THE EFFECT OF ULTRASONIC WAVES ON THE INTRAOCULAR PRESSURE AND THE PERMEABILITY OF THE VESSELS IN THE EYE

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In recent times, ultrasonic waves have found increasingly great application in medicine. Data have been accumulated on the therapeutic effect of this form of energy during various illnesses. It is known that ultrasonic therapy shows favorable results in the case of several illnesses of the support-motor apparatus, and of the nervous system [1, 2, 4].

Our investigation was devoted to the effect of ultrasonic waves on the eyes. As indices for the influence of ultrasonic waves, we used the intraocular pressure, which must remain constant for the normal functioning of the organ of vision, and the state of permeability of the hemato-ophthalmic barrier.

There already exist data in the literature, predominantly the foreign literature, on the application of ultrasonic waves in ophthalmology. Under the influence of ultrasound, hemorrhages are reabsorbed and the transparency of the vitreous body is restored, and dense scars of the eyelids are softened [9, 15]. Glaucoma is also treated with the aid of ultrasonic waves [16].

In the experimental projects devoted to studying the effect of ultrasound on the eyes, the authors considered the chief problem to be an investigation of the morphological changes in the various structures of the eyes. Baum's investigation, performed on rabbits, is of particular interest [10]. He established that a dose of ultrasonic waves in the range of 0.25-1 wt/cm^2 does not cause observable changes in the eyes. Doses of 1.5-2 wt/cm^2 caused changes of a reversible nature, which were localized in the anterior portion of the eyeball and were manifested by burns, scars, subconjunctival hemorrhages, exophthalmia, elevation of the intraocular pressure, turbidity of the cornea and chamber fluid, and constriction of the pupil. In this case, the retina and the optic nerve were not injured. Ultrassonic waves in a dose of 2.5-3 wt/cm^2 caused irreversible changes, manifested by profound degenerative processes in the tissues of the eye, including the neural elements. The author concludes that the maximum permissable dosage for "sounding" the eye is 1 wt/cm^2 for a period of 5 min.

There is only one experimental work, that of Cascio [12], specially devoted to the extremely important function, the intraocular pressure. According to the experiments of Cascio, "sounding" the eye of the rabbit leads to a decrease in ophthalmotonus by 4-8 mm Hg. In subsequent experiments, this author [13] established that, under the influence of ultrasonic waves, the penetration of fluorescein into the fluid of the chamber increases. Data on the effect of ultrasonic waves upon optic tonus are very interesting from the point of view of applying this factor in the treatment of glaucoma.

This work will present the results of our experiments, in which we studied the intraocular pressure, as well as the permeability of the hemato-ophthalmic barrier, as affected by exposure of the eye to ultrasonic waves of various intensities.

EXPERIMENTAL METHODS

The experiments were performed on rabbits and cats (a total of 32 animals). In the first series of experiments we investigated the intraocular pressure in rabbits at various intervals after "sounding" the eye. In the second series of experiments, we studied the permeability of the vessels and tissues of the eye in cats, following exposure of the eye to ultrasonic waves. Various dosage outputs were used: low (0.4-1 wt/cm^2) medium (1.5-2 wt/cm^2) and high

(3-4 wt/cm^2). The intraocular pressure was measured with a Maklakov tonometer. Premeability was determined by the use of radioactive indicators. In this case, the indicator used was radiophosphorous ($Na_2HP^{32}O_4$), which was administered parenterally, using a dosage of 22.5 microcuries per kg of weight. The animals were sacrificed 45 min after exposure to the ultrasonic waves, and 30 min after injection of the isotope. The sound irradiation was performed by the use of the therapeutic ultrasonic apparatus T and RUS2-1, with a frequency of 800 kilohertz, and a radiation area of 10 cm^2. Indirect radiation through water was used, employing a headpiece at a distance of 10 cm. In all the experiments, only one eye was subjected to the sound irradiation. The second eye served as the control. Radiophosphorous determinations were made on the chamber fluid, the tissue of the eye, and the blood serum. The radioactivity of the preparations was measured with the aid of the B-2 apparatus in a lead chamber under standard conditions. The results were expressed in the form of a proportion, related to the blood serum, using percentages. The mean results of the experimental groups were compared. The significance of the difference of the means was determined by the use of the "t" index, and the distribution table of Student.

EXPERIMENTAL RESULTS

In the first series of experiments, we were interested in both the immediate and the later reaction. For this purpose, measurement of the intraocular pressure was made immediately after the "sounding" and then ½, 1, 2, 3, 6 and 24 h after it.

During sounding of the eye with low intensities, the animals usually remained calm. With increases in the irradiation intensity, restiveness arose, which was apparently related to a painful sensation. With a low dosage of ultrasonic waves, the only observation we noted in the eye was a constriction of the pupil. Upon exposure of the eye to the greater dosages of ultrasound, the local symptoms became more manifest. We observed hyperemia of the conjunctivae, dryness and coarseness of the corneal membrane, swelling of the eyelid, occasional exophthalmia, and finally, in one experiment – turbidity of the crystalline lens (dosage of 4 wt/cm^2).

