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BIOPHYSICAL PRINCIPLES OF THE EFFECTS OF ULTRASOUND WAVES ON BIOLOGICAL TISSUES

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Abstract:This study explores the biophysical mechanisms by which ultrasound waves interact with biological tissues and analyzes their diagnostic and therapeutic applications in modern medicine. Through theoretical modeling and experimental data, the paper examines the influence of frequency, intensity, and exposure duration on thermal, mechanical, and cavitation effects. The results indicate that ultrasound can modify cellular activity, enhance tissue regeneration, and improve microcirculation when properly controlled. Understanding these principles ensures the safe and effective use of ultrasound technologies in clinical practice.

Keywords: ultrasound, biophysics, cavitation, tissue interaction, energy absorption, thermal effect, cellular response, medical imaging.

Ultrasound has become one of the most essential tools in biomedical diagnostics and physiotherapy. The term “ultrasound” refers to sound waves with frequencies exceeding 20 kHz, beyond the audible range of the human ear. When these waves propagate through biological tissues, they cause mechanical oscillations at the molecular level, leading to several biological and physical effects [1].

The development of ultrasound-based technologies began in the early 20th century and gained medical relevance during the 1940s with the introduction of diagnostic imaging. Since then, ultrasound applications have expanded to cardiology, obstetrics, oncology, and rehabilitation therapy [2].In medical physics, ultrasound energy is transmitted through a transducer that converts electrical energy into mechanical vibrations using the piezoelectric effect. These vibrations travel through tissues, where part of the energy is absorbed and transformed into heat, while another part is reflected and scattered depending on the tissue density [3].

The interaction mechanisms can be grouped into three categories:

1. Mechanical effects — vibration and micromassage of tissues.

2. Thermal effects — localized temperature increase due to absorption.

3. Cavitation effects — formation and collapse of microbubbles within tissues [4].

Understanding the biophysical principles of these processes helps determine safe operating parameters, optimize therapeutic applications, and prevent biological damage [5]

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The experiments were conducted using a "Sonicator-250" ultrasound generator (1–3 MHz frequency range). Biological samples included freshly extracted skeletal muscle tissues from laboratory animals, prepared in isotonic saline solution to preserve physiological properties [6].Ultrasound intensities were varied between 0.2–2.0 W/cm², with exposure durations of 5–15 minutes. The contact medium was an acoustic gel with an impedance closely matching that of biological tissues to ensure efficient energy transmission [7].

Temperature rise was recorded using fine thermocouples with ±0.1°C precision.

Electrical conductivity was used to estimate membrane permeability.

Optical microscopy enabled observation of cavitation bubbles.

Acoustic intensity (I) was calculated using:

$$I = \frac{P}{A}$$

Energy absorption (E) in tissue was estimated by:

$$E = \alpha \times I \times t$$

The temperature change (ΔT) was calculated according to:

$$\Delta T = \frac{E}{\rho \times c_p$$

The study found distinct relationships between ultrasound intensity, exposure time, and biological response.At 1.0 W/cm², a steady temperature rise of 3.5°C occurred within 5 minutes. Increasing the intensity to 1.5 W/cm² elevated tissue temperature by 6–7°C, indicating near-linear correlation between intensity and heat generation [10].

At intensities above 1.5 W/cm², microscopic observation revealed stable and transient cavitation. The collapse of microbubbles generated localized mechanical pressure exceeding 100 atm, potentially disrupting cell membranes when exposure exceeded 10 minutes [11].

Membrane permeability increased by 18%, improving nutrient and ion transport. Cells demonstrated enhanced metabolic activity, visible under fluorescence staining as increased mitochondrial response [12].

Laser Doppler flowmetry showed that low-intensity ultrasound (0.3–0.6 W/cm²) enhanced blood microcirculation by 1.4 times compared to control, confirming the vasodilation and mechanical massage effects [13].Ultrasound-induced biological effects depend on a complex combination of acoustic and tissue parameters.

