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Torsional Elasticity of Human Skin in vivo

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Summary. Measurements of physical properties of the intact human skin are described. An analysis of the measurements yields parameters that characterize elastic, visco-elastic and plastic properties. Between 6 and 61 years the elastic component of the extensibility of the skin under torsional conditions increases with age. The visco-elastic and plastic components are constant up to an age of fourty; at higher ages they show a small tendency to increase. Moduli of elasticity of the intact human skin derived from the torsion measurements yield values between about 2×10^4 N/m^2 and 10^5 N/m^2, the highest values corresponding to the youngest age. From these values the moduli of elasticity of the elastic fibres in the living skin are estimated between about 2×10^6 N/m^2 and 10^7 N/m^2.

Key words: Skin — Elasticity — Aging.

Elastic properties of human skin have often been determined by using skin strips excised from cadavers. The conclusions drawn from such investigations do not necessarily hold for skin under physiological circumstances.

Experiments on skin in vivo have hitherto been scarce in literature as far as measurements on large groups of normal subjects are concerned. Uni-axial loading was applied by Gibson, Stark, and Evans (1969), a suction method was used by Grahame and Holt (1969) and Finlay (1970, 1971) measured torsional characteristics of the human skin. A torque apparatus was also designed by Vlasblom (1967). We have used this instrument for the present investigation.

Method

The torque apparatus and its performance have been described in extenso by Vlasblom (1967). Via a thin bar the twisting moment (8.3×10^{-4} Nm) of a coil moving in a magnetic field under the influence of an electric current is transmitted to a circular disk (diameter 8.7 mm) that is attached to the skin of the forearm by a piece of adhesive tape sticky on both sides. The rotation of the skin results in an opposed moment and the coil moves until an equilibrium position is reached. At given times the torsion angle is recorded by means of a light beam which is reflected by a mirror attached to the above-mentioned bar.

At a constant twisting moment the rotation of the skin depends on time. One of the results is shown in Fig. 1, where the deflection of the light beam along a scale at a distance of 20 cm from the bar (and concentric with it) is given against time. The

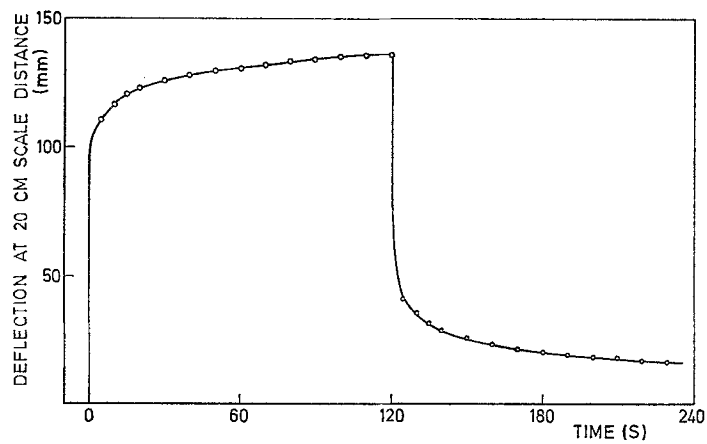

Fig. 1. Torsion of skin as a function of time at constant twisting moment. At $t = 120$ seconds the load is removed

initial quick response of the skin to the applied load can be described as a truly elastic component. This is followed by a viscous damped elastic component. After removal of the load the skin does not return to its original position, but the deflection decreases to a non-zero rest value, that remains during several min. This permanent deformation depends linearly on the loading time (Vlasblom, 1967). Using U_E for the initial response, and U_V for the amplitude of the viscous component with a time constant τ, the curve of Fig. 1 can during the load be represented by

$$U(t) = U_E + U_V [1 - \exp(-t/\tau)] + At.$$

At describes the linear dependence on time of the plastic deformation. Vlasblom (1967) showed that this dependence is not a proportionality. This means that a constant term should be added to At. As this term is small compared to U_E we neglect it here. By fitting the experimental points with the mathematical expression the parameters U_E, U_V, τ and A are obtained. The magnitudes of these parameters depend on the distance from the rotating bar to the scale.

