HOLOGRAPHIC RECORDING OF DEFORMATION WAVES IN MUSCLE TISSUES

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Recording the profile of Rayleigh-type deformation waves in a viscoelastic medium became necessary with the development of a combined method of evaluating the mechanical parameters of human skeletal muscles in health and disease.

The method involved two approaches: static and dynamic. In the first case the degree of bending (δ) of the surface of the test muscle depending on the static force (F) acting on the muscle in the transverse direction, through a circular die, and with a stepwise change of force, was measured [3].

Calculation of the slope of the linear portion of the experimental curves of $\delta(F)$ in the region of muscle tissue enabled the static shear modulus to be estimated [4], and assuming that the Poisson coefficient is 0.5 [5, 7], the value of Young's modulus could be determined. The influence of the skin was allowed for by excluding from the calculations the portion of the graphs of $\delta(F)$ which related to this layer of biological tissue.

According to measurements made on healthy subjects and patients, Young's modulus for all subjects, under all conditions of work of their skeletal muscles (in particular, for the biceps brachii muscle) ranged in value from 30 to 350 kPa under normal conditions and between 80 and 500 kPa in muscle pathology.

In the dynamic investigations a shear deformation wave was created and its profile recorded by holographic interferometry. The interference patterns (IP) were then used to calculate dynamic shear modulus and Young's modulus, the density of the medium, and its coefficient of viscosity.

Solution of the dynamic problem also was complicated by the large number of layers forming the object, including the presence of a layer of skin with subcutaneous fatty areolar tissue, lying on the surface and preceding the muscle layer. It was thus first necessary to show that the depth of penetration of the deformation waves (of the Rayleigh wave type) created by the shock in the tissues of the organ is several times greater than the thickness of the skin layer.

It can be shown by theoretical computation [1] that the mean depth (h) of penetration of deformation waves of the Rayleigh type lies within the limits λ_R to $2\lambda_R$, whre λ_R denotes the length of the Rayleigh wave. However, to calculate this value it is essential to know the velocity of spread of waves in the given medium.

Estimation of the velocity of spread of the deformation wave was based on data of the static problem, and on the assumption that the density of muscle tissue is close to 1 g/cm^3. To calculate the velocity C, an equation connecting the modulus of elasticity of the medium E, Poisson's coefficient ν, and density ρ in the following manner [6]:

$$C^2 = E/2(1+\nu)\cdot\rho^{-1}.$$

was used.

The use of experimental data for the modulus E for different degrees of tension of the muscles in the calculation showed that velocities of spread of deformation waves lie within the range 5-15 m/sec. The velocities of waves of the Rayleigh type do not differ significantly from the values obtained, because the known dimensionless Poisson function connecting them varied from 0.874 to 0.956 [1, 6]. The expected depth of penetration of

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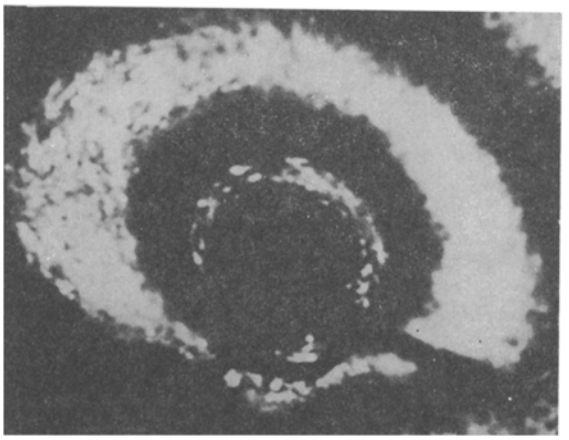

Fig. 1

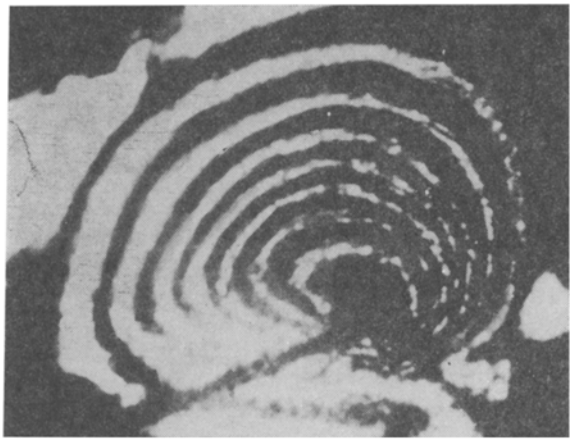

Fig. 2

Fig. 1. IP of deformation wave in viscoelastic medium (elastomer) with metal plate at a depth of 6 mm, during vibration with a frequency of 300 Hz.

