing and microrelief

There is evidence that ageing wrinkles do not arise from the emergence of new skin structures, but are merely a manifestation of alterations in the material and structural properties of the skin induced by intrinsic and extrinsic ageing (Kligman et al, 1985; Piérard et al, 2003; Pond et al, 2018). Expression (or temporary) wrinkles (or expression lines) are typically associated with facial skin movement and are rather macroscopic in nature. They can originate from either facial muscular activation (i.e. smiling) or mechanical actions on the skin’s surface, such as twisting, shear or compression.

Dynamic wrinkles at a smaller scale, that of skin microrelief—henceforth, referred to as microwrinkles (MW)—are particularly relevant to skin friction as they modulate surface deformation and short-range electromagnetic interactions that control adhesion (Israelachvili, 2011), an essential component of friction. Skin microrelief is made of a network of furrows and ridges, also called sulcus cutis or gyphic patterns, criss-crossing each other and thus delimiting polygonal plateaux with rectangular, square, trapezoidal and triangular shapes. These polygonal patterns—present at birth—lose their isotropic (i.e. properties are the same in any direction) distribution with age and become more anisotropic (i.e. properties are direction-dependent) by forming preferred structural orientations (Piérard et al, 1974).

The characteristics of skin microrelief can be classified, according to the orientation and depth of lines, into primary, secondary, tertiary and quaternary lines (Hashimoto, 1974; Piérard et al, 1974; Piérard-Franchimont and Piérard, 1987; Lévêque, 1999).

Monitoring moisture levels

Because water molecules chemically and physically interact with the skin constituents, particularly with the stratum corneum, moisture levels in the skin play a major role in the development and evolution of wrinkles. As relative humidity drops, this outer layer becomes dryer and stiffer. When this happens, MW at the surface of the skin, induced by facial muscle actions, become much deeper, larger and, therefore, more visible. This can happen in a matter of a few hours (e.g. in a dryer environment, such as a heated room or an aircraft cabin during a long-haul flight), so the immediate answer, and one we all know, is to keep the skin hydrated to minimise the creation of MW.

Developing a quantitative physics-based approach

To date, developing innovative and effective solutions for the prevention and treatment of wrinkles has mainly focused on biochemical approaches—i.e. the application of creams. Recently, the author’s computational biophysics group in Southampton and that of Ellen Kuhl, who heads the Living Matter Lab in the Mechanical Engineering Department at Stanford University (US), have developed a quantitative physics-based approach to understand how alterations in the mechanical properties of the stratum corneum, through variations in relative humidity levels, condition the geometrical characteristics of MW (Limbert and Kuhl, 2018). The hypothesis underpinning this study is that the characteristics of MW are determined by either the natural skin microrelief topography (i.e. geometry) or the
ratio of stiffness (i.e. mechanical properties) between the stratum corneum and the underlying layers (i.e. viable epidermis and dermis), depending on the magnitude of the stiffness ratio.

In the author’s biophysical modelling approach, the skin was modelled as a multilayer structure, featuring a 20 µm thick stratum corneum, laying on top of a much thicker substrate representing the viable epidermis and dermis. The partial differential equations which govern the mechanical behaviour of the skin (i.e. mathematical relationships linking deformations to applied forces) were solved for the whole.
skin structure using a computational technique called the Finite Element Method (Zienkiewicz and Taylor, 1989), which is used widely in engineering (e.g. aerospace), and has become a method of choice for applications in the life sciences.

To mimic the formation of expression MW, in-plane compression of the skin was simulated for six different scenarios, each corresponding to a maximum to low relative humidity level. The ratio of stiffness between the stratum corneum and the underlying skin layers $\alpha$ was varied from $1$ (i.e. maximum humidity and minimum stiffness of stratum corneum), through to $200$, $100$, $400$ and $600$ (i.e. minimum humidity and maximum stiffness of stratum corneum). The stiffness of the stratum corneum was used as a surrogate measure of relative humidity (Wu et al., 2006; Levi and Dauskardt, 2010; Levi et al., 2010).

Key findings

Results of the computational analyses highlighting the differences in wrinkle characteristics, depending on relative humidity level in the stratum corneum, are presented in Figure 1.

Because wrinkles are highly non-linear mechanical surface instabilities, they are very sensitive to any geometrical imperfections, such as those represented by the peaks and valleys of skin microrelief. On application of compressive forces, peaks and valleys on skin microrelief are magnified or switched into valleys and peaks. A good example of this mechanical behaviour could be demonstrated by conducting a simple experiment. By applying in-plane compressive forces on the two short edges of an A4 sheet of paper with one’s hands, the sheet will wrinkle. Depending on the direction and zones of application of these compressive forces (i.e. geometrical and mechanical perturbations), the sheet may form a peak rising above its original plane or a valley below it.

For moderate $\alpha$ values ($\leq 100$), secondary lines of skin microrelief act as geometrical imperfections that trigger wrinkling formation. As $\alpha$ increases, these imperfections, including those represented by primary lines, become less dominant on wrinkling wavelength.

Zones of compressive and tensile strains also get progressively realigned along the direction normal to that of the applied compressive force, which induces wrinkling. There is a clear correlation between the spatial frequency and amplitude of wrinkles and the ratio of stiffness $\alpha$. More in-depth analyses of the results can be found in the original paper (Limbert and Kuhl, 2018).

It is also noteworthy that, as Limbert and Kuhl’s paper (2018) suggested, and irrespective of age, despite its extreme thinness, the stratum corneum plays a key role in determining the characteristics of skin MW. This implies that even young subjects would experience more visible MW when humidity levels drop. Here, the interplay of mechanics and geometry is crucial (Cerda and Mahadevan, 2003).

Refining the model

Naturally, the skin is a much more complex system than what the author’s model captures. After all, a mathematical model is, by definition, a caricature of a physical reality. However, mathematical models implemented under the form of computer simulation programmes offer scientists and engineers practical quantitative tools to systematically and efficiently compare various physical scenarios or study the effects of particular parameters on a system response. Limbert and Kuhl (2018) developed a computational model that sheds light on the potential role of stratum corneum stiffness in relation to the mechanical properties of the underlying layers on the geometrical characteristics of expression MW. As this model gets refined with the addition of new experimental data, and becomes incrementally validated against physical observations, its potential will become more widely recognised, particularly in industrial circles. Ultimately, such a model will provide a rational, science-based approach to design innovative, preventive and longer-term treatment solutions which could delay and mitigate the effects of ageing on the skin (Yu et al., 2016).

Researchers in Southampton and collaborators at the Universities of Glasgow and Cape Town have already started the development of physics-based models (Pond et al., 2018) that demonstrate how ageing affects the mechanical and microstructural properties of the skin. The next step is to couple this modelling framework with the wrinkle simulator.

References

Levy-Mendivil MF, Lewinevics J, Page A, Bressloff NW, Limbert G. Skin microstructure is a key contributor to its friction behaviour. Tribol Lett. 2017;69:12

© 2018 MA Healthcare Ltd