Test device for the examination of the viscoplastic properties of biological tissues

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Abstract
The article shows the results of a test device development for examination of the viscoplastic properties of biological tissues. Special software provides the capability to plot a graph that represents strain in test material. A high correlation between echo density and lens viscoplastic properties was found when studying lenses extracted by extracapsular technique.

Key words: *biomechanics, crystalline lens, echo density, viscoplastic properties.*

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Recent ophthalmology research and clinical practice involve intencive investigation of the biomechanical properties of various anatomical structures. An encyclopedia definition describes the biomechanics as "a biophysics subdiscipline that studies mechanical properties of tissues and organs and mechanical phenomena that occur in living organisms during their vitae". The definition may be completed with an important thesis: "... including the consequences of diseases as well as various diagnostic and treatment methods" [2].

As literature shows, the study of eyeball biomechanical properties develops in three principal directions: experimental studies, mathematical modeling and intravital evaluation.

Experimental studies are generally targeted at surgically removed anatomical structures (e.g. cornea, lens) or their fragments, isolated cadaver eyes or eyes of experimental animals (often rabbits). The absence of reparation processes in removed tissues and cadaver eyes, possible post mortal developments and certain differences in anatomical structure of human and animal eyes make it inept to use absolute values of indices which characterize tissues biomechanics.

Nevertheless, various experimental studies of eyeball biomechanics are still widely used for scientific purposes. For example, when studying removed tissues the correlation may be revealed between the experimental data and the results of clinical tests that are used to evaluate several biomechanical indices.

In experiment with cadaver and rabbit eyes, initial biomechanical properties are comparatively evaluated as well as their reaction to modeling of various diseases or interventions (surgical, laser, etc.) Obviously, in such experimental studies, estimation of incoming changes of biomechanical properties can only be done using comparative figures. This assertion is confirmed by significant variability of the measures, characterizing the biomechanical properties of cornea, that are obtained from various experiments: Young's modulus (E); Poisson ratio (μ); material strength (σ); deformability capacity ($\sum$) etc.

Another advantage of the experimental examination of biomechanics is freedom to choose any methods and approaches, which is only limited by current scientific and technical development.

Fig. 1. **General view of the stand used for examining viscoplastic properties of biological tissues.**

An algorithm of the experimental study of biological tissues biomechanical properties involves three basic steps: 1) controlled mechanical stimulation of the sample; 2) changing the physical state of the sample (deformation, partial or severe damage); 3) data analysis.

Different experimental studies of the biomechanical properties of eye structures and tissues, that follow the algorithm described, are consolidated under the term "Ophthalmic mechanography".

A test device "Instron" belongs to serial equipment used for mechanogrpahic examination. The device is rather expensive and complicated to operate but it allows to estimate sample deformation depending on the force

