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Commentary

Physiological and Pathological Aspects of Apoptosis

Priya Raghavan*

Department of Biochemistry, Central University of Biomedical Sciences, Bengaluru, India

DESCRIPTION

Programmed cell death, is a highly regulated cellular process important for maintaining tissue homeostasis and organismal health. It is a mechanism by which cells deliberately self-destruct in response to specific cues, eliminating damaged or unnecessary cells without triggering inflammation. This is in stark contrast to necrosis, where uncontrolled cell death often provokes immune responses and tissue damage. Apoptosis occurs under normal physiological conditions, such as tissue remodelling during development and as a protective response against cellular damage or infection. The study of apoptosis has revealed intricate molecular mechanisms that underpin this essential process, highlighting its significance in both health and disease.

Morphologically, apoptotic cells exhibit characteristic changes, including shrinkage, chromatin condensation, nuclear fragmentation and formation of membrane-bound apoptotic bodies. These features distinguish apoptosis from other forms of cell death and allow efficient clearance of cellular debris by phagocytic cells. At the molecular level, apoptosis is governed primarily by two major signalling pathways: the intrinsic and extrinsic pathways. The intrinsic pathway, often called the mitochondrial pathway, is activated by internal stressors such as hypoxia, or oncogene activation. Stress signals lead to mitochondrial outer membrane permeabilization and release of apoptogenic factors, including cytochrome c, which activate initiator caspase-9 and downstream executioner caspases like caspase-3.

The extrinsic pathway, in contrast, is initiated by extracellular signals. Binding of death ligands to specific cell surface receptors triggers recruitment of adaptor proteins and activation of caspase-8, which converges with the intrinsic pathway to execute cell death. Regulation of apoptosis is critical for proper cellular function. Tumor suppressor protein p53 is another key regulator, promoting apoptosis in response to genomic damage by activating pro-apoptotic genes or directly interacting with mitochondria. Inhibitors of apoptosis proteins, along with various signaling molecules, provide additional layers of control, ensuring that cells commit to apoptosis only under appropriate conditions. This tight regulation prevents unwanted cell loss while ensuring elimination of harmful cells. Physiologically, apoptosis is indispensable. During development, it shapes organs and removes transient structures. In the immune system, apoptosis eliminates self-reactive lymphocytes, preventing autoimmune responses. It also balances cell proliferation and death in adult tissues, maintaining normal tissue architecture. Disruption of apoptotic processes contributes to a wide array of diseases.

Excessive apoptosis can cause tissue degeneration and contribute to conditions such as neurodegenerative diseases, myocardial infarction and liver injury. Conversely, resistance to apoptosis allows cancer cells to survive despite genomic abnormalities and therapeutic interventions, facilitating tumor progression and metastasis. The clinical implications of apoptosis are profound. Therapeutic modulation of apoptotic pathways represents a promising strategy for treating various diseases. In oncology, drugs targeting apoptotic regulators aim to reinstate cell death in resistant cancer cells, while in degenerative diseases, strategies that inhibit apoptosis may protect vulnerable cells. Understanding the complex interplay of apoptotic signals can also inform drug development and personalized medicine approaches, providing opportunities to fine-tune therapeutic interventions for optimal outcomes. Additionally, apoptosis research has advanced diagnostic methods, as markers of apoptosis can indicate disease progression or response to therapy.

In conclusion, apoptosis is a vital cellular process with far-reaching implications for health and disease. By orchestrating the precise elimination of cells, it ensures tissue homeostasis, prevents accumulation of damaged cells and protects against disease. Dysregulation of apoptosis underlies numerous pathological conditions, from cancer to neurodegeneration, emphasizing the need for continued research in this area. Insights into the molecular mechanisms and regulatory pathways of apoptosis not only enhance our understanding of cellular biology but also pave the way for novel therapeutic approaches. As research progresses, manipulating apoptosis holds the promise of transforming the management of diverse diseases, highlighting its central role in biology and medicine.

Correspondence to: Priya Raghavan, Department of Biochemistry, Central University of Biomedical Sciences, Bengaluru, India. E-mail: priya.raghavan@cubs.edu.in

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