Skin tensile properties revisited during ageing. Where now, where next?

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Summary

Skin and its subcutaneous layer represent a complex composite of tissues, whose mechanical characteristics depend upon the mutual interdependence of their constituent parts. The molecular and microanatomical structures of skin allow it to meet normal mechanical demands. They also determine the orientation both of Langer's lines and of relaxed skin tension lines. Ageing, photodamage, hormones, drugs, cosmetic products and dermatological interventions may modify the skin's overall tensile properties. In turn, any variation in mechanical stresses and strains imposed upon the skin's connective tissue influences the metabolic activity and phenotypic expression of fibroblasts and dermal dendrocytes.

The viscoelastic functions of ageing skin can be tested by altering the orientation and magnitude of imposed stresses and strains over time. Assessment can be made of various biomechanical properties of skin: tensile, torsional, acoustic shear wave, indentation, impact and elevation. Such objective biomechanical assessments may be applied to dermocosmetic interventions, so providing opportunity for progress in cosmetic dermatological science.

Keywords: ageing, biomechanics, dermis, elasticity, tensile property

Introduction

From a bioengineering point of view, the skin and subcutaneous tissue represent an heterogeneous but integrated load-transmitting entity. In daily life, this composite organ adapts adequately its shape to forces generated by the body volume and posture. It has also to adequately respond to diverse external mechanical demands including some local physical threats. The whole of the organ exhibits both flexibility and relative resistance to deformation, thus permitting body movements, and allowing temporary compression and distension of a part. Once the deformation has ceased, elasticity normally permits the skin to return spontaneously and progressively to its initial shape. Overall, perfect skin is never loose, sagging or stiff.

Progressive resistance to deformation, flexibility and elasticity must be adequately balanced to fulfil the ideal tensile properties of the skin. In reality, such characteristics are the functional expression of the molecular nature of the skin components, but more importantly of their structural organization at the supramolecular and microanatomical level.[1,2] Indeed, the variations in mechanical properties owing to body region, age, and gender outweigh the subtle variations in the molecular composition of the skin according to these variables. This obviously adds to the difficulties in integrating and interpreting information, because there is no correlation between gross molecular composition and the mechanical behaviour of skin (Fig. 1). This topic was extensively addressed by the EEMCO group.[3,4]

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Figure 1 (a) Pre- and (b) post-menopausal dermis. The collagen fibres become looser and less dense with age.

Clearly, the dermis and the fibrous strands partitioning the hypodermis contribute most to the overall tensile strength of skin.[3] Their global mechanical functions depend on two major aspects at a given body site in any subject. First, the mutual interdependence of the constituent parts of the skin make it almost impossible to ascribe a global mechanical response to a specific biological structure or tissue.[3] Second, the typical mechanical response of each macromolecular component is variable within the wide range of force intensities encountered *in vivo*.

Methods, instruments and tensile parameters

Several methods are currently available to assess the tensile characteristics of the skin *in vivo*. This topic was reviewed recently by the EEMCO group.[4] Those systems are based on the measurement of the changes induced in the skin by an imposed stress. Ideally, the resulting strain is maintained within the normal physiological range of skin performance. Most often, the stress involves the various components of several cutaneous and subcutaneous levels.

Methods and instrumentation can be devised from the analysis of the mechanical response to different forces imposed at the skin surface. These are basically grouped into six major classes according to the nature and orientation of the imposed force. Three of them, the tensile, torsional and acoustic shear wave types, correspond to forces applied in parallel to the skin surface. The three other types consist of the indentation, impact and elevation tests in response to the application of forces normal to the skin surface.

Variability in skin tensile properties

The existence of intrinsic and systematic directional tensions within the framework of the fibrous polymers of the dermis has been known for over 150 years after the observations of Dupuytren[5] and Langer.[6] Even under passive resting conditions the skin has a series of built-in internal tensions. The directions of Langer's lines are not constant, but show significant inter-individual variations and do not remain constant according to the body posture at a given site for a specific subject. Thus, Langer's lines do not always correspond to the so-called relaxed skin tension lines (RSTL), which may even run at almost right angles to them.[7] These effects are all due to the release of the resting tension due to cutting through the skin. The skin also appears to be mechanically anisotropic even after the removal of resting tensions by excising strips of skin and testing them *in vitro*.

