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VISCO-ELASTIC RESPONSE OF HUMAN SKIN AND AGING

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ABSTRACT

The changes in visco-elastic properties of skin belong to the most conspicuous manifestations of cutaneous aging. In spite of apparent simplicity, the measurement of mechanical parameters of skin *in vivo* presents both theoretical and practical problems. Reproducibility, standardization, duration of measurement, discomfort for experimental subjects are the main complications. Measurement and analysis of transient deformation response to pressure stress provides theoretically consistent and practically applicable methodology.

Experiment: The transient deformation response of skin was measured in two groups consisting of 15 healthy men and 17 healthy women. The range of age interval was 20 to 58 years. The deformation response was measured as reaction of skin on sudden change of pressure stress between two levels of loading on skin surface.

Results: Transient response of human skin consists of sum of two exponential curves. A "rapid" exponential curve has time constant typically of order 10 ms, while "slow" exponential curve has a time constant of order 0.1 to 1s. Both time constants increase with chronological age. Time for drop of deformation on 12.5% of full deformation proved to be a simple and sensitive criterion of skin aging, with strong correlation with chronological age.

Main advantage of the method: Measurement is quantitative and reproducible. Procedure is easy to repeat. Its average duration is approx. 2 minutes and it does not represent any discomfort for test subjects.

INTRODUCTION

Visually perceptible appearance of human skin is probably most obvious intuitive criterion for estimation of biological age. Younger skin is usually characterized as "more elastic" than older skin. The effort to find a marker of skin aging has produced procedures such as the assessment of time for standard "pinch to flatten" as a criterion.

In spite of apparent simplicity, the measurement of mechanical parameters of skin *in vivo* represents relatively complicated problem (1 - 6). The problems are both theoretical and practical. The main theoretical complication consists in correct definitions of relevant notions and quantities. Such terms as "elasticity", "mechanical parameters" or "visco-elasticity" etc. are too general or even vague. In fact, it is not clear what mechanical parameters or quantities correspond to the intuitive notion of "elasticity of the skin". Reproducibility, standardization, duration of measurement and discomfort for test subjects belong to the limiting factors from the practical point of view.

The subject of this study is focused on the relationships between deformations and stresses of the skin during aging. The goal is to suggest practical methodology of their measurement and assessment. I other words, we try to find how the stress is transformed into deformation. The procedure of derivation of mathematical description of the transformation from experiments (identification of transformation) is extremely complicated task in non-linear systems like biological materials, including the skin. On the other hand, the identification is more feasible in linear systems. Consequently, it is practical to base the methodology on the fact, that the mechanical behavior of skin is linear in cyclic loading and in case that the relationships between sufficiently small changes of stress and stain are analyzed. Quantification of skin "elasticity" may now follow from the theory of visco-elastic bodies. Mechanical behavior of this type of materials is usually explained by models containing combinations of elastic and plastic elements (5, 6, 7, 8). The transformation between stress and strain may be mathematically described by linear differential equation in this case. Transient deformation response on jump of input stress of these materials consists of sum of exponentials. Mechanical behavior of skin may be thus described by parameters of these exponentials.

We believe that the measurement and analysis of transient deformation response on pressure stress provide theoretically consistent and practically applicable methodology for assessment of mechanical properties of skin and may contribute to better availability of the cutaneous markers of aging. (6, 7, 8). We also believe that the analysis of transient response is more practical than analysis of response on sinusoidal stress (9) or, more generally, than analysis of frequency characteristics.

The main reasons consist in fact that measurement of transient responses is practically more feasible and enables reveal and describe an extent of linearity in the behavior of materials.

MATERIAL AND METHODS

Two groups consisting of 15 healthy men and 17 healthy women were used in experiment. The range of age interval was 20 to 58 years. The deformation response of skin on the palm (left hand, above the middle of abductor *pollicis brevis,* was measured. The skin was dried by alcohol solution and heated by IR lamp on temperature 34 °C.

The structure of measuring appliance (7, 8) is presented on Fig. 1. The object under measurement (left hand) is mechanically fixed between two plates. The plates are compressed by pressure 10,64 kPa (80 torr). The input force is evolved by inserting weights on gauge, which pass through aperture (diameter 20 mm) in upper plate. The fixation ensures stable position of the hand as well as the skin tension. Applied version of apparatus had sensitivity 5 μm and time constant 8 ms, both sufficient for purposes of the experiment.

Loading level (see Fig.1) S_0 = 20g (18,6 N), jump ΔS = 30 g (28,7 N), duration of jump ΔT = 20 s, interval ΔT_i = 20 s. Gauge: diameter 4 mm, spherical endings.

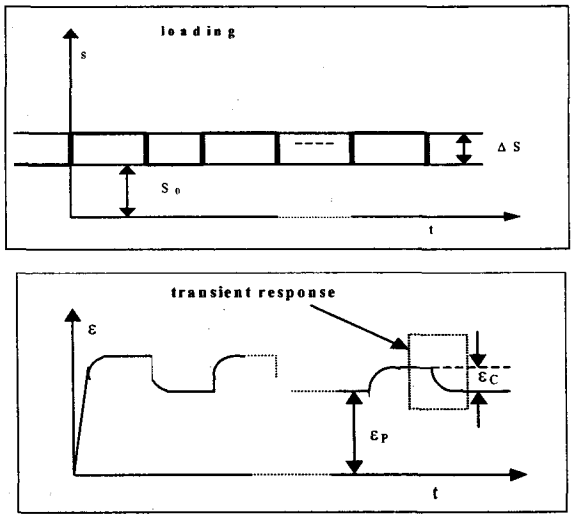

Figure 1: Typical response of skin on cyclic stress. ε_P represents permanent deformation, ε_C represents steady state response. The duration and dynamics of transient response (see dotted area) was measured .

