Silver Anode Treatment of Chronic Osteomyelitis

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Even with the wide use of broad-spectrum antibiotics, effective control of osteomyelitis has not been consistent. The use of systemic antibiotics, while helpful, has not eliminated the need for other approaches, especially for the disease in its chronic form.[6,9] The use of anodic silver therapy is a new concept which stems from the well-known antibacterial properties of silver.[3] Although these properties have long been recognized,[4] the clinical uses of silver have been limited and its potential may not yet be fully realized. The silver cation is known to have an exceptionally broad spectrum involving gram-positive, gram-negative, aerobic and anaerobic microorganisms. A number of species have been found to have a minimum inhibitory concentration for anode-derived silver considerably lower than antibiotics in current use,[2] and resistance to the silver ion is rare.[5] Despite these properties, the penetration of silver from a topical agent into infected tissue is limited. This is due in part to its chemical characteristics (low solubility and/or toxicity of some of its salts, precipitation of silver chloride, and ready binding to proteins). On the other hand, electrically activating metallic silver, while in contact with the wound surface, avoids the use of extraneous anions such as nitrate. As long as a small current is flowing, a continuous supply of silver ions is emitted from the metal surface and is available for antibacterial action.

Since 1975 we have made use of this principle, mainly in the form of anodically polarized, silver-coated nylon fabric as an aid to the surgical management of deep-bone infection. The initial experience with this technique showed it to be free of local or systemic toxicity while being able to maintain a clean wound and permitting healing to occur.[1] The present report summarizes the experience with the use of silver in 25 patients with actively draining chronic osteomyelitis. The patients selected for this procedure were considered clinical failures of conventional treatment (debridement, systemic antibiotic therapy, skin and muscle-pedicle grafting, antiseptic irrigation, etc.) and many were candidates for amputation. Since the chronic draining sinus has the potential for degeneration to squamous cell carcinoma when present for many years, we considered an experimental approach to be justified.

The tendency for osteomyelitis to remain quiescent for long periods would demand a very long-term follow-up to demonstrate permanent elimination of infection by this

or any technique. For this reason, the elimination of chronic drainage and pain and return to a more productive life for each patient may be considered a satisfactory result. Under these conditions, a well-controlled study is difficult to develop. Expanding the clinical experience is a reliable way to confirm the usefulness of this approach.

MATERIALS AND METHODS

Twenty-five patients (24 males and one female) were treated for osteomyelitis at the VA Medical Center in Syracuse, New York. Their average age was 40 years (range, 23-64 years; median, 37) and each had at least one previous operation on the infected bone (average, 4.1 operations) prior to consideration for this treatment. The age of infection ranged from 0.1 to 33.0 years (median, four years). The tibia was the most commonly affected bone, accounting for 19 of the 25 infections. The femur was infected in three cases; there were two cases of pyoarthrosis, one at the knee and one at the ankle; and there was one case of an infection in the distal tibia and fibula. Since this was a new and experimental technique, only patients who demonstrated failures of the more commonly accepted treatments for osteomyelitis were accepted for the anodic silver treatment protocol.

The general procedure for patients treated by this technique was: (1) a thorough debridement; (2) single daily irrigation; and (3) placement of a fresh silver nylon dressing that is continuously activated electrically. Since the penetration of free silver ions or silver complexes cannot be assumed to be greater than 1 cm,[8] the debridement must include resection of all necrotic tissue, opening of all pockets of infection and removal of overhanging tissue. This produces a wound in which the silver nylon can be placed in good contact with all surfaces.

The first application of the silver electrode dressing takes place in the operating room following thorough surgical debridement. The dressing is cut to cover the entire wound cavity, leaving a tail extending out of the wound for electrical contact. The dressing is placed in close contact with all exposed bone and soft tissue with the exception of tendons and ligaments, which are protected with two to three thicknesses of saline-soaked gauze (Fig. 1). The wound cavity is then packed with a wet gauze stent and covered with dry dressing, leaving the dry tail of the silver nylon exposed. This tail portion is then connected to the positive pole of the electrical source unit. On the same extremity, directly opposite the depth of the wound, a nonabrasive electrode cream is applied and the return skin electrode (negative pole) is taped firmly in place. The current source is a battery-operated, FET-controlled, DC supply with 0.9 volts, 300 μAmp upper limits and provision for measurement of current and potential.[1] These values were chosen to permit a flow of 1 to 2 μAmps per cm^2 of silver nylon.

