



**HAL**  
open science

## Mechanisms of programmed cell death

Tian Li, Guido Kroemer

► **To cite this version:**

Tian Li, Guido Kroemer. Mechanisms of programmed cell death. *Immunological Reviews*, 2023, 321, pp.5 - 6. 10.1111/imr.13303 . hal-04599808

**HAL Id: hal-04599808**

**<https://hal.science/hal-04599808>**

Submitted on 13 Jun 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## INTRODUCTION

## Mechanisms of programmed cell death

Tian Li<sup>1</sup>  | Guido Kroemer<sup>2,3,4</sup> <sup>1</sup>School of Basic Medicine, Fourth Military Medical University, Xi'an, Shaanxi, China<sup>2</sup>Metabolomics and Cell Biology Platforms, Institut Gustave Roussy, Villejuif, France<sup>3</sup>Centre de Recherche des Cordeliers, Equipe labellisée par la Ligue contre le cancer, Université de Paris, Institut Universitaire de France, Sorbonne Université, Inserm U1138, Paris, France<sup>4</sup>Department of Biology, Institut du Cancer Paris CARPEM, Hôpital Européen Georges Pompidou, AP-HP, Paris, France

## Correspondence

Tian Li, School of Basic Medicine, Fourth Military Medical University, Xi'an, Shaanxi, China.

Email: [fmmult@foxmail.com](mailto:fmmult@foxmail.com)

Guido Kroemer, Metabolomics and Cell Biology Platforms, Institut Gustave Roussy, Villejuif, France.

Email: [kroemer@orange.fr](mailto:kroemer@orange.fr)

The present volume of *Immunological Reviews* deals with the mechanisms of programmed cell death, obviously from an immunological perspective. What are the consequences of cell death on the organism and, in particular, on the immune recognition of stressed and dying cells? The long-distance effects of therapeutic manipulations resulting in the death of cancer cells are surprisingly vast, as this has been documented for the treatment with clinically approved or experimental chemotherapeutic agents. For example, cell death can cause neuropathic pain through mechanisms of neuroinflammation.<sup>1</sup> In addition, cell death induction can result in the production of Type I interferons by tumor cells that then mediate ambiguous adaptive responses ranging from an enhancement of cancer cell stemness and exhaustion of anticancer immune response within the tumor microenvironment to the stimulation of anticancer immune responses. Type I interferon can even trigger a systemic sickness response ranging from flu-like symptoms to a state of depression.<sup>2</sup> Such long-range effects of cell death are certainly also relevant to the pathophysiology of viral infections.

If induced in an appropriate fashion, one of the major positive effects of cancer cell stress and death is the induction of immune responses against tumor-associated antigen, thus sensitizing tumors to immunotherapy with immune checkpoint inhibitors.<sup>3-5</sup> This has important therapeutic implications because chemotherapeutics that induce immunogenic cell death can be used as first-line treatments to sensitize major cancer types (exemplified by KRAS-mutated colorectal cancer, non-small cell lung cancer and triple-negative breast cancer) to subsequent immunotherapy with antibodies targeting

cytotoxic T-lymphocyte-associated protein 4 (CTLA-4), programmed cell death 1 (PD-1), or PD-1 ligand-1 (PD-L1), as this has been confirmed in several clinical trials.

Of note, there are multiple different subroutines of cell death, and several if not all of them can be immunogenic, as this has been documented for apoptosis (which involves mitochondrial membrane permeabilization and the activation of caspases 3 and 7)<sup>2,3</sup> but also for necroptosis (with the implication of specific effector molecules including receptor-interacting kinase 3 (RIP3) and mixed lineage kinase domain-like pseudokinase (MLKL1)),<sup>6</sup> pyroptosis (involving inflammasome/caspase-1-mediated activation of pore-forming gasdermins),<sup>7</sup> a mixture of pyroptosis, apoptosis, and necroptosis dubbed PANoptosis,<sup>8</sup> ferroptosis (involving lethal membrane damage by peroxidation),<sup>9,10</sup> and cuproptosis (due to copper-induced aggregation of lipoylated dihydrolipoamide S-acetyltransferase).<sup>11</sup> In all cases, cell death can be preceded by immunogenic stress that favors the emission of danger-associated molecular patterns (DAMPs) appearing on the surface of the cells or secreted into the extracellular space. It is the sum of stress-associated DAMPs (that are surface-exposed or released before cells disintegrate) and that of death-associated DAMPs (that become accessible or are passively released when the plasma membrane and internal membrane of cells become permeable) that dictates the immunogenicity of cell death and hence the capacity of the immune system to detect dead cell antigens. Such antigens can be microbial (for instance in the context of infection by viruses or intracellular bacteria), tumor-associated, or autoantigens.