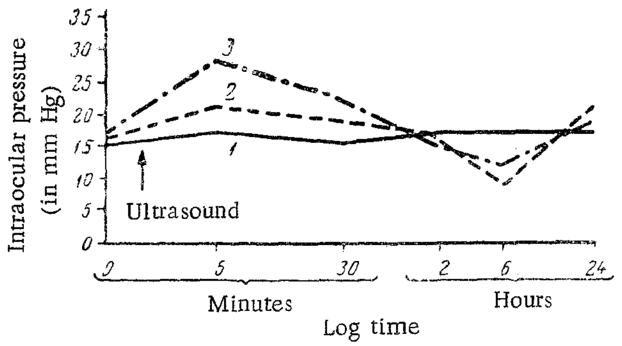

Fig. 1. Relationship between the dosage of ultrasonic waves and the degree of elevation of the intraocular pressure. Dosage of ultrasonic waves equal to: 1) 0.4 wt/cm^2; 2) 2 wt/cm^2; 3) 4 wt/cm^2.

The changes in the intraocular pressure under the influence of ultrasonic waves were biphasic in nature: initial there was an elevation, which was manifested 5-15 min after the sound irradiation; after 1-2 h, the original level w restored; in the subsequent hours, a marked hypotonia developed, most manifest after 5-6 h. On the 2nd day following the sound irradiation, no alterations in the intraocular pressure could be demonstrated.

A definite relationship was noted between the dosage of ultrasound and the degree of the initial elevation in the intraocular pressure. This expressed itself in a tendency toward increase of the degree of elevation with an increase in the dosage of ultrasonic waves. Dosages of 0.4-1 wt/cm^2 did not cause statistically significant elevations. With an increase in the dosage, there was not only a rise in the degree of elevation of the intraocular pressure, but also in the speed with which this reaction began following the "sounding." The subsequent hyptonia was observed with less constancy then the elevation in the intraocular pressure, although the decrease in ophthalmotonus (in the range of 6.5 ±3 mm) was noted in many cases.

As can be seen from Fig. 1, a dosage of 0.4 wt/cm^2 did not significantly affect the level of the intraocular pressure, either in the minutes immediately following the sound irradiation or at subsequent intervals. A dose of 2 wt elevated the intraocular pressure by from 16 to 21 mm Hg. At the 30th min the level had already begun to fall, completely attaining its original level 2h after the "sounding." The tonus of the eye subsequently decreased. In this experiment, the hypotonia was most clearly expressed (6 h after exposure to the ultrasonic waves the intraocular pressure was decreased by 8 mm). Finally, with a dose of 4 wt/cm^2, the intraocular pressure rose even more markedly five minutes after the sound irradiation, specifically from 16.5 to 28.5 mm Hg. In this experiment, the initial level was also restored after 2 h, and after 6 h the intraocular pressure was lower than the initial level by 5 mm Hg.

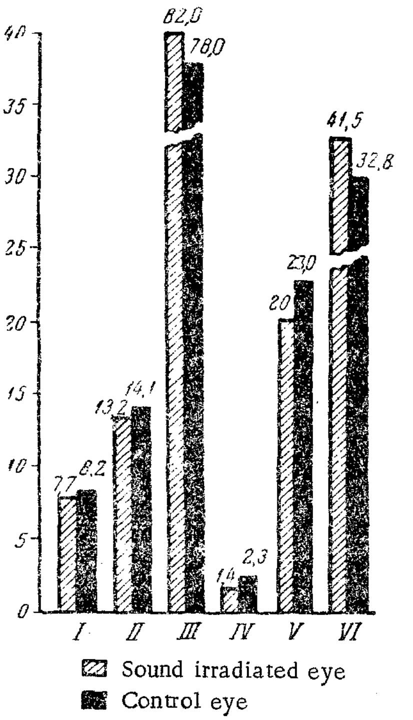

Fig. 2. The effect of a therapeutic dose of ultrasound (1.0 wt/cm^2) on the permeability of the tissues of the eye. I) Cornea; II) chamber fluid; III) iris and ciliary body; IV) vitreous body; V) retina; VI) conjunctiva.

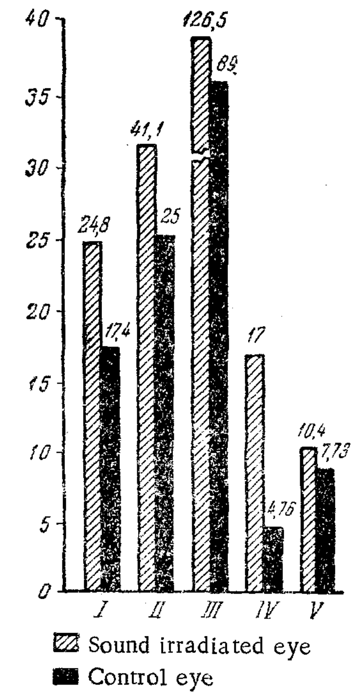

Fig. 3. The action of a maximum dose of ultrasound (4 wt/cm^2) on the permeability of the tissues of the eye. I) Cornea; II) chamber fluid; III) iris and ciliary body; IV) vitreous body; V) crystalline lens.