The anatomical support of the cutaneous tension lines is located in the dermis.[8] In relaxed skin, the elastic fibres and the single collagen fibres located within the concavity of the largest bundles of collagen are wavy. By contrast, when skin is maintained under physiological tension, they are straight and even reshape the bundles onto which they are bound.[8] The relationship between the anisotropic biomechanical behaviour of skin and the tension lines make the latter of considerable practical importance in dermocosmetology. Their direction governs the ideal orientation of surgical incisions. When orientated in the direction of the skin lines they generally gape less and produce better quality and less conspicuous scars than incisions across the skin tension lines. Methods of non-invasive mechanical testing of skin may also be strongly influenced by the relationship between the test direction and the local tension lines, particularly if the test loading is uniaxial. The orientation of the lines must

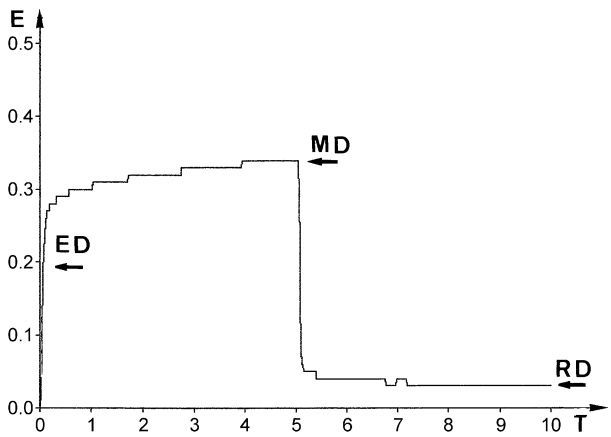

Figure 2 Steep mode evaluation of skin tensile properties. Recorded mechanical parameters during variations in the elevation of skin (E, mm) in time (T, s). ED = elastic (immediate) distension of the skin (0.15 s); MD = maximum distension of the skin at completion of the traction (5 s); RD = residual deformation of the skin at the end of the 10-s relaxation time.

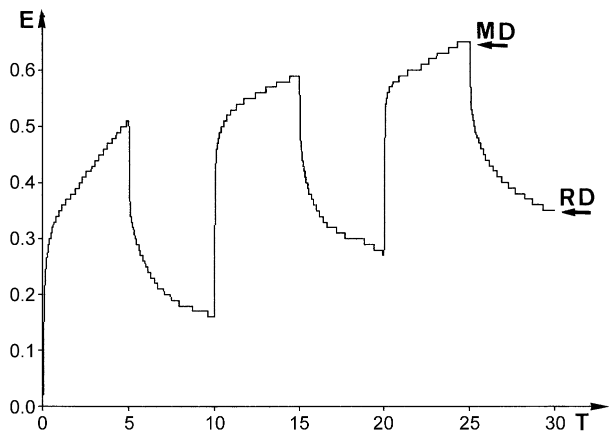

Figure 3 Steep mode evaluation of skin tensile properties. Repeated cycles of suction-relaxation induce a progressive increase in maximum distension (MD) and in residual deformation (RD) of the aged skin.

be known if useful and meaningful comparisons are to be made between the results of the tests at similar sites on different subjects, or of the secular changes at the same site on a single subject.

The real value of measuring skin tensile properties cannot be dismissed in cosmetic dermatology. However, the biomechanical field may be confused because of anatomical variations and variability due to gender, body posture, age, hormonal influences and cumulative ultraviolet and infrared exposure. These aspects are not always suspected or evidenced clinically.[3,9–15] Regional variations in tensile functions reveal a vertically orientated gradient of skin distensibility on the body which seems to be determinant in resisting both hydrostatic pressure and gravitation, particularly in the lower limb in the upright position.[16,17]