The original silver nylon dressing is left in place for two to three days and then changed, usually

Moist Gauze Stent

Ag Nylon
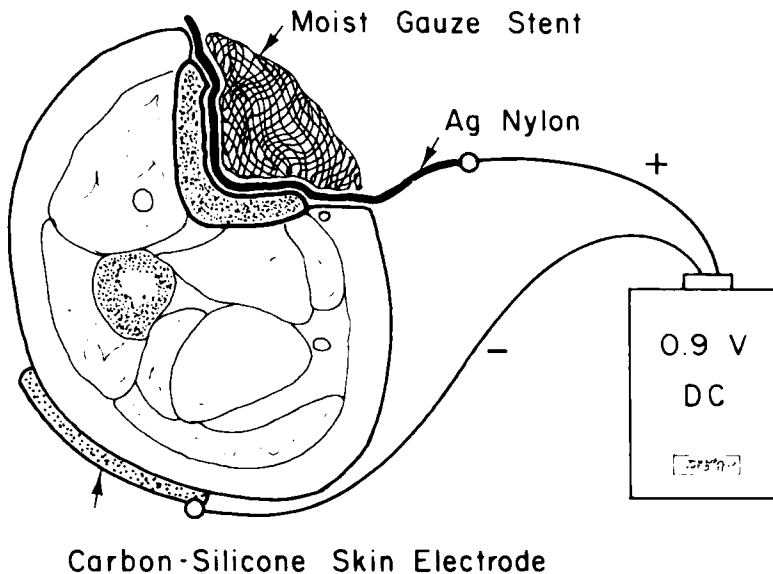
0.9 V DC

Carbon-Silicone Skin Electrode

FIG. 1. Diagram illustrating the application of a silver anode dressing to the saucerized tibia and the connection of the voltage-controlled DC source which continuously activates the silver.

without analgesia. There is minimal adherence of the dressing to the wound. The wound is irrigated with normal saline and a new silver nylon electrode, moist stents, and dry dressing are applied. The surface return electrode is changed and moved to a new position to avoid possible skin irritation. After the initial change a fresh silver nylon dressing is reapplied daily in a similar manner and, in many cases, the patient can be taught to perform the dressing change alone after a few days. Beginning at about one week after the surgical debridement, daily whirlpool therapy is used whenever possible. Local treatments with Betadine (Perdue Frederick, Norwalk, Connecticut) and Phisohex (Winthrop Laboratories, New York, New York) are carefully avoided because they appear to retard the growth of granulation tissue.

Bacteriologic cultures were taken at three- to five-day intervals throughout therapy. These were obtained by sampling the entire surface of the wound bed with a dry sterile swab and within 30 minutes directly streaking the surface of a freshly prepared brain/heart infusion agar culture plate using a consistent 20-streak pattern. Colonies were counted at 7× magnification after incubation for 24 hours at 37°C. It was found that this routinely gave a semiquantitative measure of the bacterial flora.

Because of significant loss of bone tissue, either from the original injury or surgical debridement, an open (Papineau) bone graft procedure was performed on 13 patients, but only after the bacterial counts in the debrided bone were reduced to ten colonies or less on three consecutive cultures. As experience was accumulated, this technique was used less often in the cases of osteomyelitis without nonunion. If grafting was performed, the silver dressing was placed over the grafted bone to maintain bacteriostasis. The dressing was electrically activated and changed daily as in the pregrafting situation. Both grafted and ungrafted wounds gradually granulated and then epithelized under the silver nylon mesh. Usually after two to three months it became clear if the wound was healing or developing a persistent sinus tract. Larger wounds took more time to epithelize. If areas of persistent drainage developed, the consideration was made for a second formal surgical debridement and extended silver electrode therapy. When it became clear that the wound was epithelized or the sinus tract was permanently established, the silver nylon mesh therapy was discontinued.

