Microbiol Monogr (6)
D. H. Nies, S. Silver: Molecular Microbiology of Heavy Metals
DOI 10.1007/7171_2006_086/Published online: 17 February 2007

Arsenic Metabolism in Prokaryotic and Eukaryotic Microbes

Hiranmoy Bhattacharjee · Barry P. Rosen (✉)

Department of Biochemistry and Molecular Biology,
Wayne State University School of Medicine,
540 E. Canfield Avenue, Detroit, MI 48201, USA
brosen@med.wayne.edu

Abstract This chapter will focus on recent progress on the mechanisms of metalloid uptake, metabolism, and detoxification in bacteria, archaea, and eukaryotic microbes. One of the initial challenges of the earliest cells would have been the ability to detoxify heavy metal ions, transition metal ions, and metalloids, including arsenic and antimony. The presence of arsenic resistance (*ars*) genes in the genome of by far most living organisms sequenced to date illustrates firstly that *ars* genes must be ancient and secondly that arsenic is still ubiquitous in the environment, providing the selective pressure that maintains these genes in present-day organisms. Some early cells also probably could use arsenite as an electron acceptor, giving selective pressure for the evolution of respi-

ratory arsenate reductase. As atmospheric O_2 levels increased, arsenite was oxidized to arsenate abiotically. This provided an advantage for the evolution of arsenate reductases, some for arsenate respiration and energy production, and others for arsenate detoxification. Present-day selective pressure for metalloid resistance also comes from sources such as natural release of arsenic from volcanic activities, mining activities, the burning of coal, and other human activities. In addition is the use of arsenicals and antimonials as chemotherapeutic drugs for the treatment of parasitic diseases and cancer. Resistance to these drugs is becoming a major dilemma. Thus, an understanding of the molecular details of metalloid transport systems and detoxification enzymes is essential for the rational design of new drugs, and for treating drug-resistant microorganisms and tumor cells. Finally, this chapter will summarize recent identification of novel enzymes for arsenic reduction, oxidation, and methylation that expand the possibilities for metalloid metabolism and transformations.

1 Introduction: The Arsenic Geocycle

Arsenic is widely distributed in the Earth's crust and occurs primarily in four oxidation states: arsenate [As(V)], arsenite [As(III)], elemental arsenic [As(0)], and arsenide [As(–III)]. Volcanic eruptions are a source of human exposure to arsenic. Mining, copper smelting, coal burning, and other combustion processes also bring arsenic into our environment. Anthropogenic sources of arsenic include both inorganic and organic forms. Arsenic serves as an active ingredient in various commonly used herbicides, insecticides, rodenticides, wood preservatives, animal feeds, paints, dyes, and semiconductors.

Microbes play an important role in cycling arsenic between its various oxidation states (Fig. 1) (Mukhopadhyay et al. 2002). Inorganic arsenate entering the microbial cytosol through the phosphate transport system is reduced to arsenite, which is then extruded out of the cell, either through channels or secondary transporters (Rosen 2002). Arsenite is also generated by certain microbes that use arsenate as the terminal electron acceptor in anaerobic respiration (Oremland and Stolz 2003). These arsenate-respiring microbes can release arsenite from arsenate-rich sediments, leading to arsenic contamination of ground water (Oremland and Stolz 2005). Arsenite-oxidizing microbes utilize the reducing power from As(III) oxidation to gain energy for cell growth (Stolz et al. 2006). Microbes can also convert inorganic arsenic into gaseous methylated arsenide (Bentley and Chasteen 2002; Qin et al. 2006). However, whether microbes can metabolize arsenic salts to elemental arsenic remains to be determined. Marine microorganisms can convert inorganic arsenicals to various water- or lipid-soluble organic arsenic species. These include generation of di- and trimethylated arsenic derivatives (DMA, TMA), arsenocholine, arsenobetaine, arsenosugars, and arsenolipids. Arsenobetaine can be degraded to inorganic arsenic by microbial metabolism, completing the arsenic cycle in marine ecosystems (Dembitsky and Levitsky 2004).