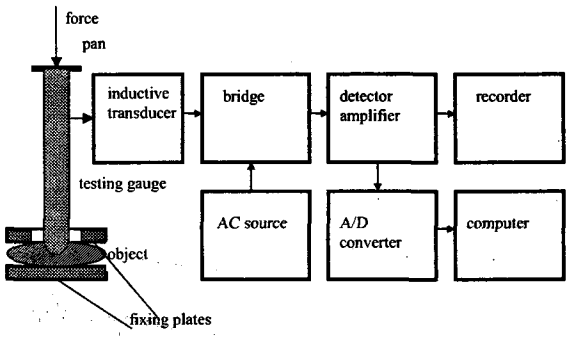

Figure 2: Measuring appliance – scheme.

RESULTS

The transient response of human skin consists of sum of two exponential curves (Fig. 3). "Rapid" exponential curve has time constant of order 10 ms, typically 30 ms. "Slow" exponential curve has time constant of order 0.1 to 1 s. Both time constants increase with chronological age. The duration of transient response depends on parameters of both exponential curves. As the mechanical parameters of skin are possible marker of biological age, we look for "one parameter" criterion of skin age, which takes into account "slow" as well as "rapid" exponential curves. We compared several possibilities, e.g. the area under the curve, half-time of its decline and/or its multiples. The time for drop of deformation to 12,5% of full deformation (three half-times) proved to be a pregnant and simple criterion.

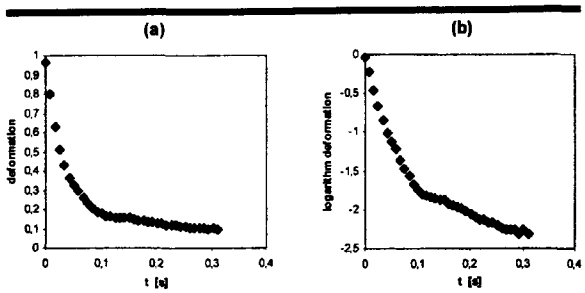

Figure 3: Typical transient response of human skin (a), the same response in semilogarithmic scale (b).

The duration of time response increases significantly with chronological age in men as well as in women. The increase is approximately 4 times higher in men than in women (Figs. 4 and 5). Results of statistical evaluation are summarized in Table 1.

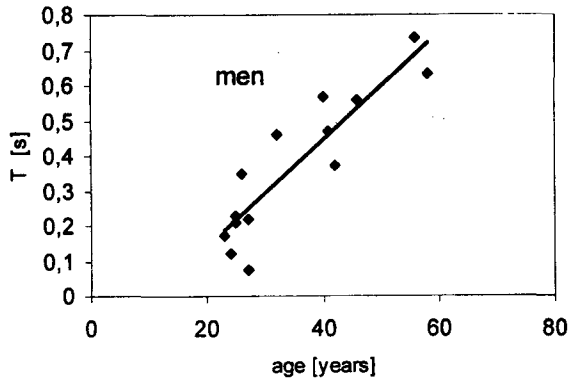

Figure 4: Return to 12.5% versus age (men). T is time for return of deformation on 12.5% of maximum deformation. Parameters of the regression: slope k = 0.0153 ± 0.002, coefficient of correlation R = 0.902. Dependence of variables proved for s.l. = 0.001.

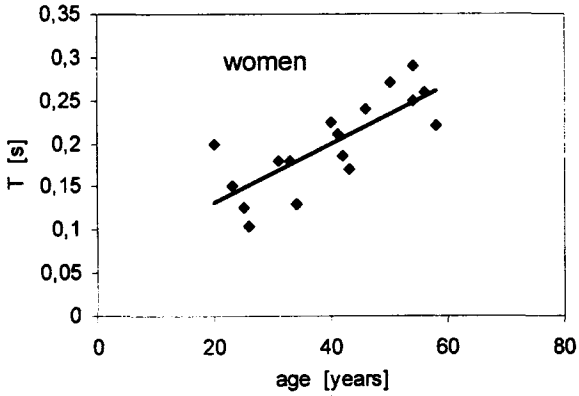

Figure 5: Return to 12.5% versus age (women). T is time for return of deformation on 12.5% of maximum deformation. Parameters of the regression: slope k = 0.0034 ± 0,0007 , coefficient of correlation R = 0.778. Dependence of variables proved for s.l. = 0.001.

Table 1: Statistical evaluation of results.

REGRESSION PARAMETERS	MEN	WOMEN
slope	0.0153 ± 0.0020	0.0034 ± 0.0007
intercept	-0.169 ± 0.074	0.064 ± 0.029
coefficient of correlation	0.902	0.778
residual standard deviation	0.090	0.035
significance level of F-test	0.001	0.001

DISCUSSION

Probably the most important conclusion is the finding that transient response of human skin consists of sum of two exponential curves, both depending significantly on age in men as well as in women.

Consequently, the time of duration of transient deformation response proved to be good "one parameter" marker of skin aging. The marker is used in a battery for determination of human biological age in our laboratory. Its sensitivity and correlation with chronological age are very good and they are at least comparable with near point or accommodation range of eyes (5). The procedure is easy to repeat. It takes approximately 2 minutes and it does not represent any discomfort for test subjects.

The measurement was performed on palm of left hand. This place was chosen for practical reasons: the comfort for test subjects, possibility of fixation and relatively small risk of spontaneous jerks. Naturally, the measurements performed on other parts of body might be also of interest.

ACKNOWLEDGMENTS

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