When skin is stressed by a load, a rapid elastic distension takes place at first to give way to a visco-elastic phase with much less easy extension (Fig. 2). When the load is maintained at a particular level for a period, further extension, known as creep or viscous extension gradually takes place. Such a presentation of the stress history also occurs when a series of stresses are consecutively applied and released (Fig. 3). When the stress is released, the initial skin position is not immediately resumed (Figs 2 and 3). The progressive return to the initial shape is characterized by the hysteresis phenomenon (Fig. 4). Because of the above considerations, the time-dependent tensile functional properties depend to some extent on the rate at which the load is applied, on the duration for which it is sustained, and the previous preconditioning

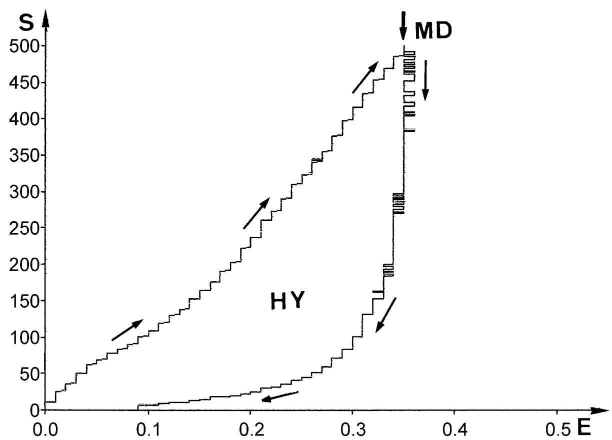

Figure 4 Progressive mode evaluation of skin tensile properties. Typical recording of the elevation of skin (E, mm) during a progressive suction increase (25 mbar/s) in a 20-s suction-on (S, mbar) until reaching the maximum distension (MD) obtained under the 500 mbar suction. This phase is followed by a 20-s suction-off decrease at the same rate. Hysteresis (HY) is defined by the area delimited by the suction and relaxation curves.

stress history of the site.[3] Skin is also normally subjected to continual anisotropic stress. It is also noteworthy that marked differences in visco-elastic properties are found when measurements are taken at different surface areas of the same test site and for different force intensities.[18]

Skin ageing from a biomechanical perspective

It does not require great clinical expertise and sophistication to perceive that skin looks and feels different with ageing. Wrinkles and folds developing around the face and the rest of the body are directly related to the mechanical functions of the skin.[19–21]

All age-related changes in skin influence its tensile properties, although it is not clear how much this is the result of changes in the intrinsic properties of the fibrous framework itself, or in the altered amount of fibres and other structureless material. Moreover, any mechanical stress applied to the skin throughout life affects in turn the structure of the cutaneous tissues and thus modifies the tensile properties. Such multiple interrelationships between the various structures of the skin, the many factors influencing ageing as well as the complexity of the biomechanical aspects preclude any clear-cut understanding of all questions on this subject.[3,20] One of the confounding factors is the variations in body mass index, which may put under tension or slacken the skin.[3,22]

There is an overall agreement to accept that ageing is featured by a reduction in skin elasticity.[3,9–12] By contrast, skin extensibility changes are diversely interpreted.[3,10,20] They are probably stress-dependent with a marked increase in the capacity of unfolding the tissues.[3,19] An obvious piece of evidence is that the skin can be readily picked up in a fold and has to be extended above its original size before it shows the properties expected of a taut collagen framework.

Response of stromal cells to mechanical stress

All mesenchymal cells react physiologically to mechanical stress. In its absence, balanced growth and development would be impossible. It is also a significant mechanism involved in several pathological processes. During embryonic and postnatal growth the dermis has to expand in surface by several degrees of magnitude while it has to keep some balanced pressure to fit the covered volume. To perform this function its fibrous polymers are under a tension that can be nicely demonstrated by comparing embryonic tissues collected by immobilizing the surface or released from its surroundings.[1] Under physiological tension its extensibility is small. To allow any extension in surface, a constant remodelling is required to build a network of increasing size simultaneously with the degradation of the elements of shorter size under excessive tension. This process explains the high rate of collagen turnover in the embryo and the growing child up to the end of puberty. Skin surface increment is not similar at all locations, meaning that besides a potential hormonal control of this metabolic process, additional factors are involved in the modulation of the biosynthetic activity. The mechanical forces to which fibrocytes are submitted allow the precise and required modulation. The capacity of skin fibrocytes to react to mechanical stimuli is indeed used in plastic surgery. For instance, tissue expansion following device inflation increases the covering surface of the tissue and allows repair of a wide area. Similarly, lifting procedures for facial skin sagging are followed by tissue remodelling until intrinsic mechanical tensions in the dermis recover values in the physiological range. The long-term effects of liposuction must also be understood along these lines.

