Anti-stress mechanisms in archaea: implications for biology and medicine. An update

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1. ABSTRACT

The connections between the Archaea and eukaryotes in matters different from evolution and phylogeny, for example in what pertains to Medicine, have been thought of by many but, in practice, little progress has been made and they are still poorly understood. These connections are explored in this Special Issue of FBS bearing in mind that archaea and eukaryotes, e.g., humans, share important molecular and biochemical characteristics evolutionarily conserved in both. The aim is to elucidate possible links between the biology of archaeal and eukaryotic organisms and, thereby, derive possible applications of archaeal molecules and pathways to elucidate mechanisms of human diseases involving their evolutionarily conserved counterparts.

2. INTRODUCTION AND OVERVIEW

This Special Issue of Frontiers in Bioscience is intended to be a lively forum, taking advantage of the extraordinary agility of electronic publication. The Issue will be updated periodically with novel developments pertaining to the topics treated in the initial series of articles, and with new articles on other topics. Advances in genomics and proteomics will be closely followed in the search for new material. Thus, the Issue should become a permanent reference source, constantly growing and renewing itself to reflect the progress of science and of our understanding of life and Nature in general.

The specific theme of the Special Issue is stated in the title: "Anti-stress mechanisms in archaea:
implications for biology and medicine." The articles were (and will be) written to show not only what is known for the archaea, but also how this knowledge relates to similar information from bacteria and eukaryotes, and how it impacts on other fields beyond the archaea. The aim is to provide an integrated view of: stress response, genes, and proteins; anti-stress mechanisms; consequences of stress on molecules, cells, and organisms when they are multicelled; mechanisms of survival in foreign environments and of adaptation to extreme conditions by comparison with those optimal for human cells; and applications of stress genes, proteins, and anti-stress mechanisms in the biotechnology industry pertaining to agriculture, environmental monitoring and bioremediation, waste treatment and utilization, fermentors for production of biologicals, medicine (e.g., adjuvants, vaccines), and other areas of human endeavor.

Stress, anti-stress mechanisms of various types, molecular chaperones and disease, heat-shock proteins (of which there is a large variety) in physiology and development, evolution, phylogeny, and biotechnological applications are just but a few of the themes that are directly or indirectly touched in this issue. As mentioned above, the focus is on the archaea but connections with bacteria and eucarya are, and will be, abundantly described.

All living cells have been classified into three main evolutionary lines of descent or Domain: Archaea (archaeobacteria, archaea bacteria), Bacteria (eubacteria), and Eucarya (1, 2). The former two are prokaryotes, but archaea differ from bacteria in many key features, and both archaea and bacteria also differ from eucarya in many important characteristics (1-4; see also Overview, subsection 4). Thus while organisms of the three phylogenetic domains share a number of properties, common to all forms of cellular life, they also differ from each other in a manner that makes it possible to sort them out into separate evolutionary lines.

Although the above-described subdivision of life forms and the common ancestor hypothesis (5) are still under debate, the three-domain classification is useful as a scaffolding to organize old and new data into a coherent matrix with an evolutionary basis, and to guide the debate. Stress genes and proteins have played an important role in the debate and have been the target of intense scrutiny by researchers in the field of evolutionary biology (6-9). This and other related matters have recently been reviewed (10). This Issue represents an update and an extension of that review by specialists in their respective fields. Others will contribute in the near future on other relevant topics not covered by the initial list of articles.

Historically, the archetypal stress response has been that caused by heat shock, hence it is often called heat-shock response. Consequently, the proteins characteristic of the heat-shock response, typically produced by genes that are stress-inducible, are called to this day heat-shock proteins and are abbreviated Hsp. Sometimes they are also abbreviated HSP. This acronym has become a name in itself: one can say that the stress response entails an increase of the Hsp. Furthermore, some chaperones whose genes are not induced by heat-shock are nevertheless named Hsp. The genes encoding the Hsp are called heat-shock genes and are abbreviated hsp. The current trend is to move away from these names and to use the terms stress response, stress proteins, and stress genes, although the designations Hsp and hsp for specific molecules and genes, respectively, are still widely used. This is not just a problem of semantics. The traditional nomenclature blurs the true meaning of the concepts it aims at defining. This situation becomes more acutely evident as our knowledge of the stress response progresses and we discover life where there is intense heat (11-13), and where there is no heat but cold (13, 14). Furthermore, not only do we learn more and more about the response to a temperature elevation, but also we are learning about life in frigid environments, and about the response of cells to a temperature decrease, below that which is the optimal temperature for growth (henceforth referred to as OTG). Thus, we have to understand how life is maintained at the various levels distinguishable between 0 and 100 °C (and beyond those limits) on a day-to-day basis, so to speak, and how cells survive a sudden decrease in ambient temperature. In other words, we have to understand the response to cold as well as we understand the response to heat, both being stress responses.

Traditionally, it has been tacitly implied that anything in terms of temperature, pH, salinity levels, etc., that is beyond the limits tolerable to human cells is abnormal, or extreme, and constitutes a stressor. Nowadays we realize that a temperature, for example, that is stressful for a given species may be optimal for another. So the term extremophile is relative, and must be understood in the context of what is physiological for human cells.

Living organisms can be classified on the basis of their OTG into the following groups: psychrophiles, psychrotolerant, mesophiles, thermophiles, and hyperthermophiles (or extreme thermophiles) with OTG (in °C) of 15 or lower, 20-30, 35-40, 50-70, and 80 or higher, respectively (13). Similarly, organisms that live in high-salt (within the range of about 3% to saturation) environments are halophiles, and have been grouped into these categories: halotolerant, halophiles, and extreme halophiles (13). As in the case of temperature, it is obvious that a salt concentration that is optimal for the growth of a given species might cause a hyper-osmotic shock on another organism or a hypo-osmotic stress on a third, different life form.

Lastly, it is important to understand that the response of the cell to a given stressor is usually made up of two phases: one immediate that may last only minutes or very few hours, and the other delayed. These two phases have distinctive landmarks, dynamics, effects, etc., but they overlap to some extent. The initial stages of the late phase are superimposed on the last portion of the immediate phase.

The second, delayed phase of the response to heat stress, or to cold stress, is called acclimation when it is long
lasting, as the result of the stressor persisting in the environment. The same applies to other stressors, such as increase or decrease in salinity levels.

The response of archaea to heat stress, and to hypo- and hyper-osmotic shocks, and their adaptation to hot, cold, and high-salt environments are treated in this initial series of articles of the Special Issue. There are also articles on oxidative stress, molecular chaperones and other anti-stress mechanisms, and the distinctive characteristics of extremophilic molecules and membranes.

Lastly, the connections of Archaea with Medicine are always taken into account as, for example, a) the indirect pathogenic roles of methanogens that inhabit body cavities (mouth, intestine, vagina) and that favor the growth of disease-causing bacteria (15); and b) the use of archaean model systems to elucidate mechanisms of human diseases caused by defective chaperones, the chaperonopathies, since molecular chaperones are very similar in humans and archaea (16).

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4. REFERENCES


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