Fig. 2. IP of deformation wave in viscoelastic medium (elastomer) with metal plate at a depth of 3 mm, and with vibrations at a frequency of 500 Hz.

the deformation wave in viscoelastic tissues of the type investigated ought to be about 10-30 mm, which corresponds to the depth at which human muscle tissues are located.

The calculated values were verified experimentally as follows. An elastomer, whose density, modulus of elasticity, and Poisson coefficient were close to the corresponding values for muscle tissue, was chosen as the model of biological tissues. A model was made from the elastomer in the form of a bar incorporating a metal plate, simulating a nonhomogeneity, located at different depths. The source of deformation waves was a vibrator 6 mm in diameter, which made contact with the surface of the object and excited mechanical oscillations in it with frequencies of 300 and 500 Hz.

Deformation of the surface of the object was recorded by a standard dual-beam system on a holograph [2], in which the source of light was a continuous-acting type LG-38 laser. IP were obtained by the time averaging method. The wave front was recorded on photographic plates (Agfa-Gevaert, type 10E-75).

Calculation of the deformation "field" from the data of IP showed that in materials of the type studied (with high viscosity) and if the amplitude of oscillations of the vibrator was about 100 μ, what was in fact recorded was not the wave as such, but oscillations of the surface of the object as a membrane.

IP of deformation of elastomer models incorporating a metal bar at different depths and with different frequencies of operation of the vibrator, are given in Figs. 1 and 2. The IP clearly demonstrate distortion of the shape of the interference rings in the region of the nonhomogeneity at depths of both 3 and 6 mm, thus qualitatively confirming the results of theoretical calculations of the depth of penetration of deformation waves.

To ascertain whether this method can be used to investigate "fields" of deformation and tension of homogeneous viscoelastic media the experiment was modified as follows: a bar of the homogeneous elastomer was fixed in a holder so that it was compressed uniformly from one edge and locally from the other. In this case the IP reflects the pattern of distribution of tension in the model, so that a region of increased compression can be established.

This method thus enables a change in the mechanical properties of both homogeneous and nonhomogeneous viscoelastic media to be investigated under conditions of nondestructive monitoring of changes taking place in them, so that in this way the "field" of the given material can be recorded.

To allow for the layered nature of the structure (including the effect of comparatively thin surface layers, including the skin) the method of recording IP was modified as follows. The vibrator exciting deformation waves was brought up to the model on its dorsal aspect. The thickness of the material under the vibrator varied from one model to another between

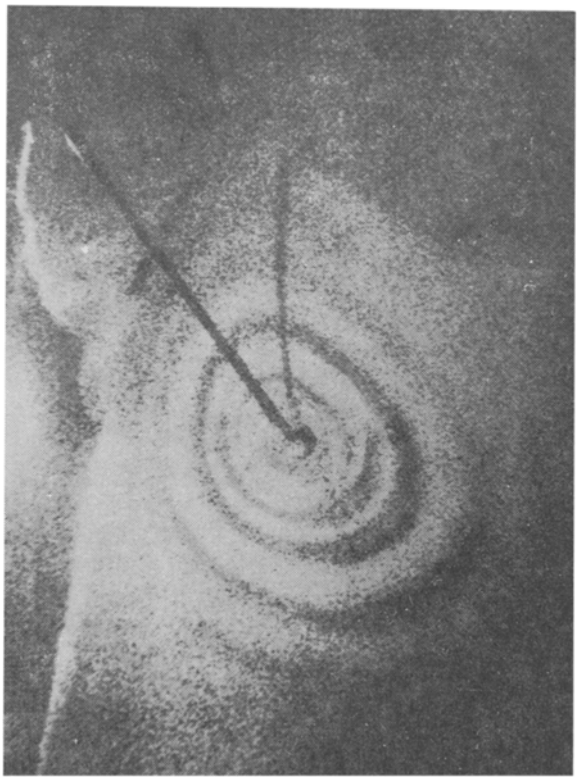

Fig. 3. IP of deformation wave in human biceps brachii muscle.