The different types of collagen are not only essential for determining the skin tensile strength, but are also signalling molecules defining cellular shape and behaviour. The communication between collagens and cells is achieved by cell surface receptors.[23] The three types of cell surface receptors for collagen are integrins, discoidin domain receptors and glycoprotein VI. They independently trigger a variety of signalling pathways upon collagen-binding. Besides regulating numerous cellular responses, both integrin and discoidin domain receptors monitor the integrity of the collagenous extracellular matrix by triggering matrix degradation and renewal.[23] The mechanisms of locally controlled expression of collagen, collagen-binding receptors and collagen-degrading proteases in the cellular microenvironment are operative during ageing. In addition to skin fibrocytes, dermal dendrocytes enriched in factor XIIIa are also sensitive to skin tensions.[24–26] These cells are less numerous when the tissues are so loose or so tight that no or little variations in stress can be transmitted to the cells. As a consequence, they are often in low numbers in the dermis during ageing.

Effects of drugs and cosmetics on skin tensile properties

The mechanical properties of the stratum corneum are affected by the level of hydration.[27–29] Indeed, the extensibility, visco-elasticity and shear wave propagation are markedly influenced by the water content of corneocytes. They are also modified by some hormones and other biologically active compounds. Hence, measurements of the skin tensile properties in specific experimental conditions can be used to support claims about product efficacy at the stratum corneum level.[27]

Retinoids

Topical applications of tretinoin and retinol have been shown to improve the mechanical properties of atrophic skin.[30–33] Skin elasticity was increased as well as the numerical density in factor XIIIa-positive dermal dendrocytes in the superficial dermis.

Hormone replacement therapy (HRT) at menopause

Beginning at menopause, a correlation was found between the decreases in both skin elasticity and bone mass density.[33–38] Oral HRT appears to slow down the skin ageing process after menopause. The skin mechanical properties are indeed less altered in time than in untreated women.[38–40]

Dehydroepiandrosterone (DHEA)

Similarly to menopause (oestrogen decline), andropause (testosterone decline) and somatopause (growth hormone decline), adrenopause was coined to relate the progressive age decrease in serum level of DHEA originating from the surrenals. Oral DHEA supplementation is offered to consumers in order to slow down the ageing process. We performed a study in 23 women aged 60–73 years receiving 50 mg DHEA daily for 1 year. None of them improved their skin elasticity, extensibility and speed of shear wave propagation on the face and forearms.

Deanol

The skin of older individuals is characterized by a decrease in the speed of propagation of acoustic shear waves.[22,41,42] Deanol (2-dimethylaminoethanol) is a synthetic analogue of choline. It exhibits cholinergic effects. Many cutaneous cell types possess receptors for such a compound and thus participate in a complex transduction network with acetylcholine as a common cytotransmitter. It has been shown experimentally that deanol applied topically onto ageing facial skin improves the acoustic shear wave bringing more turgidity to the tissues.[43]

Discussion

Biomechanics gives great insight into the clinical expression of skin biology. Many studies document the effects of physiological and environmental variables upon the tensile properties of skin. This information provides a framework for greater understanding of some aspects of skin ageing. Advances in knowledge of the tensile characteristics of skin are hampered by the difficulties outlined above, but these must not inhibit the research endeavour of those investigating skin ageing and cosmetic dermatology. The link between wrinkles and skin tensile properties is obvious.

Conclusions

Most dermocosmetic procedures aiming at correcting wrinkles can be assessed non-invasively by measuring specific mechanical parameters.

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