A similarity was observed between the changes in the intraocular pressure under the influence of the ultrasonic waves and changes which we encountered earlier using roentgen irradiation of the eye [7]. The action of both roentgen rays and ultrasound leads to a transient, hypertensive reaction in the eye. However, along with the similarity in the initial reaction, we also noted a difference in the actions of these two physical factors. Thus, the eye subjected to roentgen irradiation subsequently reacts with a sharp elevation in the intraocular pressure when pharmacological substances are administered. However, therapeutic substances do not cause this pathological reaction in the sound irradiated eye. Apparently, application of a dosage of ultrasonic waves does not leave appreciable changes in the condition of the regulatory mechanism for the intraocular pressure.

Our data on the effect of ultrasonic waves on intraocular pressure differ somewhat from those presented by Cascio [12], who observed a marked drop in ophthalmotonus in the majority of experiments within the first few minutes after sound irradiation, the low level remaining for several hours. Apparently, this is explained by different methods in sound irradiating. Cascio applied a dosage of 1.5 wt/cm^2, with a frequency of 2000 kilohertz, while the wave frequency limit for our apparatus was 800 kilohertz.

In the second series of experiments, performed on cats, we studied the effect of ultrasound on the permeability of the vessels and tissues of the eye. The conditions of sound irradiation and the dosages were the same as those in the experiments investigating the intraocular pressure. Radiophosphorous served as the permeability indicator.

It was established that ultrasonic waves show an effect on the intensity of radiophosphorous penetration into the different structures and media of the eye. Our experiments showed that the changes in permeability occurred in direct proportion to the doses of ultrasonic waves.

Figure 2 shows the effect of a therapeutic dose of ultrasound (1 wt/cm^2) on the permeability of the tissues of the eye.

Although the difference in P^{32} penetration into the sound irradiated and control eyes, using a dose of 1 wt/cm^2 was not statistically significant for all the tissues investigated, nonetheless we may speak of a tendency toward some lowering of the permeability.

Figure 3 shows the action of the maximum dose of ultrasound for our apparatus on the permeability of the tissues of the eye (4 wt/cm^2). "Sounding" the eye with the large dose of ultrasound sharply elevated the penetration of P^{32} into the tissues and media of the sound irradiated eye (the difference in the relative activity of the structures from the sound irradiated and control eyes was statistically significant: $P < 0.05$).

Attention is also drawn to the increased activity of all the optic tissues studied. The activity of the chamber fluid in the sound irradiated eye was equal to 41.1% in one experiment, while in the control it was only 25%; the activity of the corneal membrane on the side exposed to ultrasound was 7.4% higher than the activity of the corresponding tissue in the intact eye; for the iris and ciliary body the increase was 37.5%. Even in the vitreous body the relative activity rose by 4 times.

If we compare the results of the first and second series of experiments, a definite parallel is observed between the changes in the intraocular pressure and the permeability subsequent to the action of ultrasonic waves. With an increase in the intensity of the ultrasonic waves, both the eye tonus and the permeability of its vessels and tissues increase. This increase also coincides in time. Apparently, the increase in permeability is also one of the reasons for the increase in ophthalmotonus. We have also noted a relationship between the intraocular pressure and the permeability of the vessels of the eye during other actions on the eye [3, 5, 6].

Thus, the action of ultrasonic waves on the eye can cause changes in the intraocular pressure as well as in the permeability of the vessels and tissues of the eye. These changes are apparently explained by a manifold action of ultrasound on the biological substrate. Its depolymerizing action on hyaluronidase probably is important here [8]. In addition, it is known that ultrasonic waves speed up the processes of diffusion through semipermeable membranes [14, 11]. It should also be kept in mind that ultrasound shows a substantial effect on the tonus of vessels, causing a notable hyperemia in sound irradiated tissue.

SUMMARY

In experiments on rabbits and cats a study was made of the effect produced by ultrasound on the eye. Ultrasonic waves of various intensity within the range of 0.4-4.0 wt/cm^2 were used. Intraocular tension was examined by Maklakov's tonometer; the permeability of eye vessels and tissues was studied by the radioisotope method. Changes in the intraocular tension were of biphasic character: a primary rise with subsequent reduction of the ocular tone. Ultrasonic action increases the extent of radiophosphorus penetration into various ocular structures and media Permeability changes are in direct relationship to the dose of ultrasound.

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