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PHOTOBIOLOGICAL REGULATION OF INFLAMMATORY PROCESSES AND TISSUE REPAIR IN PURULENT PATHOLOGY: MECHANISMS AND THERAPEUTIC POTENTIAL OF ULTRAVIOLET RADIATION

Turayeva Madina Ilhom kizi
Asia International University

Abstract. Purulent-inflammatory diseases represent a persistent clinical challenge due to complex pathogenetic mechanisms involving microbial persistence, dysregulated immune responses, oxidative stress, and microcirculatory impairment that collectively hinder effective tissue repair. In recent years, the increasing prevalence of antimicrobial resistance has stimulated interest in complementary therapeutic strategies capable of modulating fundamental biological processes associated with inflammation and infection. Among such approaches, ultraviolet radiation (UVR) has attracted considerable attention as a biologically active physical factor capable of initiating photochemical and immunomodulatory responses in living tissues.

The present review aims to analyze contemporary experimental and clinical evidence concerning the biological effects of ultraviolet radiation and its potential role in the regulation of inflammatory and immune processes in purulent pathology. Particular attention is devoted to wavelength-dependent photobiological mechanisms, molecular targets of ultraviolet exposure, and the modulation of oxidative and inflammatory signaling pathways. Current data indicate that controlled ultraviolet irradiation can influence multiple biological systems, including microbial viability, microvascular function, and immune homeostasis. These effects are mediated through photochemical alterations of nucleic acids, generation of reactive oxygen species, and subsequent activation of cellular signaling networks involved in inflammatory regulation and reparative processes.

In addition to its antimicrobial activity, ultraviolet radiation has been shown to affect tissue perfusion, endothelial function, and immune cell activity, which may contribute to improved conditions for wound healing and inflammatory resolution. However, the therapeutic application of ultraviolet-based technologies remains constrained by variability in irradiation protocols, insufficiently standardized dosimetric parameters, and the need for rigorous evaluation of long-term biological safety.

Overall, the available evidence suggests that ultraviolet radiation possesses significant potential as an adjunctive modality in the complex management of purulent-inflammatory diseases. Further interdisciplinary research integrating photobiology, immunology, and clinical medicine is required to establish standardized therapeutic algorithms and evidence-based guidelines for the safe and effective implementation of ultraviolet technologies in clinical practice.

Keywords: ultraviolet radiation, photobiology, immune modulation, purulent inflammation, oxidative stress, microcirculation.

Introduction

Purulent-inflammatory diseases represent a complex pathological process characterized by microbial invasion, tissue destruction, oxidative stress, and disturbances of immune regulation. Despite substantial progress in antimicrobial therapy, the increasing prevalence of multidrug-resistant microorganisms and biofilm-associated infections continues to complicate clinical management. In many cases, insufficient microcirculation, impaired oxygen delivery, and persistent inflammatory activity delay tissue repair and prolong disease progression.

Under these circumstances, growing scientific attention is being directed toward physical therapeutic factors capable of influencing the fundamental pathogenetic mechanisms of inflammation. Among these factors, ultraviolet radiation occupies a special position due to its ability to induce primary photochemical reactions that trigger secondary biochemical and immunological processes within biological systems.

Unlike conventional pharmacological agents that primarily act on microbial metabolic pathways, ultraviolet radiation simultaneously affects microbial structures and host regulatory mechanisms. This dual biological action provides the theoretical basis for its application as an adjunctive therapeutic modality in inflammatory pathology.

Spectral Characteristics and Biological Specificity of Ultraviolet Radiation

Ultraviolet radiation represents electromagnetic waves occupying the spectral region between visible light and ionizing radiation. The biological effects of ultraviolet radiation depend largely on wavelength and penetration depth within biological tissues.

Ultraviolet radiation is commonly divided into three spectral regions:

- **UVA (400–320 nm)** – long-wave radiation with relatively deeper tissue penetration and interaction primarily with protein chromophores.
- **UVB (320–280 nm)** – mid-wave radiation responsible for erythemal reactions and modulation of immune responses.
- **UVC (280–180 nm)** – short-wave radiation with pronounced germicidal properties due to direct nucleic acid damage.

Different cellular components demonstrate selective absorption of ultraviolet photons. DNA, RNA, membrane lipids, and intracellular enzymes represent major molecular targets responsible for the photobiological effects observed following irradiation.

