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"Role of Antioxidant in Oxidative Stress and Human Pathology "

Lakshmi. OS, Jasna. PA, Swaliha. KA, Gopika. KA, Althaf. N
Department of Pharmacology
Holy Grace Academy of Pharmacy, Mala
Thrissur, Kerala

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ABSTRACT:
Oxidative stress occurs when the production of reactive oxygen species (ROS), commonly known as free radicals, exceeds the body's natural antioxidant defense system. This imbalance can lead to damage of important cellular components such as lipids, proteins, and DNA, ultimately affecting normal cell function. Prolonged oxidative stress has been closely linked to the development and progression of several chronic diseases, including cardiovascular disorders, diabetes mellitus, neurodegenerative diseases, respiratory illnesses, and various inflammatory conditions affecting the skin and hair.

Antioxidants play an essential role in protecting the body from such damage by neutralizing free radicals and maintaining cellular balance. The body possesses both enzymatic antioxidants, such as superoxide dismutase, catalase, and glutathione peroxidase, as well as non-enzymatic antioxidants including vitamins C and E, flavonoids, polyphenols, carotenoids, and glutathione. Together, these antioxidants help reduce oxidative stress and support overall health.

A diet rich in natural antioxidants, particularly from fruits, vegetables, nuts, and whole grains, has been associated with lower disease risk and improved health outcomes. In addition to their systemic benefits, antioxidants are increasingly recognized for their importance in skin and hair health, where they help reduce inflammation, protect against UV-induced damage, support collagen production, and delay premature aging.

Recent developments in fields such as nanotechnology and personalized nutrition have further improved the effectiveness and bioavailability of antioxidant therapies, expanding their potential in disease prevention and treatment. This review discusses the mechanisms underlying oxidative stress, the biological importance of antioxidants, their therapeutic role in various diseases, and emerging advancements in antioxidant-based approaches. Overall, antioxidants continue to be vital in maintaining physiological balance and protecting the body against oxidative stress–related disorders.

I. INTRODUCTION:

Oxidative Stress and Reactive Oxygen Species:

Oxidative stress is a biological condition that occurs when there is an imbalance between the production of reactive oxygen species (ROS) and the antioxidant defense system of the body. Reactive oxygen species, commonly referred to as free radicals, are highly reactive molecules formed during normal cellular metabolism and through exposure to environmental factors such as ultraviolet radiation, pollution, smoking, chemicals, and infections. Under normal physiological conditions, free radicals play beneficial roles in cell signaling, immune defense, and metabolic regulation. However, excessive generation of ROS or reduced antioxidant protection leads to oxidative stress, causing damage to lipids, proteins, carbohydrates, and nucleic acids. This cellular damage contributes significantly to aging and the development of various acute and chronic diseases.

Role and Classification of Antioxidants:

Antioxidants are protective substances that help defend cells against oxidative damage by neutralizing free radicals and maintaining redox balance in the body. They act through different mechanisms, including scavenging reactive species, inhibiting lipid peroxidation, chelating metal ions, and supporting endogenous antioxidant systems. Antioxidants are broadly classified into enzymatic and non-enzymatic antioxidants. Enzymatic antioxidants include superoxide dismutase, catalase, and glutathione peroxidase, while non-enzymatic antioxidants include vitamins C and E, glutathione, carotenoids, flavonoids, and polyphenols. These antioxidants are naturally present in fruits, vegetables, grains, herbs, and other dietary sources, although some may also be administered as supplements.

Oxidative Stress in Human Diseases:

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In recent years, oxidative stress has received significant scientific attention because of its major role in the onset and progression of several pathological conditions. Increased oxidative damage has been associated with cardiovascular diseases, diabetes mellitus, neurodegenerative disorders, chronic respiratory diseases, inflammatory skin conditions, premature aging, and hair disorders. Oxidative stress contributes to endothelial dysfunction and atherosclerosis in cardiovascular diseases, impairs insulin signaling in diabetes, and accelerates neuronal degeneration in disorders such as Alzheimer's and Parkinson's disease. Similarly, excessive ROS generation is involved in inflammatory conditions affecting the skin and scalp, including psoriasis, atopic dermatitis, vitiligo, seborrheic dermatitis, alopecia, and premature greying of hair.

Importance of Antioxidants in Skin and Hair Health:

The skin and hair are continuously exposed to environmental oxidative stressors such as ultraviolet radiation, air pollution, and chemical agents, making antioxidants particularly important in dermatological and cosmetic applications. Antioxidants help protect cellular structures, preserve collagen and elastin integrity, reduce inflammation, delay photoaging, and improve skin barrier function. In hair-related disorders, antioxidants contribute to follicular protection, reduce inflammatory damage, preserve melanocyte activity, and support overall scalp health. Due to these protective properties, antioxidants are increasingly incorporated into pharmaceutical, nutraceutical, and cosmetic formulations aimed at improving skin and hair health.

Emerging Advances in Antioxidant Research:

Apart from their role in disease prevention and management, antioxidants have become an important focus of modern research in nutrition, nanotechnology, and targeted drug delivery systems. Innovative approaches such as nano-antioxidants and personalized nutrition are being developed to improve antioxidant bioavailability, stability, and therapeutic efficiency. These advancements have expanded the potential applications of antioxidants in preventive medicine and clinical therapeutics, offering promising strategies for the management of oxidative stress-related disorders.

Aim of the Review:

This review article aims to provide a comprehensive overview of oxidative stress and the role of antioxidants in human health and disease. It discusses the mechanisms of free radical generation, classification and functions of antioxidants, and their significance in skin disorders, hair-related conditions, cardiovascular diseases, diabetes mellitus, neurodegenerative disorders, and chronic respiratory diseases. Furthermore, the review highlights recent advances in antioxidant therapy, dietary strategies, nanotechnology-based antioxidant delivery systems, and future perspectives in oxidative stress research.

II. CONCLUSION

Antioxidants play a vital role in protecting the human body against oxidative stress caused by excessive free radical production. By neutralizing reactive oxygen species, antioxidants help prevent cellular damage to DNA, proteins, and lipids, thereby reducing the risk of various chronic diseases such as cardiovascular disorders, diabetes mellitus, neurodegenerative diseases, respiratory disorders, and inflammatory skin and hair conditions. Natural antioxidants obtained from fruits, vegetables, whole grains, and medicinal plants provide significant health benefits by supporting the body's defense mechanisms, reducing inflammation, slowing aging, and promoting tissue repair. In dermatology and hair care, antioxidants help maintain structural integrity, reduce pigmentation, delay premature aging, and support healthy hair growth. Recent advances in nanotechnology and personalized nutrition have further enhanced the therapeutic potential of antioxidants by improving their delivery, stability, and effectiveness. Overall, maintaining a balanced diet rich in natural antioxidants along with healthy lifestyle practices remains the most effective strategy for preventing oxidative damage and promoting long-term health and well-being.

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