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ULTRAVIOLET RADIATION AS A MODULATOR OF INFLAMMATORY AND IMMUNE RESPONSES IN PURULENT-INFECTIOUS PATHOLOGY: MECHANISTIC FOUNDATIONS AND CLINICAL IMPLICATIONS

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Abstract: Purulent-inflammatory diseases remain a complex clinical problem characterized by persistent microbial contamination, dysregulated immune reactions, impaired microcirculation, and delayed reparative processes. In the context of escalating antimicrobial resistance, non-pharmacological adjunctive strategies capable of pathogenetic modulation are attracting increasing scientific attention. Ultraviolet radiation (UVR), as a biologically active electromagnetic factor, induces a spectrum of photochemical and immunobiological responses that may influence the course of inflammatory pathology.

This analytical review synthesizes current experimental and clinical evidence regarding spectral characteristics, molecular targets, immunoregulatory mechanisms, and antimicrobial properties of UVR. Particular emphasis is placed on dose-dependent biological responses, systemic microcirculatory modulation, and the integration of ultraviolet-based approaches into complex therapeutic protocols. The necessity for standardized dosimetry, objective immunomorphological assessment, and evidence-based safety criteria is critically discussed.

Ultraviolet radiation demonstrates potential as a controlled adjunctive modality in purulent-inflammatory diseases; however, its broader clinical implementation requires rigorous methodological validation and harmonized therapeutic algorithms.

Keywords: ultraviolet radiation, immunoregulation, purulent inflammation, photobiology, antimicrobial resistance, reparative processes.

Introduction

Purulent-inflammatory processes represent a multifactorial pathological continuum in which microbial invasion, oxidative stress, vascular dysfunction, and immune imbalance interact dynamically. Despite advances in antimicrobial pharmacotherapy, the persistence of biofilm-forming microorganisms, increasing resistance patterns, and impaired local perfusion remain major obstacles to effective management.

In this context, physical therapeutic modalities capable of influencing fundamental pathogenetic mechanisms are undergoing reconsideration. Ultraviolet radiation occupies a unique position among such modalities due to its capacity to initiate primary photochemical reactions that subsequently trigger secondary biochemical and immunological cascades.

Unlike conventional antimicrobial approaches that target microbial metabolism directly, ultraviolet exposure modifies both microbial nucleic acids and host regulatory systems, thereby exerting a dual mechanism of action.

Spectral Determinants and Biological Specificity

Ultraviolet radiation encompasses wavelengths between visible light and ionizing radiation. Its biological specificity is largely determined by spectral range and tissue penetration depth.

- **Long-wave UV-A (400–320 nm)** penetrates relatively deeper into dermal layers and primarily interacts with protein chromophores.
- **Mid-wave UV-B (320–280 nm)** induces erythemal and immunomodulatory effects.
- **Short-wave UV-C (280–180 nm)** demonstrates maximal germicidal capacity due to direct nucleic acid photodamage.

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The differential absorption characteristics of intracellular chromophores explain the selective biological effects observed across spectral ranges. DNA, RNA, membrane lipids, and enzymatic proteins represent principal photobiological targets.

Photochemical and Molecular Mechanisms

The primary biological impact of ultraviolet radiation arises from photon absorption leading to electronic excitation of biomolecules. This event initiates a cascade of oxidative and structural modifications, including:

- formation of cyclobutane pyrimidine dimers in DNA;
- generation of reactive oxygen species;
- lipid membrane destabilization;
- alteration of intracellular signaling pathways;
- modulation of gene transcription involved in inflammatory regulation.

Importantly, the biological outcome is not linear but dose-dependent. Suberythemal therapeutic exposures may activate adaptive responses and antioxidant defense systems, whereas excessive cumulative irradiation shifts the balance toward cytotoxicity and mutagenesis.

Microcirculatory and Hemodynamic Modulation

Microvascular dysfunction is a key pathogenetic component of purulent-inflammatory conditions. Hypoxia, endothelial damage, and increased blood viscosity exacerbate tissue injury and impair reparative capacity.

Ultraviolet-mediated vasodilatory responses appear to involve nitric oxide pathways and reflex neurovascular mechanisms. Observational data suggest:

- improved erythrocyte membrane flexibility;
- enhanced tissue oxygen delivery;
- modulation of platelet aggregation;
- partial normalization of rheological parameters.

Ultraviolet blood irradiation techniques have been proposed to influence systemic inflammatory markers; however, heterogeneity of study designs limits quantitative generalization.

Immunological Reprogramming and Inflammatory Regulation

A critical aspect of ultraviolet radiation lies in its ability to modulate immune homeostasis. Rather than exerting purely stimulatory effects, UVR appears to reprogram immune reactivity depending on baseline functional status.

Reported mechanisms include:

- activation of macrophage phagocytic capacity;
- induction of interferon synthesis;
- regulation of cytokine balance;
- modulation of complement activation;
- attenuation of excessive hypersensitivity responses.

This bidirectional immunomodulatory profile may explain its potential relevance in chronic inflammatory states characterized by dysregulated immune signaling.

Antimicrobial Action and Clinical Relevance

The germicidal activity of UV-C radiation is mechanistically linked to microbial DNA disruption, resulting in replication arrest and loss of viability. In purulent wounds, reduction of surface microbial burden may facilitate secondary intention healing.

However, antimicrobial efficacy must be interpreted within a multifactorial therapeutic framework including surgical sanitation, drainage adequacy, systemic antimicrobial therapy, and

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host immune competence. UV radiation does not substitute for standard care but may potentiate comprehensive management.

Risk Stratification and Safety Considerations

The therapeutic window of ultraviolet radiation is narrow. Excessive exposure may induce:

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

The absence of universally accepted dosimetric standards remains a critical limitation. Objective monitoring through laboratory and immunological markers is essential for minimizing adverse outcomes.

Discussion

The available body of evidence suggests that ultraviolet radiation exerts complex, multi-level biological effects relevant to purulent-inflammatory pathology. These include antimicrobial action, vascular modulation, oxidative stress regulation, and immune recalibration.

Nevertheless, methodological variability, small sample sizes, and inconsistent dosimetic parameters restrict evidence integration. Future research directions should prioritize:

- controlled randomized trials;
- standardized wavelength-specific dosing algorithms;
- incorporation of quantitative immunomorphological indices;
- long-term oncological safety evaluation.

Only through such methodological rigor can ultraviolet-based interventions transition from empirical physiotherapeutic practices to fully evidence-based clinical modalities.

Conclusion

Ultraviolet radiation represents a biologically potent yet mechanistically intricate physical factor capable of modulating inflammatory and immune responses in purulent-infectious pathology. When applied within carefully controlled parameters and integrated into comprehensive treatment protocols, UV-based approaches may enhance microbial control and reparative processes.

However, widespread clinical adoption necessitates harmonized dosimetric standards, objective biomarker monitoring, and high-quality clinical validation to ensure both efficacy and safety under modern medical conditions.

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