The measurements were performed at the dorsal side of the subject's left forearm about 40 cm from the tip of the middle finger. Nineteen healthy persons, comprising five females and fourteen males, varying in age from 6 to 61 years, were repeatedly examined on different days. The temperature and humidity of the air were maintained constant throughout the experimental period.

Results

In Fig. 2 the deflection of the light spot on a scale at 20 cm from the rotating bar after 2 min of loading (after which the deflection does not increase considerably) is plotted against age. These experiments performed under physiological circumstances clearly show that the extensibility of the intact skin increases with age.

In order to examine which component is responsible for this behaviour, the results of several measurements were fitted to the mathe-

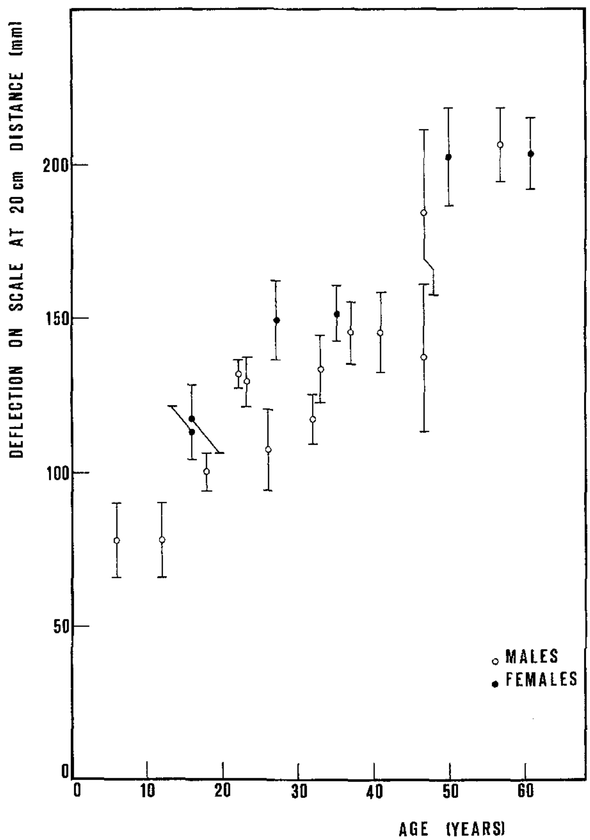

Fig. 2. Deflection of light spot at 20 cm scale distance after 2 min of loading as a function of age. The vertical bars represent standard deviations

mathical expression given above with the aid of a computer programme using a least squares procedure. The resulting parameters are given in Fig. 3, again as a fuction of age. The elastic component U_E shows a clear dependence on age, while the time constant τ of the visco-elastic component does not. The parameters U_V and A do not show a dependence on age up to about 40 years. At higher ages they seem to increase.

The modulus of elasticity can now be derived from the formula (see Vlasblom, 1967).

$$Y = \frac{2M(1 + \nu)}{4\,aR^2\varphi}$$

in which M = twisting moment, ν = Poisson's ratio, a = skin thickness, R = radius of disk, φ = angle of rotation.

