Communications

Electric Silver Antisepsis

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***Abstract*—Use of silver as a topical antimicrobial agent has been hampered by the absence of a method of providing sustained delivery of the silver ions. One possible solution is the use of silver-coated fabrics as both wound dressings and silver-ion emitting anodes in a simple electric circuit. The antimicrobial dose would then be determined by Faraday's law. In the biological environment, silver-coated materials studied thus far have not behaved as predicted. We have discovered a silver-coated fabric, designated IT, that is almost perfectly Faradaic *in vitro* up to 0.8 C. The silver ions thus liberated were effective in inhibiting the growth of microorganisms. IT has potential for development as a charge-controlled topical antimicrobial agent.**

Silver is a potent inhibitor of microorganisms, with a broad spectrum of action against bacteria, fungi, and yeasts [1]-[4]. One reason it has not achieved widespread use in clinical medicine is that convenient means of application have not been devised; various creams, solutions, and metallic foils have been tried, with only limited success.

Silver, when operated as an anode in an electrical circuit, will produce silver ions into an ionically conducting medium. Since the amount of silver liberated is related to the current, a silver anode is, at least in principle, a controllable source for the local administration of silver ions for control of infection. Several such attempts have been reported [5], [6]. One difficulty was that the rate of silver-ion production was less than that predicted by Faraday's law when a given charge was passed through the electrode. The chemical reactivity of silver ions in the biological environment was also a problem. Silver ions did not migrate more than 1 cm from their source, and thus it was difficult to adequately treat an area greater than 1-2 cm^2.

The latter problem can be overcome by employing the silver as a coating over an inert fabric substrate. We are interested in several such substrates, of which nylon presently seems the most promising.

Six silver-coated nylon fabrics (Swift Textile Metalizing Corp., Hartford, CT) of various weaves and knits were studied *in vitro* to determine the dynamics of their electrochemical production of silver ions. The fabrics consisted of nylon fibers, 20-50 μm in diameter, that had been uniformly coated with pure silver to a calculated average thickness of 0.02-0.4 μm, depending on the fabric. The silver was applied via a chemical process involving the immersion of the fabric in a silver solution. The test system consisted of two 400 ml beakers, each containing 50 ml of tryptic soy broth (a standard medium that supports microbial growth, and contains chloride ions), separated by a salt bridge. The material under test was operated as an anode in one beaker against a metal cathode in the second beaker. Electrical connection to the fabric was made by spring-loaded clips. Silver concentrations were measured by atomic absorption spectroscopy.

The fabric sought was one that would produce predictable levels of silver in solution. This required: 1) a nonlabile silver coating that did not produce significant levels of silver in the absence of a current, and 2) a Faradaic response upon the passage of charge. Only one fabric, designated IT, exhibited these properties. IT was a light (10.2 g/m^2) knit fabric (0.76 mm cell size) with a surface electrical resistance of 1.3 ± 0.1 Ω/□ and a silver content of 371 $\mu g/cm^2$.

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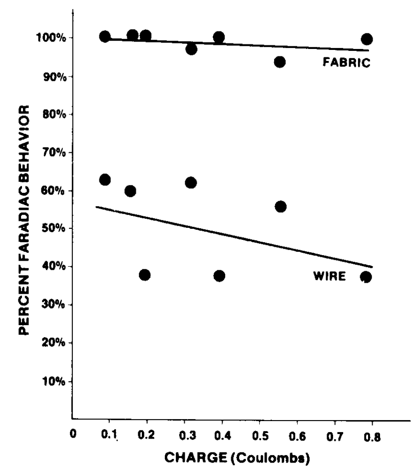

Fig. 1. Percent Faradaic behavior of IT fabric and pure silver wire. Data are expressed as the ratio of the measured silver concentration to the concentration predicted by Faraday's law based on the charge passed.

The response of IT and silver wire to the passage of charge (1-7 h) is shown in Fig. 1. IT was almost perfectly Faradaic over the range studied (up to 0.8 C). Silver wire, in contrast, was only 37-63 percent Faradaic, depending on the particular charge. At an average current density of 1.2 $\mu A/cm^2$, IT produced 4.9 $\mu g \cdot Ag/cm^2$ of fabric for up to 7 h. The corresponding figures for an average current density of 2.8 $\mu A/cm^2$ were 11.6 $\mu g/cm^2$ of fabric for up to 4 h. Duration of silver-ion production depended on the actual geometry of the fabric, as well as the total charge passed. Details are given elsewhere [7]. In an *in vitro* system, we showed that silver ions electrolytically liberated by silver-nylon fabrics were effective in controlling the growth of *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Candida albicans* [8] at concentrations that were several orders of magnitude below those associated with silver toxicity [9].

The other five materials tested were less effective than IT because: 1) their silver coatings were chemically more labile and released silver into solution even in the absence of current, and 2) the magnitude of their release in response to the passage of charge was not significantly different from that of silver wire. The reasons for IT's superior performance are presently unknown.

The results suggest that it may be possible to develop practical systems for local application of silver for infection control. One of the principal advantages of an IT anode is the apparent precise control of dose that it affords via regulation of the magnitude and duration of current. Further, the typical IT dressing would be relatively inexpensive because it would contain only a few milligrams of silver. Presently envisioned applications include treatment of soft-tissue infections and prevention of burn-wound sepsis. By metallizing absorbable substrates, it may prove possible to extend the silver-anode approach to the treatment of infections inside the body.

A disadvantage of silver-coated nylon fabrics is their tendency to develop electrochemical corrosion which can significantly degrade the Faradaic response. IT is particularly prone to this limitation, but it appears that it can be minimized by appropriate choice of electrode configuration.

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