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Skin Mechanical Properties Present Adaptation to Man's Upright Position

In vivo Studies of Young and Aged Individuals

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In tall animals dependent tissues are stiffer to prevent oedema formation in the upright posture, but whether the same adaptation is operating in man is not known. Skin elasticity and distensibility were measured in vivo in 18 young and 15 aged individuals in the morning before getting up (baseline) and 12 h later. In young individuals skin was stiffer (less distensible) and less elastic in the acral parts of the extremities (ankle, forearm). In the evening distensibility and elasticity of the skin increased. In aged individuals skin was less elastic and no diurnal variability in elasticity and distensibility was detected. We propose that these unique mechanical properties of the acral skin reflect a major role of the integument in the protection against the gravitational stress and the development of the postural oedema. Altered skin mechanical properties may contribute to the poor compensation for gravitational stress in elderly.

Key words: elasticity; distensibility; oedema; ageing; gravitation.

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Among numerous adaptation mechanisms that protect against oedema formation in the upright posture, mechanical properties of the skin in the legs are likely to play a significant role in mammals (1). In the erect posture veins and the skin in the lower extremity are subjected to high hydrostatic (gravitational) pressures (70–100 mm Hg) that enhance plasma ultrafiltration to the extracellular space and oedema formation (2, 3). An appropriate stiffness of the skin in the lower extremity is necessary for the maintenance of intercellular fluid pressure, which according to Starling law governs plasma ultrafiltration. Elastic forces generated in the skin enhance the removal of onceformed oedema in a manner similar to the compressive hosiery (4). The compensation for the gravitational stress seems to be impaired in elderly, and at the end of the day a residual oedema is detected in the majority if not all aged individuals (3).

To investigate whether the mechanical properties of the limb skin may contribute to the compensation for the gravitational stress in humans, we measured skin elasticity and distensibility in vivo in young and aged individuals. The effects of gravitation may accumulate during the day and reach maximum in the afternoon. Therefore we also investigated diurnal variations of skin mechanical properties.

MATERIAL AND METHODS

Two groups of volunteers were studied: 1) healthy young people (14 women, 4 men, range 17–26 years) and 2) healthy old people (9 women, 6 men, median age 89, range 75–100 years). All participants gave their informed written consent to take part in the study. Ethical approval for the study was given by the Copenhagen Ethic Committee. To measure skin distensibility and elasticity Dermaflex A (Cortex Technology, Hadsund, Denmark) was used (5, 6). The instrument was set to exert a negative pressure of 450 mBar in 5 cycles of 20 s. Residual skin elevation after the release of the first suction is named resilient distension. Distensibility is a value of skin elevation (in millimetres) at the end of the first suction. Elasticity was calculated from the formula:

$$\text{Elasticity} = \frac{\text{distensibility-resilient distension}}{\text{distensibility}} \times 100\%$$

A 100% value of elasticity represents the perfect recovery of skin shape after stretch.

Study design

The measurements were made in supine position twice daily: just after waking up but before getting up (the baseline measurement), and 12 h later (in the evening). The following sites were examined: middle medial arm, middle volar forearm, middle anterior thigh, middle lateral calf and 5 cm over the medial malleolus. Both measurements with Dermaflex A (morning and evening) were made exactly from the same sites on the skin.

Statistics

Regression analysis was performed to describe site-related changes of distensibility, elasticity and hysteresis within each extremity. The unpaired two-sided *t*-test was used to compare mean values between the young and the old population. For the analysis of the diurnal changes of distensibility and elasticity, morning and evening mean values for a given site were compared with a paired *t*-test. The normality of data distribution was formally checked with a Shapiro-Francia test.

RESULTS

Skin distensibility showed marked variations dependent on the site of measurement (Fig. 1). In young individuals distensibility was low in acral regions (ankle, forearm) and increased centripetally within the lower and upper extremity. The lowest distensibility was found in the ankle skin. The regression of distensibility against the site of measurement yielded the statistically significant coefficients: 1.10 (S.E. 0.11, $p < 0.001$) and 1.13 (S.E. 0.22, $p < 0.001$) for the lower and upper extremity, respectively. When compared with a *t*-test, skin distensibility of aged individuals was not different from the youths in the corresponding areas. However, the vertical gradient of distensibility in the extremities was weaker in the aged group; the regression coefficients equalled 0.22 (S.E. 0.10, $p = 0.033$) in the leg and 0.69 (S.E. 0.34, $p = 0.054$) in the upper extremity.

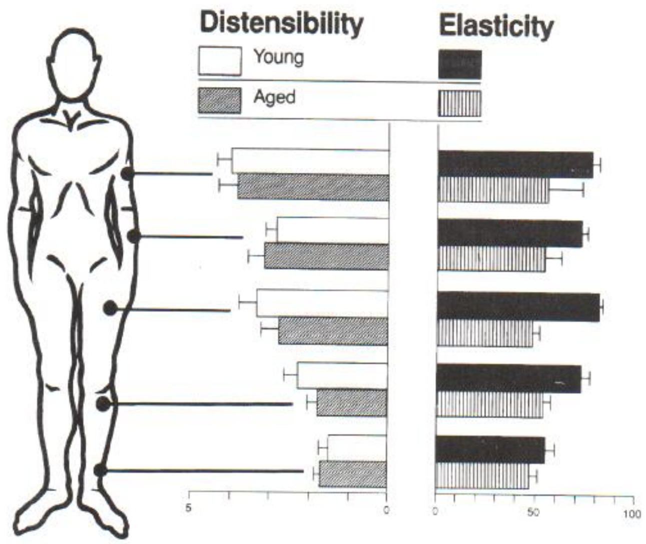

Fig. 1. Distensibility and elasticity of the skin in young and aged individuals in different sites of the upper and lower extremity (means with 2 S.E.). Distensibility is measured in mm (elongation after suction), elasticity in % of skin retraction after stretch.

