

Microbiology of the Toxic Noble Metal Silver

Sylvia Franke

Biology Department, Skidmore College, 815 North Broadway,
Saratoga Springs, NY 12866, USA
sfranke@skidmore.edu

1	Introduction	343
2	Use of Silver as a Biocide	344
3	Silver Resistant Bacteria	345
3.1	The <i>Sil</i> Determinant of <i>Salmonella</i> pMG101 and Homologous Systems . . .	346
3.2	Other "Strategies" of Silver Resistance	350
3.3	Bacterial Silver Resistance: Where to Go from Here	351
	References	352

Abstract One of the transition metals without a function in biological systems is silver. Silver interferes with the normal protein function of the organism and is extremely toxic because of its ability to bind to the metal binding sites in proteins. The use of silver as a biocide has long been known and today there is an increasing number of applications for silver, not only in hospitals but also in everyday life. In addition, silver resistant bacteria have been isolated from hospitals, silver mines, and silver-contaminated areas. There are different resistance mechanisms, as strains of *Pseudomonas* appear to precipitate silver to remove it from the medium. In contrast, silver resistance in *Salmonella typhimurium* is plasmid-encoded and based on silver binding and export. Genome sequencing projects increasingly reveal the presence of this *sil* determinant, indicating a more widespread occurrence than previously expected.

1 Introduction

The transition element silver (Ag) is not relevant for living organisms as a trace element. Naturally occurring silver is composed of two stable isotopes, ^{107}Ag and ^{109}Ag with 51.9 and 48.1% natural abundance, respectively, and 28 radioisotopes have been characterized. Silver combined with arsenic, sulfur, antimony, or chlorine is mainly found in copper, lead, and lead-zinc ores as elemental silver or silver compounds, e.g. horn silver (AgCl) and argentite (Ag_2S).

Silver has a long history. Silver mining in Mesopotamia (now Iraq, east Syria, and southeast Turkey) goes back as far as 2500 B.C. In ancient Egypt the bones of gods were thought to be of silver, and there it was first described as "white metal". Since it was very rare, silver was considered

more valuable than gold (<http://touregypt.net/featurestories/silver.html>). Silver mining then spread to Europe, where first Greece and later Spain were the mining centers but also regions of Saxony in Germany. The “discovery” of the “New World” opened a new resource of the highly treasured metal (<http://www.silverinstitute.org/facts/>). For thousands of years, silver was used for trade, ornaments, and utensils.

Currently silver is mined in more than 50 countries (19 700 t in 2004) with Peru being the world’s leading producer followed by Mexico, China, and Australia. Because of its physical properties, silver is an excellent electrical and thermal conductor. It has a wide range of industrial applications, such as in batteries, fuses, electrical switches, or heated automobile windows. The light sensitivity of silver is used in photography. And still today’s best-known use of silver is in jewelry and silverware (Brooks 2004).

2

Use of Silver as a Biocide

The antibiotic effect of silver has long been known and goes back to ancient Greece and Rome, where silver coins were used to disinfect water even before understanding of infectious diseases (Brett 2006). Today silver compounds are still used to control the formation of bacterial biofilms in water piping (Rogers et al. 1995).

Medical use of silver nitrate goes back to the Middle Ages when it was probably first used to treat chronic wounds and ulcers, and was eventually used as an alternative method to cauterizing iron in the treatment of fistulas (Klasen 2000a). In the nineteenth century silver was also used in burn wound treatment, one of today’s best-known uses of silver in medicine. Early publications refer to concentrations of 3.4 to 8.4% silver nitrate (Klasen 2000a), whereas today silver nitrate in wound treatment is largely replaced by silver sulfadiazine (Klasen 2000b; Graham 2005) (usually 1% silver sulfadiazine plus 0.2% chlorhexidine in a hydrophilic cream, market name Silvazine) and silver ion releasing dressings (Cooper 2004), which are shown to be effective to generally prevent the growth of a variety of burn wound pathogens (Bowler et al. 2004). Besides silver salts, at the beginning of the twentieth century silver foil was used in wound treatment (Klasen 2000a). Silver-containing bandages are now also commercially available from different companies for in-home wound treatment (Silver et al. 2006).

Another medical application of silver ions is the use of a 2% AgNO_3 solution in the eyes of newborn children to prevent gonorrhea infections, introduced in 1880. The so-called silver filling amalgam in dental restoration, which contains 50% mercury and 35% silver, is still common in dental restoration although it is being replaced by other materials (Klasen 2000a). Silver-coated catheters are used to prevent the formation of biofilms and