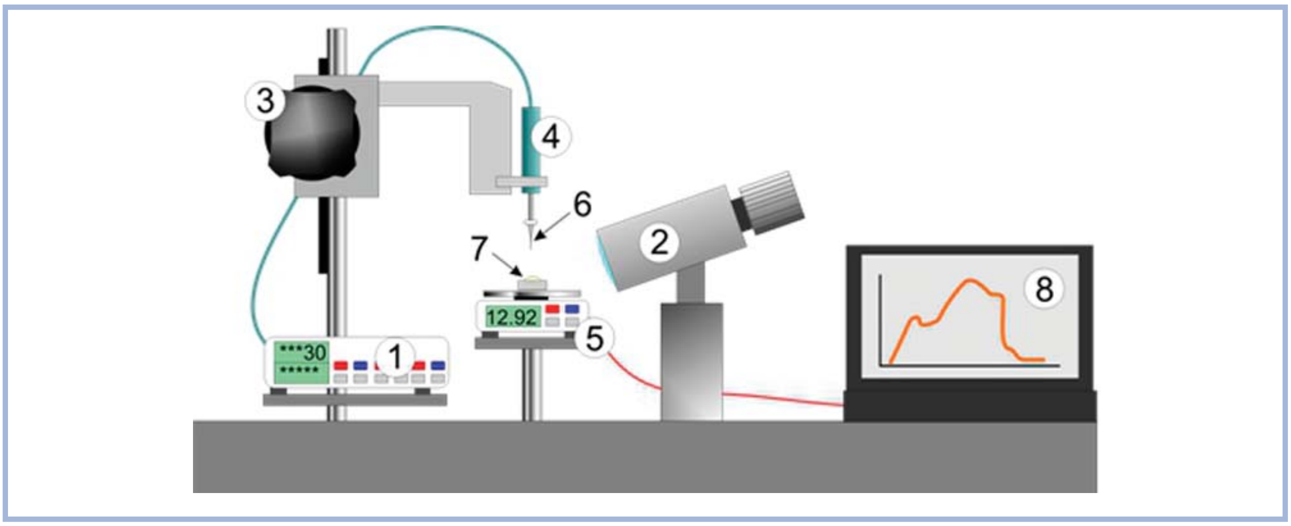

Fig. 2. **Schematic diagram of the stand (refer to the text).**

applied. The approach is fairly practical for studying elastic and viscoelastic properties of tissues, such as cornea [1]. However, the technique is unreliable when trying to describe permanent deformations of the test object. This limitation becomes crucial when examining the biomechanical properties of such "plastic" intraocular structures as lens or vitreous body.

Suggested testing stand (Figure 1) is meant for experimental studies and allows quantitative estimation of viscoplastic and brittleness properties of biological tissues. The device has two distinctive modular blocks:

1) hydraulic power system that advances the test tool (the plunger piston) at the programmed rate;

2) system that evaluates the stimulation applied to the sample.

Both modular blocks are installed onto the same body along with a binocular microscope that allows visual monitoring of the sample.

The test machine schematic (Figure 2) includes the following system components:

1 – hydraulic plunger positive pressure system with programmed constant rate (the device utilizes serial infusion pump used for dosed intravenous injections);

2 – optical system for plunger position micromonitoring;

3 – system for gross adjustment of plunger position;

4 – plunger hydraulic power drive;

5 – system for quantitative estimation of force transmitted to the sample (high precision digital weigh-scale);

6 – test tool (plunger piston), the fixation system allows any plunger body configuration;

7 – sample fixation frame;

8 – PC with custom software for processing results.

Hydraulic plunger delivery system allows translational motions of the testing tool at the rate of 0.06 to 30 mm/min. Compared to direct mechanical delivery, the hydraulics makes the system more damped and practically takes off the tool excessive inertia effect at the moment of pressure unloading and tissue local destruction.

The force transmitted to the sample is estimated by the system that reads data at 0,02 gf (gram-force) resolution 5 times per second (force estimation is limited at 300 gf). After that a PC with custom software is used to plot a graph. The graph shows the substance breakdown force value depending on plunger descend level. The x-axis of the graph corresponds to the breakdown force (measured in gram-force), while the y-axis represents the level of plunger descending into the sample (measured in μm).

The preliminary evaluation of the device was done in the course of investigation of three-dimensional ultrasound for the examining various lens properties, particularly its echo density. The results of ultrasound phacoemulsification of cataract showed that lens echo density correlates with cumulative dissipated energy consumed in the course of phaco surgery.

Although the data was indirect, it still confirmed the possibility of preoperative lens density estimation by the three-dimensional ultrasound method. Direct demonstration of the method reliability may be achieved by comparison between echo density values and lens biomechanical properties.

For that matter, 9 lens extracted extracapsularly due to cataract, undergone mechanographic tests. Densitometric comparison study of nuclear, anterior and posterior lens cortex was conducted in the course of preoperative ultrasound investigations. The study included the estimation of so-termed combined ultrasound density (measured in common units – c.u.) based on two-dimensional tissue bar graph. Prior to the study, the samples were stored in a balanced solution at the temperatures of around 5-7o Celsius. The plunger body, shaped as hemisphere, was 0.25 mm2.

In the course of the experiment, enough data for each sample was gathered to plot breakdown force graphs that characterize the viscoplastic properties of lens material. The table shows echo density (in c.u.) data and viscoplastic index for each sample tested. The viscoplastic index is based on graph analysis indicating mean viscosity level (in gf/mm2). As follows from the table, there is a marked relation between echo density of the lens and its viscoplastic properties (correlation ratio 0.74; Figure 3). The results of sample №9 make an exception presumably due to local nature of the lenticular opacity, which mainly occurred in posterior layers.

The results of summarized echo density and mean viscosity level of crystalline lens

Sample №	Echo density (c. u.)	Mean viscosity (gf/mm^2)
1	8.85	28.16
2	27.65	188.8
3	64.67	157.56
4	59.08	94.6
5	100.07	161.52
6	126.83	281.76
7	104.81	462.04
8	2.29	69.72
9	32.57	6.72

For descriptive reasons, Figure 4 shows two graphs that reflect the viscoplastic properties of conventionally ‘soft’ and ‘hard’ crystalline lenses according to three-dimensional ultrasound examination data (echo density of 8.85 and 27.65 c.u. respectively).

