Fundamental biotribological aspects of skin ageing.

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Abstract– The fundamental changes in structural and material properties of the skin associated with ageing are important factors to consider when studying biotribology of the skin. Moreover, in the light of global trends in ageing of populations, these aspects are critically important for the rational development of new and improved products interacting with the skin. In this paper, the tribological consequences of ageing are discussed and illustrated through selected in silico studies based on physics-based mechanistic models.

Key words: skin, biotribology, ageing, aging, biophysics.

I. Introduction

Elucidating the nature of the complex processes underpinning skin physiology and biophysics has emerged as a very active multidisciplinary research arena where close integration of imaging, physical and computational experiments enable novel quantitative mechanistic insight [1-3]. Of particular societal relevance, the ageing process results in significant degradations/alterations of the biophysical properties of the skin [4-8] which lead to further, and potentially life-threatening complications such as pressure ulcers and skin tears [9]. Moreover, the ageing population is more active than in previous generations, and is rapidly becoming a significant market segment, across many industrial sectors (e.g. medical devices, personal care products, sport equipment and consumer electronics). For many of these products the biophysical and tribological responses of the skin [4-6] are crucial in terms of comfort, performance and safety. It is therefore essential to engineer products that take into account altered biophysical characteristics of an aged skin (i.e. "inclusive design") so to optimise their performance. To assist in such a technological endeavour it is essential to first establish a mechanistic understanding of the fundamental aspects skin mechanobiology in ageing. In this paper, experimentally-based modelling techniques developed to address a wide range of scientific questions in relations to skin micromechanics [5,8], wrinkle formation [10] and skin friction [11-13] are presented in the context of ageing. Novel work of our group on stochastic finite element techniques to address biological variability of skin biophysical properties are also be discussed.

II. Materials and Methods

Here, a form of qualitative meta-analysis encompassing numerical micromechanical models of human skin [3,8,10-13] is conducted to establish fundamental links between skin microstructural and tribological properties, and, critically, to highlight the evolution of their interplay over the life course.

The micromechanical multi-layer skin models to be presented are based on a combination of anatomical imaging data and finite element techniques developed in our group [5,8,10-13].

III. Results and Discussion

By developing a quantitative and mechanistic insight into skin micromechanics through parametric finite element analyses, it is shown how skin microstructure and micromechanical properties can play a critical role in determining the way macroscopic deformations are modulated at the microscopic level, and how these effects are affected by age or hydration levels (Fig 1).

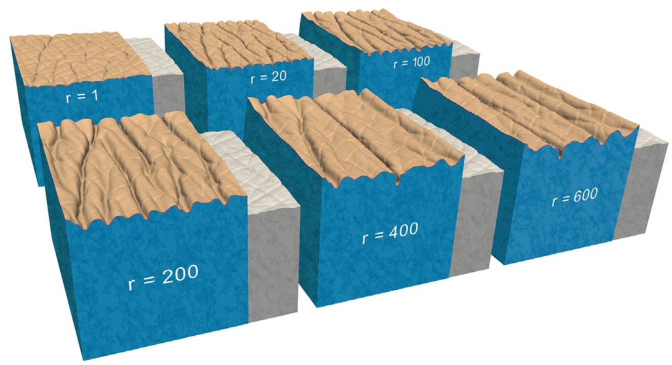

Fig. 1 Structural deformations of an anatomically-based bi-layer finite element model of the skin upon application of a 25% in-plane compression as a function of the ratio of the ground state Young's modulus between the 20 micrometre-thick *stratum corneum* and that of the underlying substrate representing the living epidermis and dermis. The ground state Young's modulus of the substrate was fixed at 0.6 MPa so that the ratios r = 1, 20, 100, 200, 400, 600 correspond respectively to a 0.6, 12, 60, 120, 240 and 360 MPa ground state Young's modulus for the *stratum corneum*. The deformed and undeformed geometries are respectively presented in light brown/blue colour and grey colour. This original plot is adapted from the computational study of Limbert and Kuhl on skin micro-wrinkles [10].