RESULTS

Follow-up of all 25 patients by personal examination was from six months to two and one-half years. The success of treatment was assessed by serial X-rays, clinical evaluation of stability, absence of pain, the amount of residual drainage, the requirement of orthopedic devices and other walking aids, surgical or medical complications, local or systemic reactions to silver, total time required for treatment, and time to procure a negative culture in the wound. In the absence of satisfactory prospective controls, each patient was considered their own control as each represented the failure of previous standard orthopedic treatments for osteomyelitis.

BACTERIOLOGIC RESULTS

Bacteriologic data were compiled systematically during treatment on 19 of the 25 patients entered in this study; two patients had two sites treated with silver nylon, giving a total of 21 wound sites. The frequency of occurrence of bacteria species initially cultured from the wound sites is shown in Table 1. Eighteen of the sites had multiple bacteria present. Eleven out of the 21 sites had bac-

TABLE 1. Bacteria Isolated Prior to Treatment with Anodic Silver

Species	Frequency (No. of Patients)
Gram-positive	26
Staphylococcus aureus	16
Staphylococcus epidermis	1
Streptococcus Group A	1
Streptococcus Group D	3
Streptococcus Group G	1
Streptococcus Mutans	1
Streptococcus species	1
Yeast	1
Clostridium species	1
Gram-negative	32
Pseudomonas aeruginosa	12
Enterobacter cloacae	5
Enterobacter hafniae	1
Escherichia coli	4
Proteus mirabilis	4
Klebsiella pneumoniae	3
Serratia marcescens	2
Acinetobacter calcoaceticus	1

TIME REQUIRED TO REDUCE BACTERIAL
COLONY COUNTS <100
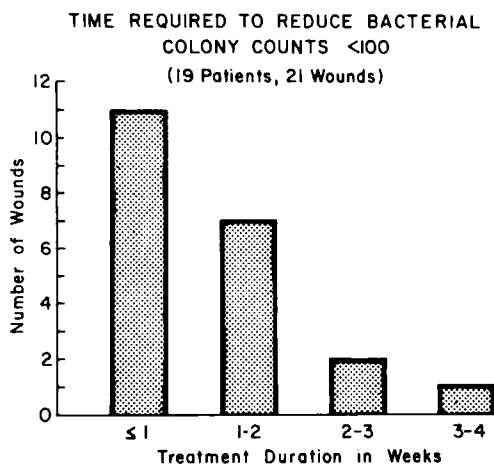(19 Patients, 21 Wounds)

FIG. 2. The number of wounds achieving a bacterial plate count of less than 100 colonies after debridement and inception of silver mesh anode applications. Sequential bacterial counts were available for 21 wounds in 19 patients. Counts fluctuated throughout the remaining treatment period (two to three months), but generally remained low. After open-bone graft procedures the counts tended to rise.

terial counts that decreased to less than 100 colonies within one week, two of which began at that level after debridement (Fig. 2). After four weeks of treatment all 21 sites had achieved a count of less than 100 colonies per wound at some point. In most cases, colony counts were not maintained at this low level and tended to fluctuate. There was no evidence in these cases of resistance to the silver ion, as judged by *in vitro* susceptibility of the patient's bacteria to a silver anode. Persistance of moderate or high colony counts was felt to be secondary to undebrided clusters of bacteria in the bone and not reached by the electrically injected silver ions.

It is noteworthy that the bacterial counts as measured in this study did not always reflect the healing process and the ultimate fate of the wound. For example, wounds after open-bone grafting generally did well and appeared clinically clean, despite the recording of significantly high bacterial counts on the wound surface. It was also noted that

if silver anode treatment was interrupted for a few days bacterial counts tended to rise dramatically.