The results of the experiment lead to a suggestion that the designed test facility may be used to examine viscoplastic properties of biological tissues. Studies of the above mentioned properties of the cornea are expected to begin in the near future.

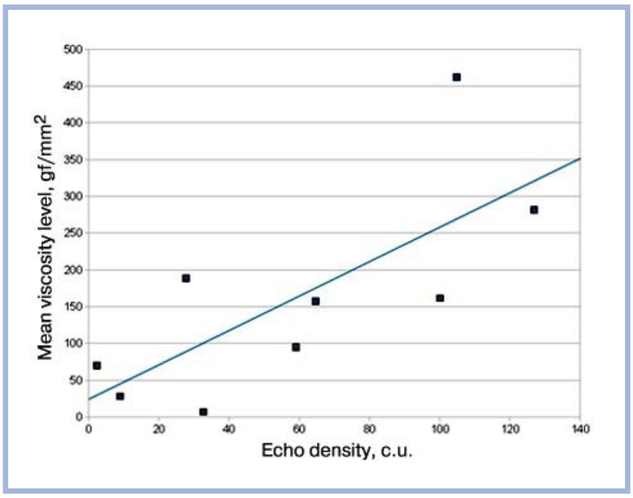

Fig. 3. **Dependence of lens mean viscosity on its echo density.**
Graph: Mean viscosity level, gf/mm^2. Echo density, c.u.

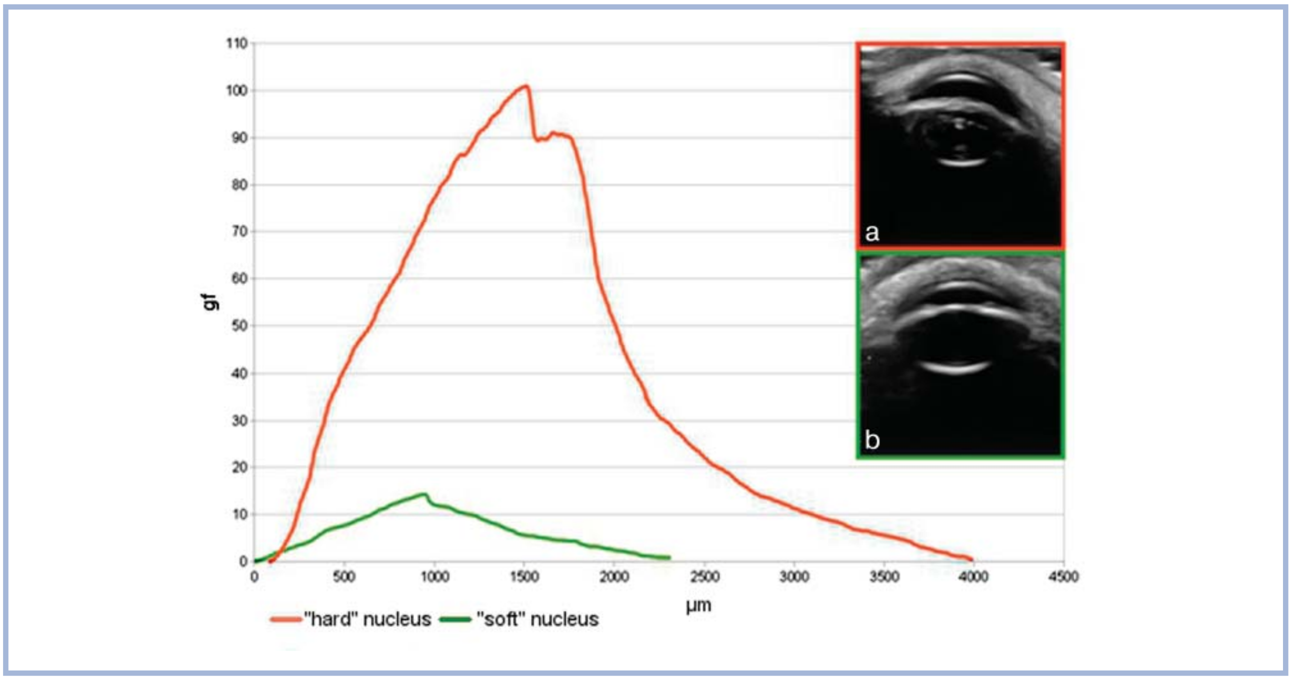

Fig. 4. **Diagrams of the breakdown force which reflect the viscoplastic properties of “soft” and “hard” crystalline lenses.**
The results of the ultrasound examination are shown for clarity: *a* – “hard” nucleus, *b* – “soft” nucleus.

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