This article introduces a series of reviews covering Mechanisms of programmed cell death appearing in Volume 321 of *Immunological Reviews*.

© 2023 John Wiley & Sons A/S. Published by John Wiley & Sons Ltd.

Immunogenic cell death is not only induced by drugs but can also occur in the context of radiation therapy,<sup>12</sup> photodynamic, and photothermal therapy,<sup>13</sup> as well upon infection by microbes including oncolytic viruses.<sup>14</sup> Logically, attempts are underway to create novel galenic formulation including nanoparticle-based drug delivery systems to administer drugs that induce immunogenic cell death in tumors, yet do not mediate any systemic effects.<sup>13,15</sup> Interestingly, cell death of cancer cells can be accompanied by the release of nanoscale extracellular vesicles dubbed exosomes that constitute potential biomarkers of ongoing cell death events and establish short- and long-distance communication with neighboring cells and distant tissues.<sup>16</sup> As a possibility, such exosomes might be engineered for the nanodelivery of therapeutic agents.

When cells undergo immunogenic stress and death, they interact primarily with dendritic cells,<sup>17</sup> in particular with Type-1 conventional dendritic cells (cDC1) that appear to be particularly competent in eliciting responses against dead cell antigens.<sup>18</sup> Dendritic cells can be loaded with stressed and dying cancer cells and then be used as prophylactic or therapeutic vaccines.<sup>17</sup> Moreover, dendritic cells can be manipulated pharmacologically to enhance their capacity to present tumor antigens to T cells.<sup>18</sup> Such dendritic cells educate cytotoxic T lymphocytes to recognize and lyse malignant cells. Importantly, this process of T-cell-mediated cytotoxicity can elicit immunogenic cell death, hence amplifying the phenomenon and protracting the anticancer immune response.<sup>19</sup> However, cell death affecting immune cells may play down such a desirable immunosurveillance. Specifically, it appears that dying neutrophil granulocytes produce so-called neutrophil extracellular traps (NETs) that shield cancer cells from cytotoxic immunity, hence impairing their clearance.<sup>20</sup> Moreover, dying neutrophils can stimulate unwarranted inflammatory and autoimmune responses.<sup>21</sup>

Altogether, this volume of *Immunological Reviews* illustrates to which extent different cell stress and death modalities affecting malignant cells, pathogen-infected cells, or immune cells can elicit innate and cognate immune responses with vast consequences for whole-body physiology. It appears that processes that for long have been studied exclusively by cell biologists have acquired a major immunological dimension that already yields tangible impact with respect to the clinical management of malignant diseases. Future will tell whether the knowledge generated in this field will also contribute to the prevention and treatment of infectious and autoimmune diseases.

#### CONFLICT OF INTEREST STATEMENT

The authors declare no relevant conflicts of interest.

