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Molecular role of oxidative stress and antioxidant defense in human diseases

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Abstract

Oxidative imbalance is now viewed as an important biological process in the development and progression of various pathological conditions. Oxidative imbalance is the process by which the rate of production of reactive oxygen species (ROS) outstrips the capacity of the cellular protective mechanisms, which maintain the equilibrium of the cellular redox state. Oxidative activity, if sustained, can damage cellular macromolecules, interfere with molecular signaling, and accelerate cellular dysfunction. This review presents an updated discussion of the molecular mechanisms of oxidative damage, the role of the antioxidant defense system, and the clinical relevance of oxidative imbalance in various diseases. New diagnostic markers and therapeutic interventions in oxidative imbalance are also discussed to present an updated perspective of the current knowledge in the field of oxidative biology in health and disease.

Keywords: Oxidative Imbalance; Antioxidant Enzymes; Oxidative Damage; Chronic Diseases; Molecular Diagnostics

1. Introduction

Cell survival is maintained through an intricate balance, with oxidants being produced, while antioxidants work to keep them at bay. In everyday, healthy physiology, reactive oxygen species are involved in important functions, including signaling and metabolism. However, when oxidants accumulate beyond what can be managed, the balance is disrupted, leading to negative consequences on cell structure and function. There is increasing evidence showing that oxidative imbalance is associated with aging and the development of several chronic diseases, which confirms the importance of this problem in modern medicine (1).

2. Molecular Basis of Oxidative Injury

The reactive oxygen intermediates have the capability to damage critical biomolecules, which disrupts the balance of the cell. The oxidation of cell membranes disrupts their permeability and fluidity. This has an impact on the movement of substances into and out of the cell. The oxidation of proteins also has negative effects. The oxidation of enzymes compromises their function, leading to damage to their structure. The nucleic acids in the cell do not escape damage, leading to genomic instability. The mitochondria in the cell produce reactive oxygen species internally. The mitochondria produce reactive oxygen species if they do not function properly. Oxidative activity in the cell has negative effects if it persists (2).

3. Antioxidant protective network

In the fight against oxidative stress, the human body has an antioxidant defense system that is highly regulated. These include enzymes like superoxide dismutase, catalase, and glutathione peroxidase, which react with reactive

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intermediates in the production of less harmful substances. The non-enzymatic antioxidants include vitamins C and E, glutathione, and bioactive substances that play the role of maintaining the redox balance in the cells (3).

4. Clinical relevance

Oxidative dysregulation is a key player in numerous diseases. In cardiovascular and vascular diseases, reactive oxygen species are involved in endothelial dysfunction and vessel damage. In cancer, these reactive oxygen species can enhance mutations and tumor growth. Prolonged oxidative stress is also associated with metabolic syndromes such as diabetes and neurodegenerative and chronic inflammatory diseases. The key to understanding oxidative biology is to obtain valuable insights into the pathogenesis of diseases (4).

5. Emerging perspectives

Recent developments in the field of science focus on the identification of biomarkers for the early detection of oxidative imbalance and the development of targeted therapeutic strategies for the restoration of redox balance. Developments in molecular diagnostics and precision medicine offer promise for improving early risk assessment and management of diseases. Therapeutic modulation of oxidative pathways represents a new frontier for the future of biomedical research and therapy (5).

6. Conclusion

The maintenance of redox homeostasis is vital to cell integrity and physiological stability. The alteration of this equilibrium has been implicated in the causation of several chronic conditions. The boosting of antioxidant defenses and reduction of oxidative damage may confer considerable preventive and therapeutic benefits in conditions of oxidative stress.

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