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Static and dynamic nanomechanical properties of human skin tissue using atomic force microscopy: Effect of scarring in the upper dermis

C.A. Grant [a,*], P.C. Twigg [a], D.J. Tobin [b]

[a] Advanced Materials Engineering RKT Centre, School of Engineering, Design and Technology, University of Bradford, Bradford BD7 1DP, UK
[b] Centre for Skin Sciences, School of Life Sciences, University of Bradford, Bradford BD7 1DP, UK

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ABSTRACT

Following traumatic injury, skin has the capacity to repair itself through a complex cascade of biochemical change. The dermis, which contains a load-bearing collagenous network structure, is remodelled over a long period of time, affecting its mechanical behaviour. This study examines the nanomechanical and viscoelastic properties of the upper dermis from human skin that includes both healthy intact and scarred tissue. Extensive nanoindentation analysis shows that the dermal scar tissue exhibits stiffer behaviour than the healthy intact skin. The scar skin also shows weaker viscoelastic creep and capability to dissipate energy at physiologically relevant frequencies than the adjacent intact skin. These results are discussed in conjunction with a visual change in the orientation of collagenous fibrils in the scarred dermis compared with normal dermis, as shown by atomic force microscopy imaging.

1. Introduction

Skin, the most voluminous organ in the human body, is a complex multilayered biomaterial consisting of a compact keratin-rich epidermis overlying a dermis consisting of a collagenous and elastin fibril phase within an extracellular matrix (ECM). The ECM is rich in proteoglycans (PG), providing hydration throughout the tissue. The functions of skin are manifold and include barrier protection, heat regulation, sensory reception and transpiration, while being sufficiently supple that it will allow for biomechanical mobility and locomotion [1]. While the outer layer of skin (epidermis) is an avascular multilayered structure containing mostly keratinocytes and minor subpopulations of melanocytes, Langerhans cells and few Merkel cells, the dermis layer consists of a collagenous connective tissue containing hair follicles, blood vessels, and sweat and sebaceous glands. The upper (papillary) dermis layer is densely packed with bundles of collagen fibres, which include those fibrils that provide attachment between the epidermis and dermis. The lower (reticular) dermis by contrast is much less fibrillar and merges with a hypodermis (also known as subcutis) that connects with a muscle layer and then to underlying bone.

Given its strategically important location at the interface with an often noxious external environment, the skin is imbued with a remarkable regenerative and repair capacity, e.g., as in wound healing. Upon receiving a trauma, the repair process gets started with platelet aggregation at the wound site to stop bleeding, via the formation of a fibrin clot. Subsequently, this fibrin clot forms a matrix for hosting a variety of cell types, predominately fibroblasts that dissolve the fibrin clot while depositing collagen. In the final phase of wound healing, the composition of the ECM changes over a number of months [2]. It has been shown recently that silver nanoparticle treatment on excisional wounds had a positive effect on the acceleration of the healing process with improved tensile properties, matching those of the normal skin [3].

Disfigurement of the skin by scars is associated with significant psychological and potential functional burden, which may lead to a significant decrease in quality of life [4]. Scars are normally classified according to their clinical behaviour and appearance: normotrophic, hypertrophic and keloidal. Although the histological distinction between these scar types remains controversial, Fourier imaging has shown clear differences in the collagen morphology within these scar types [5]. Skin wounds on early mammalian foetuses heal perfectly with no scars, whereas wounds to adult mammals result in scar formation [6]. Experimental studies suggest that specific anti-TGF-beta therapeutic strategies can improve scar formation in adult wound repair and fibrotic diseases [7]. Comparison between fetal and post-natal wound healing has revealed differences in inflammatory response, cellular mediators, cytokines, growth factors and ECM modulators [8].

Atomic force microscopy (AFM) studies on skin have been carried out to examine the adhesion, friction and wear at the nanolevel, where it was shown that skin cream reduces surface roughness

* Corresponding author. Tel.: +44 (0) 1274 235808; fax: +44 (0) 1274 235925.
E-mail address: c.grant@bradford.ac.uk (C.A. Grant).

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