Photochemical and Molecular Mechanisms

The biological effects of ultraviolet radiation originate from the absorption of photon energy by cellular chromophores. This process results in excitation of electrons and the initiation of photochemical reactions that alter molecular structures and intracellular signaling pathways.

Key molecular mechanisms include:

- formation of DNA photoproducts such as cyclobutane pyrimidine dimers;
- generation of reactive oxygen species;
- lipid peroxidation and membrane destabilization;
- modification of gene expression involved in inflammatory regulation;
- activation of cellular stress response pathways.

The biological response to ultraviolet radiation is highly dose-dependent. Low therapeutic doses may stimulate adaptive cellular responses and antioxidant defense mechanisms, whereas excessive exposure may induce cytotoxicity and mutagenic effects.

Effects on Microcirculation and Hemodynamic Regulation

Microcirculatory disturbances represent an essential pathogenetic component of purulent-inflammatory processes. Tissue hypoxia, endothelial dysfunction, and impaired rheological properties of blood contribute to the progression of inflammatory damage.

Ultraviolet radiation may influence microvascular regulation through several mechanisms. Experimental observations indicate that ultraviolet exposure can induce vasodilation mediated by nitric oxide signaling pathways and neurovascular reflex mechanisms.

Potential physiological effects include:

- increased erythrocyte membrane flexibility;
- improved tissue oxygen delivery;
- normalization of blood rheology;
- modulation of platelet aggregation.

These changes may enhance tissue perfusion and create favorable conditions for reparative processes.

Immunomodulatory Effects of Ultraviolet Radiation

One of the most significant biological properties of ultraviolet radiation is its ability to influence immune system activity. Rather than producing purely stimulatory effects, ultraviolet radiation appears to exert complex regulatory actions that depend on the physiological state of the organism.

Reported immunological effects include:

- activation of macrophage phagocytic function;
- stimulation of interferon synthesis;
- modulation of cytokine production;
- regulation of complement system activity;
- reduction of excessive inflammatory hypersensitivity reactions.

These immunomodulatory mechanisms may contribute to the restoration of immune balance in chronic inflammatory conditions.

Antimicrobial Properties and Clinical Significance

Ultraviolet radiation demonstrates pronounced antimicrobial activity, particularly in the UVC spectral range. The germicidal effect is primarily associated with photochemical damage to microbial DNA, leading to inhibition of replication and loss of cellular viability.

In clinical practice, ultraviolet irradiation has been investigated as an adjunctive method for reducing microbial contamination in infected wounds and inflammatory lesions. However, it should not be considered a substitute for conventional antimicrobial therapy. Effective treatment of purulent-inflammatory diseases requires a comprehensive approach including surgical debridement, adequate drainage, antimicrobial therapy, and optimization of host immune defense.

Safety Considerations and Risk Assessment

Despite its therapeutic potential, ultraviolet radiation possesses a relatively narrow safety margin. Excessive exposure may produce adverse biological effects, including:

- suppression of DNA synthesis in host tissues;
- disturbances of endocrine regulation;
- neurofunctional alterations;
- phototoxic or photoallergic reactions;
- long-term carcinogenic risk.

For this reason, careful control of irradiation parameters and strict adherence to dosimetric standards are essential for safe clinical application.

Discussion

The available experimental and clinical evidence indicates that ultraviolet radiation exerts complex biological effects that may be beneficial in the management of purulent-inflammatory diseases. These effects include antimicrobial action, improvement of microcirculation, modulation of oxidative stress, and regulation of immune responses.

Nevertheless, many studies are characterized by methodological limitations such as small sample sizes, heterogeneous treatment protocols, and inconsistent irradiation parameters. These factors complicate the interpretation and comparison of results.

Future research should focus on:

- development of standardized irradiation protocols;
- randomized controlled clinical trials;
- integration of molecular and immunomorphological biomarkers;
- long-term evaluation of safety and oncological risks.

Conclusion

Ultraviolet radiation represents a biologically active physical factor capable of influencing multiple pathogenetic mechanisms involved in purulent-inflammatory diseases. Controlled therapeutic exposure may contribute to improved antimicrobial control, enhanced microcirculation, and regulation of immune responses.

However, the successful integration of ultraviolet technologies into modern clinical practice requires rigorous methodological standardization, objective biological monitoring, and comprehensive safety evaluation.

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