ELECTRICAL BEHAVIOR

In actual operation, the driving voltage required by the DC sources was 0.8 to 0.6 volts with a corresponding current remaining between 100 to 250 μAmps throughout the treatment period. This corresponds to a nominal current density at the silver nylon of about 0.7 to 1.6 μAmps/cm^2.*

After each daily dressing change, the current would tend to decrease slowly and at 24 hours be typically 10% to 50% lower than the initial value as impedence of the electrode/tissue/electrode circuit increased. The initial current level was restored after fresh electrodes (silver nylon and skin pad) were replaced each day. These changes depend on the condition of the skin electrode, the moisture content of the wound and dressing, and the amount of chloridization of the silvered surface. On occasion, the current at 24 hours was found to be very low or nil, especially when the silver dressing and wound were small. This appeared to be due to the complete chloridization of the silvered surface. As treatment progressed and the wound became smaller, initial current readings upon the application of a new dressing decreased as well.

CLINICAL STATUS AND RESULTS

Patients were grouped into three categories according to the clinical status of their wounds at the termination of the study (Table 2). Those patients whose wounds were completely closed and epithelized were considered successfully treated, and those with persistent drainage or requiring amputation because of persistent drainage were considered failures. Sixteen of the 25 patients

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* The actual current density would, of course, be much lower due to the high-specific surface area of the coated woven fabric.

TABLE 2.   Results of Treatment of Chronic Osteomyelitis (All Patients)

Patient Classification	Number of Patients	Completely Epithelized	Persistent Drainage	Amputation	Nonunion United
Osteomyelitis and nonunion	12	7	3	2	9
Osteomyelitis alone	13	9	3	1	—
Total	25	16	6	3	9

(64%) healed to closed nondraining, pain-free wounds. Two of these patients had a second formal surgical debridement before their final successful result and one patient, a severe alcoholic who had a completely healed wound with no drainage for nine months, was then readmitted with a severe compound refracture through the original site. It was felt that this patient would not benefit from further treatment and amputation was elected. (Figs. 3A–3D and 4A–4D)

Nine patients were considered failures of treatment, six of these patients developing recurrence of drainage with at least one of the original bacteria after treatment was considered complete. Their bacteriologic count during treatment usually remained high and pain persisted as the wound epithelized down to a small sinus tract. The other three patients developed persistent drainage as treatment progressed and ultimately elected for amputation of their extremity. Two of the nine failures had a second formal surgical debridement and prolonged silver nylon treatment without a satisfactory resolution of the problem. All patients with persistent drainage are ambulatory with various forms of external support including braces, canes, and crutches, and are considered to have persistent active chronic osteomyelitis.

When a large amount of bone was removed during the surgical debridement and it was believed that the structural strength was significantly diminished, an open autogenous bone graft was performed. The results of this procedure, used in conjunction with the silver nylon are summarized in Table 3.

Thirteen patients had open bone grafting. Seven (54%) completely epithelized and appear to be healed. The other six patients had persistent drainage, of whom two underwent amputation.

On initial presentation, 12 patients had nonunions complicated by osteomyelitis. Three of five nonunions united without bone grafting procedures following the silver mesh treatment for osteomyelitis. Seven patients had open-bone grafting to the area of the infected nonunion two to four weeks after the original surgical debridement and start of silver mesh treatment. Six of these seven nonunions united radiologically; however, two continued to drain and are considered failures of treatment because of their osteomyelitis.

No statistically significant correlation could be found between the success of treatment and the patients' age or age of the infection. Patients with fewer previous surgical treatments tended to have successful outcomes, but this fell short of statistical significance.

SIDE EFFECTS

No side effects of anodic silver administration, toxic or otherwise, were noted in this series. Most patients received two to three months of continuous treatment and one patient remained in the program with active treatment for six months. No adverse reaction to the silver, either local or systemic, has been seen. There was no apparent discoloration of the tissues and no apparent retardation of granulation or epithelization over the wound. Indeed, the later two processes seem, in our experiences, to have been

FIGS. 3A–3D. (A) Radiograph of an infected nonunion in a 25-year-old white man who had an open fracture right tibia 1.5 years previously. He developed delayed union, underwent ORIF with grafting which subsequently became infected and required plate removal, several debridements, and intravenous antibiotic therapy. (B) Clinical status two weeks after surgical debridement and initial silver mesh treatment. (C) Final clinical results after 57 days of silver anode application. No drainage present. Limb is stable. (D) Final radiologic appearance. Nonunion stabilized.

accelerated. In the early use of anodic silver, there was some indication of deterioration of tendons and ligaments in contact with the electrode. This contact was thus avoided in the current series as a precaution, although there was no further indication of such a reaction. Irritation of the skin beneath the return electrode seemed to occur after prolonged usage but was avoided by frequent changes in the location and the use of nonchlorided, nonabrasive electrode gels.