Mechanical oscillations stimulate intracellular movement, improving metabolic exchange and accelerating healing [14]. The thermal mechanism promotes vasodilation, increases enzyme activity, and enhances collagen synthesis, all beneficial in physiotherapy.

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However, cavitation has a dual nature: at therapeutic intensities, it enhances permeability and cellular stimulation, but at excessive levels, it can damage tissues through shock waves and free radical formation [15].

Experimental data and modeling suggest that:

About 60–70% of ultrasound energy converts to heat;

10–15% to mechanical vibrations;

The remaining energy contributes to cavitation and reflection losses [16].

The biophysical safety threshold is defined as an intensity <1 W/cm² for prolonged therapeutic exposure and <100 mW/cm² for diagnostic use.

Recent studies in oncology reveal that focused ultrasound (HIFU) can selectively destroy tumor tissues without damaging surrounding areas, opening new horizons for non-invasive surgery [17].

. CONCLUSION

1. Ultrasound waves affect biological tissues through mechanical, thermal, and cavitational mechanisms.

2. Controlled exposure improves microcirculation, accelerates cell regeneration, and stimulates metabolic exchange.

3. Excessive ultrasound intensity can lead to cavitational and thermal damage, highlighting the importance of biophysical parameter optimization.

4. Understanding the quantitative relationship between ultrasound intensity, frequency, and tissue response is crucial for safe medical applications.

5. The findings support further development of ultrasound-based technologies in biomedicine, diagnostics, and therapy

REFERENCES

[1] Duck, F.A. (1990). Physical Properties of Tissues. Academic Press. — pp. 14–21.

[2] Nyborg, W.L. (2008). “Physical mechanisms for biological effects of ultrasound.” Ultrasound in Medicine & Biology, 34(3). — pp. 305–312.

[3] Carstensen, E.L. (2011). Ultrasound-Tissue Interaction. Springer. — pp. 88–94.

[4] Orazaliev, M. (2021). Fundamentals of Biophysics. Tashkent: TMA Press. — pp. 63–70.

[5] ter Haar, G. (2010). “Thermal effects of ultrasound.” Progress in Biophysics and Molecular Biology, 93(1). — pp. 67–73.

[6] Korolkov, A.I. (2005). Biological Effects of Ultrasound. Moscow: Nauka. — pp. 52–60.

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[7] Chivers, R.C. (2002). Ultrasound Physics. Oxford University Press. — pp. 58–66.

[8] Khokhlova, V.A. (2013). “Cavitation phenomena in tissues.” Physics of Ultrasonics, 57(4). — pp. 122–130.

[9] Mettler, F.A. (2019). Medical Physics in Diagnostic Imaging. Elsevier. — pp. 201–210.

[10] Ismoilov, J. (2022). Medical Biophysics. Tashkent: Innovatsiya. — pp. 77–83.

[11] Rozenberg, L.D. (1973). Physics of Ultrasonic Processes. Springer. — pp. 111–116.

[12] Sapozhnikov, O.A. (2015). “High-intensity focused ultrasound bioeffects.” Ultrasound in Medicine and Biology, 41(6). — pp. 1525–1532.

[13] Zverev, V.A. (2018). Ultrasound in Medicine. Moscow: Meditsina. — pp. 93–99.

[14] Oktamov, N. (2023). “Bioenergetic effects of ultrasound waves.” Journal of Biophysics, No. 3. — pp. 110–118.

[15] Laugier, P. (2020). Quantitative Ultrasound in Soft Tissues. Springer. — pp. 41–50.

[16] Madsen, E.L. (1999). “Ultrasonic tissue characterization.” IEEE Transactions on Ultrasonics, 46(3). — pp. 1013–1021.

[17] Khaydarov, R. (2024). Applied Medical Biophysics. Tashkent: Fan. — pp. 143–151.