THE USE OF ELASTOGRAPHY TO ASSESS THE RHEOLOGIC PROPERTIES OF THE SOFT TISSUES OF THE HUMAN LIMB WITH NORMAL AND DISTURBED PERIPHERAL LYMPHATIC CIRCULATION

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A method of investigating the rheologic properties of the soft tissues of the human limbs with normal and disturbed peripheral lymphatic circulation is described. The curves recorded (elastograms) are analyzed. The suggested coefficients are shown to reflect differences in the rheologic properties of the soft tissues in health and disease.

KEY WORDS: rheologic properties; soft tissues; elastogram; mechanical resistance.

The study of the rheologic properties of human soft tissues began a long time ago. In the earlier studies [1, 2, 4], in which the degree of deformation of muscles was measured in response to mechanical action, changes in the hardness index of muscles were determined during physical and mechanical loads. The same principle has been used to study changes in the mechanical properties of the eye in glaucoma [3].

Previously the writers found that some rheologic indices of pathologically changed tissue differ significantly in the character of deformation during mechanical action from healthy tissue.

This paper describes a first attempt to assess quantitatively the rheologic parameters of the soft tissues of the human limb when the peripheral lymphatic circulation is normal and disturbed.

For this purpose the apparatus described below was used. The principle of its action is based on measurement of the mechanical force developed by the tissue when compressed by a metal rod with cylindrical head, performing to-and-fro plunging movements with a frequency of 0.06 Hz. Movements of the rod and the forces developed were converted into electrical signals by means of strain gauges. The curves (elastograms) were recorded on an automatic x-y writer (Honeywell).

Tests were carried out on 20 healthy subjects (40 limbs). The area selected was the middle part of the posterior surface of the calf, when the subject lay in the prone position. The point of measurement was chosen so that when the rod pressed into the tissues, the presence of bone did not affect the results of measurement. The depth to which the rod sank was always constant, namely 9 mm. The number of successive plunging movement of the rod depended on the time taken for the elastogram to reach the steady state (as a rule 10 plunging movements).

A typical elastogram recorded from a healthy human lower limb is illustrated in Fig. 1. Clearly the elastogram is a loop-shaped curve, with its concave side facing the origin of the coordinates. This loop-shaped appearance of the curve can evidently be explained by internal friction of the muscle tissue. In fact, when the rod compresses the tissues it overcomes the elastic forces of the deformed tissue and the force of internal friction; on its return movement the compressed tissue presses on the rod and the force of internal friction acts in the opposite direction. The elastogram of the healthy limb reaches the steady state after two or three plunging movements.

The rheologic properties of the tissues were assessed by the mechanical resistance of the tissue to compression (hardness index $\gamma = F/S$, where S is the depth to which the rod sinks into the test tissue (abscissa),

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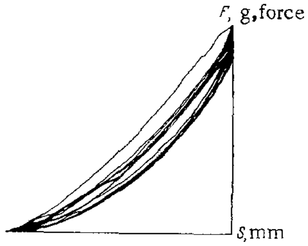

Fig. 1

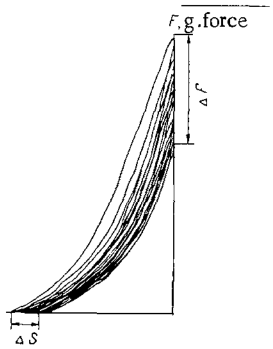

Fig. 2

Fig. 1. Elastogram of healthy human lower limb. $\gamma = 10.7$; $K = 0.08$; $\theta = 0.03$. Here and in Figs. 2 and 3, calibration: horizontal line corresponds to rod sinking into tissue to a depth of 2 mm; length of vertical line corresponds to a force of 20 g force.

Fig. 2. Elastogram of edematous limb. ΔF) relaxation of maximal force during 10 plunging cycles of rod; ΔS) depth of hollow. $\gamma = 23.7$; $K = 0.38$; $\theta = 0.17$.

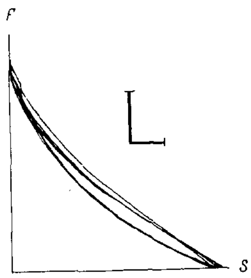

Fig. 3. Elastogram of same patient as in Fig. 2 recorded 7 days after operation of lymphovenous anastomosis. $\gamma = 13.4$; $K = 0.02$; $\theta = 0.03$.

and F the force developed during plunging (ordinate). As Fig. 1 shows, the value of γ measured as a result of the first mechanical compression was somewhat greater than that measured in the steady state of the loop. The reason was evidently that as a result of the first compression a certain quantity of interstitial fluid is always expressed from the region tested, and has not had time to return when the next compressions take place. In healthy tissue this process, known as relaxation of mechanical resistance, is negligible, and can be disregarded; consequently, the value of γ is calculated from the amplitude of the loop in the steady state.

The investigation showed that in healthy subjects the value of γ measured in the middle part of the posterior surface of the calf varies from 10.7 to 14.4 g force/mm in women and from 14.7 to 20.0 g force/mm in men.

The elastogram recorded from edematous tissues (Fig. 2) differs sharply from that recorded from the healthy limb. To begin with, the loop recorded from edematous tissue does not reach the steady state until after 5 or 6 plunges of the rod, depending on the degree of edema. In patients with pronounced edema the loop does not reach the steady state even after 10 to 15 plunges. Consequently, the process of relaxation of mechanical resistance for edematous tissue is manifested much more strongly, and for that reason the value of the coefficient γ should be calculated twice: $\gamma_1 = F/S$ reflects the state of the tissue during the first mechanical compression, when the maximal quantity of fluid is evidently expressed from the test region; $\gamma_2 = (F - \Delta F)/(S - \Delta S)$ is calculated when dynamic equilibrium is established between the outflow of fluid from the test region and the inflow of fluid into it for the selected conditions of measurement (the elastogram reaches the steady state).

Elastograms lying between the first and the "steady-state" characterize the change in the mechanical resistance of the tissue as a result of gradual expression of fluid from the test region. As Fig. 2 shows, the process of relaxation of mechanical resistance for edematous tissue is expressed, on the one hand, by relaxation of the initial force applied to the metal rod, and on the other hand, by the formation of a hollow in the region of investigation. The process of gradual reduction of the initial force is more pronounced under these circumstances than the process of formation of the hollow. To express the relaxation of the force quantitatively a coefficient of relaxation $K = \Delta F/F$ is used. In patients with different degrees of edema its value ranges from 0.19 to 0.54. For healthy limbs $K = 0.02$-0.09.

The process of formation of a hollow in the tissue is recorded as relaxation of movement of the rod. The relative depth of the hollow can be expressed by the coefficient $\theta = \Delta S/S$, where ΔS is the absolute depth of the hollow. For edematous tissues ΔS varied from 0.02 to 0.3, whereas for healthy limbs it varies from 0.02 to 0.06.

The elastograms can be used to study the dynamics of changes in the state of edematous tissue in the course of treatment. The elastograms in Fig. 3 was recorded from the same patient as that in Fig. 2, 7 days after an operation of lymphovenous anastomosis. The elastogram is the typical curve characteristic of healthy limbs.

By the method described above it is possible to assess some important rheologic parameters of human soft tissues in health and disease.

LITERATURE CITED

1. Yu. M. Uflyand, Gig. Truda, No. 8, 3 (1927).
2. A. Exner and J. Tandler, Mitt. Grenzgeb. Med. Chir., 20, 458 (1909).
3. C. W. Hargens and R. H. Field, US Patent No. 345289.
4. H. Schade, Z. Exp. Path. Ther., 11, 369 (1912).