DISCUSSION

Although the use of antibacterial silver dressings does not circumvent the need for adequate standard surgical debridement, it seems to present an effective aid in the treatment of chronic osteomyelitis, especially when other methods are inappropriate.

Silver ions delivered by this technique have proved to be an effective antibacterial agent. Because of its wide spectrum and negligible toxic effects, both systemically and locally, on healing musculoskeletal tissues, it represents a definite advantage over the long-term antibiotic therapy. Its range of active tissue penetration cannot be assumed to be greater than 1 cm and, therefore, effective use of this modality necessitates a thorough debridement of all infected tissues.

The procedure includes surgical debridement and good wound care which, although ultimately contributing to the outcome in these patients, cannot be assumed to be effective alone since they had failed in previous treatment. In general, antibiotics were used minimally for a few days after surgery. Bone grafting did not improve the outcome in this series (Table 2). It therefore may be concluded that the antibacterial action of the silver ions delivered by iontophoresis was an

important component in the healing in those cases treated successfully. Although this was probably due to decreased bacterial activity, the possibility cannot be ruled out that the localized application of electrical current per se could have changed local wound conditions and promoted healing in some as yet unknown fashion.

Uniformly, the bacterial counts tended to increase after a Papineau open-bone graft despite the continued use of silver treatments over the graft site. One explanation for this is that after the bone graft, the surface upon which the silver nylon must lie is quite irregular. Therefore, the silver nylon is not in contact with the entire surface area. Diffusion into the interstices of the cancellous bone may be slow. These increased-surface bacterial counts, however, do not seem to interfere with the healing rate of the wound, and gross pus did not develop under the silver dressings. It was also noted that pieces of cortical bone included in the graft were often extruded and appeared to be the nidus for small areas of persistent infection. Only cancellous bone should be used in the open bone graft.

The silver mesh dressing was used in connection with the Papineau open-bone graft and seemed to prevent the purulent phase that often develops with this technique. However, the use of open grafts often nearly doubled the amount of time required for treatment. Thus, the open-graft technique is probably best used only in extreme situations when only a small portion of the original cortical bone remains after surgical debridement.

A number of patients treated had their situation complicated by a nonunion. It was interesting to note that nine of the 12 pa-

A. M.C. 5-18-77

B. 5-31-77

C.

D. M.C. 8-5-79
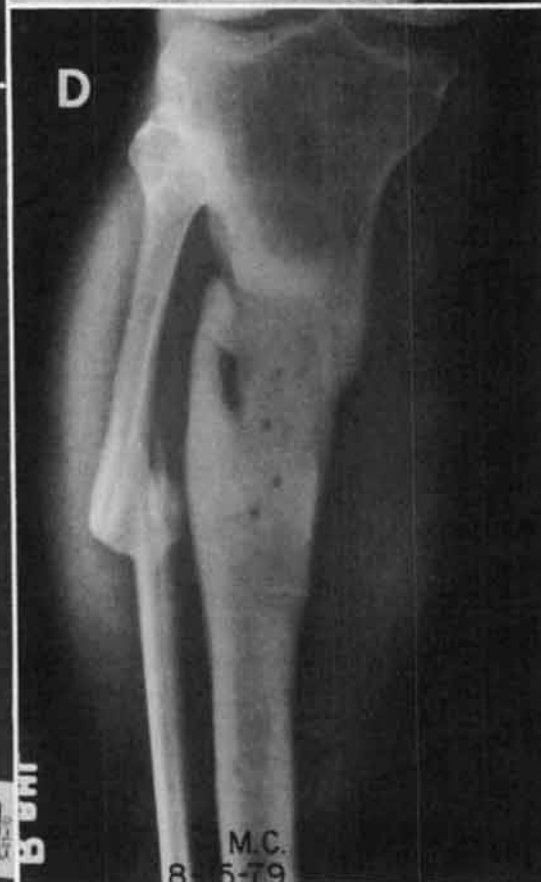
FIGS. 4A–4D. (A) Pre-silver mesh treatment radiograph of an infected segmental nonunion of a 28-year-old white man who had an open fracture two years prior to this exam. It was treated originally by debridement and a cast. He subsequently underwent sequestrectomies and intravenous antibiotic therapy. (B) Clinical status ten days after debridement and first silver mesh application. (C) Clinical status three years after treatment: no drainage or pain present. Successful synostosis and augmentation graft were without complications. (D) Final X-ray appearance.

