Chapter 1
Reactive Oxygen Species: Generation and Signaling Pathways

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ABSTRACT

Reactive oxygen species (ROS) are highly reactive molecules that are constantly generated as natural byproducts of cellular metabolism. While traditionally considered detrimental due to their potential to cause oxidative damage, recent research has unveiled their intricate involvement in cellular signaling pathways. This book chapter provides a comprehensive overview of ROS generation mechanisms, encompassing enzymatic and non-enzymatic processes and their pivotal roles in redox signaling pathways. Additionally, it delves into the various functions of reactive oxygen species (ROS) in cellular signaling, highlighting their influence on redox balance, gene expression, and stress reactions. This chapter tries to establish the foundation for understanding ROS biology and their intricate functions in both health and illness by clarifying some basic concepts.

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A. INTRODUCTION:

Highly reactive molecules known as Reactive Oxygen Species (ROS) are produced during the cellular metabolism in the form of byproducts. This oxygen containing natural byproduct species include non-radical species like hydrogen peroxide (H_2O_2) and free radicals such as superoxide (O_2^-) and hydroxyl (OH·) radicals (Jakubczyk et al., 2020). Although reactive oxygen species (ROS) are commonly perceived as harmful byproducts of cellular metabolism that can cause oxidative damage to proteins, lipids, and DNA, their function in cellular physiology is significantly more complex (Saikolappan et al., 2019). The dual nature of ROS has been elucidated by recent research, which highlights their vital functions in defense mechanisms, homeostasis, and cell signalling (Sies et al., 2022).

Under typical physiological settings, a variety of cellular functions produce ROS under control. For example, during the ATP-producing electron transport chain, ROS are produced by mitochondria (Rabinovich-Nikitin et al., 2021; Yin & O'Neill, 2021; Auger et al., 2021). In a similar vein, ROS are produced on purpose by NADPH oxidases (NOX) and other enzymes as signaling molecules. These compounds participate in redox signaling, whereby they oxidize particular protein targets in a reversible manner to modify cellular functions. Maintaining cellular homeostasis and adapting to environmental changes depend on this redox control (Bedard & Krause, 2007; Vermot et al., 2021; Jaquet et al., 2009; Pecchillo Cimmino et al., 2023). The concept of ROS functioning as signaling entities marks a paradigm shift from the traditional view of ROS solely as damaging agents. ROS function as secondary messengers in intracellular signaling cascades that affect a variety of physiological processes, such as immunological responses, cell proliferation, and differentiation, at low to moderate concentrations. They modulate the function of multiple transcription factors, including Nrf2 and NF-κB, which govern the production of genes linked to cellular stress responses, antioxidant defense, and inflammation (Xue et al., 2020; Huang et al., 2022).

Nonetheless, it's crucial to strike a careful balance between the generation and removal of ROS (Figure 1).