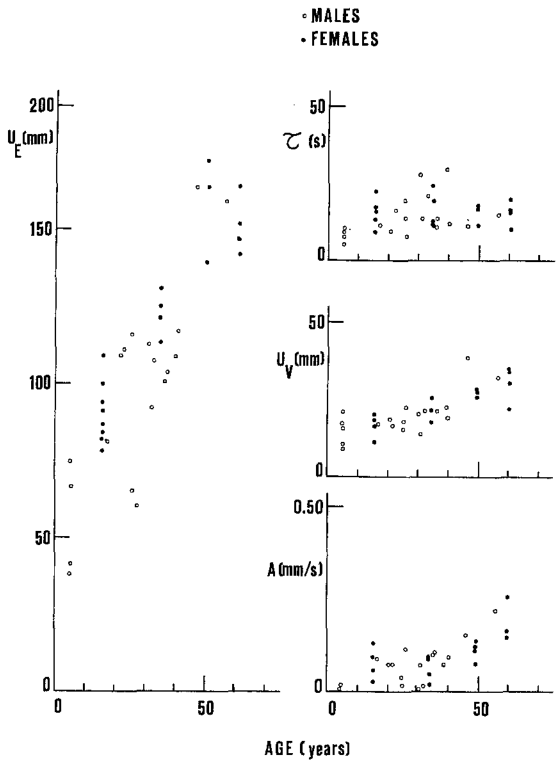

Fig. 3. The parameters U_E, U_V, τ and A at different ages

Deriving this formula the skin was assumed to be a homogeneous and isotropic elastic plate of uniform thickness a with infinite boundaries. The bond between skin and subcutaneous tissue was neglected. Vlasblom (1967) showed that the influence of this bond was indeed small at a tangential loading of the skin.

Values for M and R are given above. A good approximation for Poisson's ratio may be $\nu = 0.5$. By taking $a = 0.1$ cm we will not introduce a large error. The angle φ is $d/2l$, where d is the distance covered by the light spot on the scale at distance l. In the equipment used, l was 20 cm. Considering the elastic component only, we take $d = U_E$. Substituting all these values in the formula given above, we find a modulus of elasticity Y for each U_E. The moduli for the skin as a whole thus derived from our measurements are given in Table 1. Over the age range covered we obtain values from about 2×10^4 N/m^2 to about 10^5 N/m^2, the highest values corresponding to the youngest age.

Table 1. Moduli of elasticity of the intact human skin calculated from torsion measurements

Subject	Age (years)	Sex	Modulus of elasticity (10^4 N/m^2)
1	6	M	5.4
			6.0
			5.5
			9.7
			10.7
2	16	F	4.8
			5.1
			4.9
			4.4
3	16	F	3.7
			4.0
			4.6
			4.3
4	18	M	5.6
5	22	M	3.6
6	23	M	3.6
7	26	M	6.2
8	26	M	3.4
9	31	M	3.5
10	32	M	5.5
11	33	M	3.7
12	35	F	3.2
			3.0
			3.3
			3.5
13	37	M	3.9
14	40	M	3.7
15	41	M	3.4
16	47	M	2.4
17	50	F	2.8
			2.4
			2.3
			2.4
18	57	M	2.5
19	61	F	2.4
			2.7
			2.8
			2.6

Discussion

Grahame and Holt (1969) found values for the modulus of elasticity from 1.8×10^7 N/m^2 to 10^8 N/m^2 from in vivo measurements of human forearm skin by a suction method. These values are comparable to that found from pure collagen. In constrast to our results they find a slight increase in the modulus of elasticity at higher ages. This stiffening up in a direction perpendicular to the skin surface can be understood, as the authors mention, as being due to the increase of cross-linkages between peptide chains of the collagenous network.

It is well known that the elastic fibres show fraying and fragmentation at advancing age. It is therefore tempting to ascribe the loss of elasticity in a direction parallel to the skin surface that we observed, to this phenomenon. This becomes still more likely if we divide the moduli we found by the volume fraction (0.01) of the elastic fibres in human skin (Tregear, 1966). For the moduli of elasticity of the elastic fibres in the living skin we then obtain values between about 2×10^6 N/m^2 and 10^7 N/m^2, in agreement with the value 5×10^6 N/m^2, mentioned by Tregear (1966) for pure elastic tissue.

In addition to observing a tendency for the elastic modulus to increase with age, Grahame and Holt (1969) obtained significantly higher values for females than for males. Although the number of females examined in the present work was very small, there may be a slight indication of smaller values for females, while the moduli of elasticity decrease with age. From a mechanical point of view the skin of females seems to be somewhat older than the skin of males.

Comparison of our results with literature shows that the modulus of elasticity of skin is not simply a material constant. Because skin is not a homogeneous and isotropic medium, quite different moduli can be found under different experimental conditions.

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