These structural mechanisms are also at the heart of skin tribology by being part of, and conditioning mechanical load transmission [12]. The corollary of these results is that any alterations of material and microstructural properties associated with intrinsic ageing or any other factors (e.g. diet, photo-exposure, air pollution, smoking) must be accounted for to design safer and more comfortable products interacting with the skin. It is well established that ageing significantly alters the biochemical activity (e.g. synthesis/degradation), quality and distribution of its building blocks such as collagen and other essential proteins (Fig. 2) [7-8]. The links between ageing and some aspects the skin's tribological response are therefore deeply rooted in skin's sub-surface micromechanics.

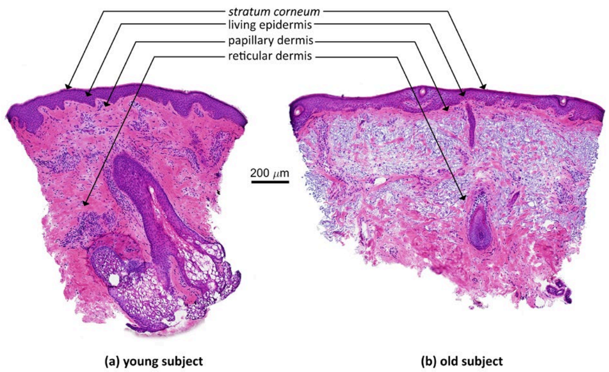

Fig. 1 Histological sections of human facial skin (forehead) highlighting the microstructural features of the epidermis and dermis, in particular, the *stratum corneum*, living epidermis, papillary dermis and reticular dermis. Sections were cut from biopsies obtained with ethical approval and consent from Caucasian female subjects. (a) 24 year-old female subject; (b) 68 year-old female subject. Compared with photo protected and/or young skin (which may be mildly photo-damaged), chronically photo exposed skin is commonly characterised by a flattening of the dermal epidermal junction, the loss of fibrillar collagens, accumulation of glycosaminoglycan content (including hyaluronic acid) and disruption of elastic fibre organisation. Adapted from Limbert et al. [6].

IV. CONCLUSION

Moving research on skin biotribology forward, one key objective should be to understand how age-related alterations of skin biophysics can be accounted for in the development of new or enhanced products that will improve health, quality of life, and enable the aged and ageing population to remain active longer. Particular research efforts should be devoted to gain a fundamental and quantitative insight into the mechanisms that drive and govern the ageing process. Unravelling the inherent complexity of the skin ageing process, firstly by identifying its biophysical drivers, underlying modulating factors and effects, and secondly, by gaining a mechanistic insight into their interplay, is a formidable challenge at both experimental and modelling levels. This stems from the fact that: (1) ageing is a multi-factorial problem which features multiple types of processes rooted in biology, chemistry and physics, and more particularly, mechanics; (2) these processes are non-linear and lead to complex non-linear feedback loops and (3) there is a significant intra-individual (primarily due to anatomical location and environmental exposure) and inter-individual (as a consequence of age, sex or genetics) variability. This complexity currently hinders our ability to develop a mechanistic understanding of ageing, and therefore, a rational basis to design prevention and treatment strategies against its mischievous effects. The provision of experimentally-based mathematical and computational models of skin ageing holds the promise of offering a rational quantitative basis to develop such solutions whilst also enabling and accelerating innovation, and alleviating the reliance on animal models through a better quantitative understanding of human ageing.

One of the main challenges in developing, testing and validating biophysics-based model lies in the (limited) availability of relevant experimental data. It is strongly believed that only inter- and multidisciplinary approaches integrating experimental characterisation, imaging, clinical observation and modelling from the outset, will have a real chance to deliver predictive modelling tools to account for skin ageing in the design of treatment solutions and products through careful integration of age-dependent biotribological properties [6,14] with anatomically-accurate structural characteristics.

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