5 and 15 mm. Averaged IP were recorded from the front surface by the method described above. Under these circumstances IPs were obtained initially from the free surface, after which a flap of the animal's skin (with the layer of subcutaneous fatty tissue), dissected immediately before the IP were recorded, was glued to the model. To ensure acoustic contact the surfce of the elastomer was smeared with glycerin. The degree of pressure with which the vibrator was applied to the model was unchanged.

Analysis of the IP confirmed the validity of the hypothesis that at frequencies of between 200 and 500 Hz the vibrator creates deformation waves whose depth of penetration is sufficient to enable muscle tissues to be investigated, and that the skin has virtually no effect on the IP.

The next stage of the work was done on the biceps brachii muscle. Since the living object virtually rules out any possibility of using the time averaging method (i.e., long holding times are not permitted), a method of two exposures with a delay of about 100 μsec between flashes from the pulsed laser was used. A standard dual-beam system was used to form the hologram. The source of light was an "Apollo 22-ND" two-cascade pulsed ruby laser with output energy of about 0.5 J.

The test object was the upper limb, flexed at the elbow to a right angle, and placed in an antivibration pad, while the subject himself sat in an armchair, with insulation against vibration. The source of deformation waves (a vibrator, excited by a single pulse) was applied to the surface of the biceps muscle. The moment of contact and the strength of the shock were recorded by means of an electrical circuit. The time between the shock and the flash of the laser was controlled by means of a delay circuit.

One typical IP of the spread of the deformation wave in human muscle tissues is illustrated in Fig. 3, which clearly shows the vibrator creating the wave and the asymmetrical circular interference structrues on the surface of the object, reflecting the "field" of deformation. The appearance of the ring structures and the character of their changes reflect primarily the shape of the "relief" (in this case a depression), formed in the material in response to the action of the vibrator. In particular, it follows from the data that in this case we have, not the wave as such, but only its initial part, i.e., the trough,

the amplitude and radius of which vary in accordance with a harmonic rule with decay time determined by the value of the coefficieint of viscosity.

The absence of a wave indicates a high degree of viscosity of the tissues forming the test object. Asymmetry of the ring structures in turn reflects the difference (in this case, of 1.5 times) between the modulus of elasticity "along" the fibers of the tissues, and "across" them.

This account of the results of the preliminary stage of these investigations of the biochemical parameters of human muscle tissues by methods of nondestructive monitoring of changes taking place in them during the development of tension in response to work done in health and disease, it must be pointed out that the suggested method can also be used to determine and investigate nonhomogeneities in any viscoelastic material.

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AN OCULAR STEREOMETRIC GRID FOR INVESTIGATION OF THE LIVER

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KEY WORDS: histometry of hepatocytes; lobular microcirculation

The study of pathological changes in the hepatic lobule demands great precision in the evaluation of microcirculatory disorders and changes in the ratio between unchanged hepatocytes and cells in various states of degeneration. Stereometric grids and methods of investigation of liver sections have been described in the literature [1, 2].

However, the known methods do not provide results with the required accuracy, for they do not take account of differences in the morphological and functional structure of peripheral and central zones of the hepatic lobule and, in particular, the mutual arrangement of the hepatic artery, portal vein, and biliary and lymphatic capillaries, and the radial arrangement of the trabeculae of the hepatocytes and of the sinusoids relative to the central vein and the microciruclation in the lobule. The aim can be achieved by measuring the relative volume of the hepatocytes and of components of the microcirculatory bed of the lobule by means of the proposed grid and method of its use [3].* The ocular sectorial grid is a circle divided into six equal sectors A, B, C, D, E, and F. Each sector contains 55 dots arranged on 10 circumferences. The distance between neighboring dots on each circumference is equal to the distance between the neighboring circumferences. The circumference nearest the center of the grid has six dots, the next away from the center has 12 dots, and so on, up to 60 dots on the 10th circumference.

When histologic structures in the peripheral zones of the lobules are counted the center of the grid coincides with the center of the triad and the hepatic artery must be located in sector A. If the biliary capillary is on the right of the artery, the structures in

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