Skin elasticity in the young volunteers showed site-dependent variation similar to that observed for distensibility (Fig. 1). We observed the vertical gradient of elasticity within extremities with the regression (elasticity vs. site) coefficients 12.9 (S.E. 1.2, $p < 0.001$) for the lower and 5.6 (S.E. 2.4, $p = 0.029$) for the upper extremity. In all the sites examined skin elasticity of aged individuals was significantly lower than in the corresponding areas of the youths (*t*-test). The vertical gradient of elasticity in the extremities was absent in the aged group (analysis of regression).

Distensibility and elasticity showed significant changes during the day (Fig. 2). In the young group meaningful diurnal changes of skin elasticity and distensibility were found only in the acral skin: on the ankle (Fig. 2) and forearm (data not shown). In contrast, in the aged group no such changes were observed.

DISCUSSION

The stiffness of the skin is characterized by the value of distensibility (6). In young individuals skin distensibility presented a vertical gradient: it was the lowest around the ankle and gradually increased in the centripetal direction. Although no differences of skin distensibility in the corresponding sites were detected between the young and the aged group, the vertical gradient of distensibility within the limb was weaker in the latter.

Low dermal distensibility at the level of the ankle is an advantageous phenomenon, because stiff skin may effectively counteract hydrostatic pressures and prevent extensive fluid accumulation due to gravitational stress. Low distensibility of the acral skin may be an evolutionary adaptation to the upright posture; an adaptation of a similar nature is found in giraffes (7), that despite their height and very high hydrostatic pressures in the legs do not develop oedema in the extremities.

While distensibility reflects tissue stiffness, elasticity measures the ability of the skin to recover shape after stretch (6). Similarly to distensibility, skin elasticity decreased centrifugally in the extremities and was minimal in ankle and forearm of young individuals. Prominent diurnal variation of elasticity and distensibility was found in the acral skin in this group. Diurnal variation of skin mechanical properties has not previously been reported.

Skin elasticity may be an important factor governing the process of oedema clearance. According to the current understanding of the dermal biomechanical properties (4), skin has a sponge-like viscoelastic structure (fibres and colloidal ground substance) filled with a free-movable (Newtonian, colloid-poor) fluid. The stretching of the skin enhances the time-dependent dermal accumulation of free movable fluid, while restoration of the previous shape is associated with fluid removal. Skin elastic forces significantly contribute to the recovery of skin shape after stretch and thus enhance the clearance of the interstitial free-movable water. Evening increase of elasticity of the acral skin would be most advantageous, because strong recoil forces assist in the free-movable (oedematous) fluid removal. This phenomenon may present an adaptation of the skin to counterbalance the effects of diurnal gravitational stress.

Aged people presented with a generalized decrease of skin elasticity and absence of vertical elasticity vector. Less elastic skin is likely to assist less effectively with the removal of oedema once formed and in restoration of leg shape. Moreover, elasticity in aged individuals was constant during the day. The loss of normal diurnal variation may be responsible for further impairment of the gravitational oedema removal in aged individuals.

This study provides evidence that the mechanical features of the limb skin inhibit oedema formation during standing and thus reflect an adaptation to the upright posture. In the aged population this "antigravity suit" is damaged so that skin counterbalances gravitational stress less efficiently.

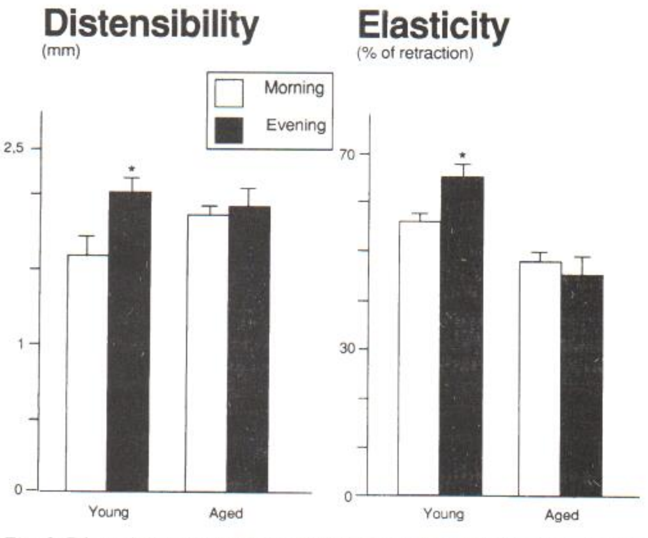

Fig. 2. Diurnal changes of skin distensibility and elasticity in young vs. aged individuals. * significant $p = 0.002$, paired *t*-test.

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