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tients who originally presented with an infected nonunion went on to some bony healing during treatment for osteomyelitis and showed radiographic evidence of new bone formation at the fracture site. This was most likely owing in part to thorough debridement, immobilization, and a reduction in the infection at the nonunion site due to the silver anode dressings. Again, the possibility that the healing may have been related to current flow *per se* at the nonunion site cannot be dismissed. Other metals, used as the positive electrode, have been shown in several laboratories to interfere with bone production.[7] However, in the present case the actual current density at the silver mesh electrode is several orders of magnitude lower, and is only in contact with bone tissue in the early phase of treatment, *i.e.*, prior to granulation. Also, the nature of oxidative reactions at the silver anodes result largely in the formation of relatively insoluble silver chloride in contrast to the soluble corrosion products at stainless steel, cobalt-chrome, and other metal anodes reportedly not conducive to bone formation.

Although the silver nylon technique has been used mainly in the treatment of osteomyelitis in long bones, it also appears useful in the treatment of residual chronic pyoarthrosis as a preamble to joint fusion. In our series, an infected knee and ankle were both cleared of infection in preparation for fusion of these joints. The affected joint should be immobilized and distracted by an external fixation device to allow a thorough surgical debridement and insertion of a silver mesh electrode.[1] When the wound is cleared of bacteria, the external fixation can be compressed to assist in fusion.

For chronic osteomyelitis it is clear that the treatment is limited by the surgical debridement. Unless the surgeon can completely remove all infected and potentially infected material, the technique is doomed to failure. Resection of the entire infected portion of the bone, the use of external fixation techniques, and subsequent massive bone grafting might be considered in the appropriate case. However, if the extremity beyond the area of osteomyelitis is of marginal functional quality, then amputation is the better course to follow. There can be no claim to have cured the patients presented in this series with the use of the anodic silver dressing. Since the natural history of chronic osteomyelitis includes long periods of quiescence with flareups, only a long-term follow-up study will determine the absolute effectiveness of this treatment. However, it may be a reasonable consideration when standard treatment modalities have failed.

SUMMARY

Twenty-five patients with active, chronic osteomyelitis, resistant to conventional man-

TABLE 3.   Results of Treatment of Chronic Osteomyelitis
(Patients Receiving Open-bone Graft)

Patient Classification	Number of Patients	Completely Epithelized	Persistent Drainage	Amputation	Nonunion United
Osteomyelitis and nonunion	7	3	3	1	6
Osteomyelitis alone	6	4	1	1	—
Total	13	7	4	2	6

agement, were treated with surgical debridement and daily application of electrically activated silver dressings. Sixteen (64%) cases resulted in closed, stable, pain-free wounds, with the remainder resulting in persistent drainage or amputation. Nine of 12 cases complicated by nonunion achieved union. In 13 patients an open-bone graft was performed and silver treatment continued: these tended to remain free of purulent drainage but fared no better than average in the long-term follow-up. The silver anode dressing seems to be an effective aid in the treatment of chronic bone infection when combined with adequate surgical debridement, thereby reducing the need for prolonged systemic antibiotics.

ACKNOWLEDGMENT

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