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Letter to Editor

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Light and Sound Waves in Reproductive Biology: A Double-Edged Sword

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Dear Editor,

Advances in Assisted Reproductive Technologies (ART) have markedly enhanced the treatment of infertility. However, the role of environmental and physical factors—particularly light and sound waves—in influencing gamete integrity and fertilization success remains an active area of research. Recent evidence indicates that both photobiomodulation and mechanical acoustic stimulation can alter cellular processes in sperm and oocytes, offering potential avenues for optimizing fertility and refining ART protocols (1).

Exposure to electromagnetic radiation, especially Radiofrequency Electromagnetic Fields (RF-EMFs) emitted by mobile phones and Wi-Fi routers, has been linked to adverse effects on sperm quality. In vitro and animal studies consistently show that RF-EMF exposure reduces sperm motility, viability, and DNA integrity, primarily through oxidative stress and mitochondrial dysfunction (2,3). Experimental studies in rats have shown that exposure to 2.45 GHz Wi-Fi radiation can adversely affect sperm parameters and increase apoptotic activity in testicular tissue, with effects varying according to exposure duration (4). These findings underscore growing public health concerns regarding prolonged mobile phone use and its implications for male reproductive health.

In contrast, Low-Level Light Therapy (LLLT), which typically uses red or near-infrared light, has demonstrated beneficial effects on sperm motility and viability without inducing genetic damage (5-8). A recent in vitro study revealed that short-term exposure to 660 *nm* light significantly increased the proportion of motile sperm and enhanced progressive motility by activating cytochrome c oxidase and boosting ATP production (9). Additional studies have further confirmed that LLLT can regulate nitric oxide production and mitochondrial energetics in human sperm, enhancing motility and viability in a wavelength-dependent manner (6). In oocyte and embryo culture, mechanical stimulation via sound waves has emerged as a promising adjunct. Exposing culture dishes to specific musical rhythms or vibrational frequencies has been correlated with improved fertilization rates and early embryonic development (10,11). Recent investigations have demonstrated that acoustic stimulation can accelerate

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embryo development and improve fertilization outcomes through enhanced nutrient diffusion and mechanotransduction pathways (12,13). A pioneering study by López-Teijón *et al* demonstrated that embryos cultured with rhythmic music had higher cleavage rates than those maintained in silence (14). This effect is thought to stem from improved nutrient diffusion and mechanical stimulation of the zona pellucida, which may facilitate sperm entry.

Moreover, recent innovations in Surface Acoustic Wave (SAW) technology have enabled non-invasive oocyte denudation and micromanipulation, minimizing the physical stress and variability associated with conventional pipetting. Preliminary results indicate that acoustic microfluidics can enhance oocyte handling efficiency while preserving high survival and fertilization rates (15).

Safety and clinical applicability

Emerging evidence indicates that both light and acoustic interventions can be applied safely within defined exposure limits. LLLT at appropriate wavelengths and doses has not shown genotoxic effects, whereas excessive exposure may induce oxidative stress. Acoustic stimulation, including rhythmic music or SAW-based manipulation, appears well-tolerated in vitro, but standardized safety thresholds for human ART applications remain to be established. These considerations are essential before clinical translation to ensure gamete integrity and embryo viability.

Variability in implantation and live birth outcomes

While some studies report enhanced fertilization and embryo cleavage rates following light or sound exposure, findings for implantation and live birth outcomes are inconsistent. These discrepancies may reflect differences in experimental design, wave type, intensity, exposure duration, and patient population. Hence, careful standardization of protocols and larger controlled studies are needed to assess true clinical efficacy.

Clarifying wave types

It is important to distinguish between different modalities: red light (620-700 *nm*), near-infrared light (700-1100 *nm*), and various acoustic stimuli (rhythmic music, vibratory frequencies, or surface acoustic waves). Each modality may activate distinct cellular pathways, influencing sperm motility, oocyte quality, or embryo development differently. Clear definitions enhance comprehension and allow replication of observed effects. Despite these promising findings, current studies are constrained by small sample sizes, variability in exposure parameters, and a lack of long-term developmental follow-up. For instance, while some research supports the use of music or light exposure during IVF, other studies report no significant improvements in implantation or pregnancy rates (16). Additionally, the potential influence of acoustic or optical interventions on epigenetic reprogramming and offspring health remains largely unexplored.

Given the dual nature of wave-based interventions—ranging from harmful electromagnetic exposure to potentially beneficial photostimulation—there is a pressing need to establish standardized guidelines and safety thresholds for their use in reproductive medicine. Key priorities include:

- Dose–response characterization of light and acoustic exposure across various developmental stages.
- Mechanistic investigations to elucidate the cellular and molecular pathways affected by wave-induced stimuli.
- Well-controlled clinical trials evaluating not only fertilization rates but also embryo quality, implantation success, and live birth outcomes.
- Long-term safety assessments, including possible transgenerational effects.

In summary, the intersection of physical wave exposure and reproductive biology represents a compelling yet underexplored frontier. Understanding how light and sound influence gamete physiology could lead to non-invasive strategies for improving ART outcomes. However, a careful, evidence-based approach is crucial to maximizing benefits while minimizing potential risks. The scientific community should pursue multidisciplinary collaborations—integrating reproductive biology, bioengineering, and biophysics—to advance research in this promising field.

Conflict of Interest

There was no conflict of interest in this manuscript.

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