#### ORCID

Tian Li  <https://orcid.org/0000-0002-8281-4459>

Guido Kroemer  <https://orcid.org/0000-0002-9334-4405>

#### REFERENCES

- Li L, Li T, Qu X, Sun G, Fu Q, Han G. Stress/cell death pathways, neuroinflammation, and neuropathic pain. *Immunol Rev.* 2024;321(1):33-51.
- Holicek P, Guilbaud E, Klapp V, et al. Type I interferon and cancer. *Immunol Rev.* 2024;321(1):115-127.
- Laureano RS, Vanmeerbeek I, Sprooten J, Govaerts J, Naulaerts S, Garg AD. The cell stress and immunity cycle in cancer: toward next generation of cancer immunotherapy. *Immunol Rev.* 2024;321(1):71-93.
- Ghiringhelli F, Rebe C. Using immunogenic cell death to improve anticancer efficacy of immune checkpoint inhibitors: from basic science to clinical application. *Immunol Rev.* 2024;321(1):335-349.
- Li S, Wang A, Wu Y, et al. Targeted therapy for non-small-cell lung cancer: new insights into regulated cell death combined with immunotherapy. *Immunol Rev.* 2024;321(1):300-334.
- Guo Y, Zhou J, Wang Y, Wu X, Mou Y, Song X. Cell type-specific molecular mechanisms and implications of necroptosis in inflammatory respiratory diseases. *Immunol Rev.* 2024;321(1):52-70.
- Hong X. Pyroptosis in glioma: the known unknowns. *Immunol Rev.* 2024;321(1):152-168.
- Sun X, Yang Y, Meng X, Li J, Liu X, Liu H. PANoptosis: mechanisms, biology, and role in disease. *Immunol Rev.* 2024;321(1):246-262.
- Tang D, Kroemer G, Kang R. Ferroptosis in immunostimulation and immunosuppression. *Immunol Rev.* 2024;321(1):199-210.
- Le J, Pan G, Zhang C, Chen Y, Tiwari AK, Qin JJ. Targeting ferroptosis in gastric cancer: strategies and opportunities. *Immunol Rev.* 2024;321(1):228-245.
- Liu WQ, Lin WR, Yan L, Xu WH, Yang J. Copper homeostasis and cuproptosis in cancer immunity and therapy. *Immunol Rev.* 2024;321(1):211-227.
- Galassi C, Klapp V, Yamazaki T, Galluzzi L. Molecular determinants of immunogenic cell death elicited by radiation therapy. *Immunol Rev.* 2024;321(1):20-32.
- Xi Y, Chen L, Tang J, Yu B, Shen W, Niu X. Amplifying "eat me signal" by immunogenic cell death for potentiating cancer immunotherapy. *Immunol Rev.* 2024;321(1):94-114.
- Huang J, Duan F, Xie C, et al. Microbes mediated immunogenic cell death in cancer immunotherapy. *Immunol Rev.* 2024;321(1):128-142.
- Xu W, Liu W, Yang J, Lu J, Zhang H, Ye D. Stimuli-responsive nanodelivery systems for amplifying immunogenic cell death in cancer immunotherapy. *Immunol Rev.* 2024;321(1):181-198.
- Li X, Jing Z, Li X, et al. The role of exosomes in cancer-related programmed cell death. *Immunol Rev.* 2024;321(1):169-180.
- Agostinis P. Decoding immunogenic cell death from a dendritic cell perspective. *Immunol Rev.* 2024;321(1):350-370.
- Liu P, Zhao L, Zitvogel L, Kepp O, Kroemer G. Immunogenic cell death (ICD) enhancers-drugs that enhance the perception of ICD by dendritic cells. *Immunol Rev.* 2024;321(1):7-19.
- Luri-Rey C, Gomis G, Glez-Vaz J, et al. Cytotoxicity as a form of immunogenic cell death leading to efficient tumor antigen cross-priming. *Immunol Rev.* 2024;321(1):143-151.
- Hu Y, Wang H, Liu Y. NETosis: sculpting tumor metastasis and immunotherapy. *Immunol Rev.* 2024;321(1):263-279.
- Li Y, Wu Y, Huang J, et al. A variety of death modes of neutrophils and their role in the etiology of autoimmune diseases. *Immunol Rev.* 2024;321(1):280-299.

**How to cite this article:** Li T, Kroemer G. Mechanisms of programmed cell death. *Immunol Rev.* 2024;321:5-6. doi:[10.1111/imr.13303](https://doi.org/10.1111/imr.13303)