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Silver in Wound Care—Friend or Foe?: A Comprehensive Review

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Background: Due to its strong antimicrobial activity, silver is a commonly used adjunct in wound care. However, it also has the potential to impair healing by exerting toxic effects on keratinocytes and fibroblasts. The published literature on the use of silver in wound care is very heterogeneous, making it difficult to generate useful treatment guidelines.

Methods: A search of high-quality studies on the use of silver in wound care was performed on PubMed. A detailed qualitative analysis of published articles was performed to evaluate the evidence for the use of silver in infected wounds, clean wounds, burns, and over closed surgical incisions.

Results: Fifty-nine studies were included in this qualitative analysis. We found that, overall, the quality of the published research on silver is poor. While there is some evidence for short-term use of dressings containing nanocrystalline silver in infected wounds, the use of silver-containing dressings in clean wounds and over closed surgical incisions is not indicated. Negative-pressure wound therapy accelerates the healing of contaminated wounds, especially when silver is used as an adjunct. For burns, silver sulfadiazine slows healing and should not be used. Instead, nanocrystalline silver, or alternatives such as octenidine and polyhexanide, lead to less infection and faster healing.

Conclusions: In infected wounds, silver is beneficial for the first few days/weeks, after which nonsilver dressings should be used instead. For clean wounds and closed surgical incisions, silver confers no benefit. The ideal silver formulations are nanocrystalline silver and silver-coated polyurethane sponge for negative-pressure wound therapy. Silver sulfadiazine impairs wound healing. Proper use of silver-containing dressings is essential to optimize wound healing. *(Plast Reconstr Surg Glob Open 2019;7:e2390; doi: 10.1097/GOX.0000000000002390; Published online 9 August 2019.)*

INTRODUCTION

The usefulness of silver for wound treatment has been known since 69 B.C.[1] While silver metal (Ag) has no medicinal activity, silver ion (Ag^+) has a broad antimicrobial spectrum, and is cytotoxic to bacteria, viruses, yeast, and fungi.[2] Ag^+ binds to DNA, RNA, and various proteins, leading to cell death via multiple mechanisms,[3] such as protein and nucleic acid denaturation, increased membrane permeability, and poisoning of the respiratory chain.[4] For this reason, resistance against the silver ion has only rarely been reported.[5–7]

The past few decades have seen a renewed interest in silver as a topical antimicrobial agent. Silver sulfadiazine (SSD) is a very widely used silver formulation, especially in burns. More recently, dressing with nanocrystalline silver has been developed. These novel dressings release silver ions into the wound in a sustained fashion.

While the silver ion has great antimicrobial and bactericidal properties, it is also toxic to fibroblasts when present in high concentration.[1,16,17] Injudicious use of silver-containing dressings can lead to impaired wound healing.[45] It is imperative, therefore, that guidelines be developed on the proper use of silver-containing dressings.

Our purpose in this study was to evaluate the existing evidence on the use of silver in wound care. The questions that we sought to answer were:

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1) What is the quality of the published studies on the use of silver in wound care?
2) What are the advantages and disadvantages of various silver delivery systems?
3) What is the evidence for the use of silver-containing dressings in infected and heavily contaminated wounds?
4) What is the evidence for the use of silver-containing dressings in clean and clean-contaminated wounds?
5) What is the evidence for the use of silver-containing dressings in burns?
6) What is the evidence for the use of silver-containing dressings over closed surgical incisions?
7) What is the optimal strategy for the use of silver-containing dressings?
8) How does silver compare to alternative, lesser known agents?

METHODS

A PubMed literature search was performed using the following search parameters: silver AND (antimicrobial OR antibacterial) AND wound AND randomized; Silver AND epithelialization AND randomized; Silver AND negative pressure. The results were screened manually to exclude articles that were not relevant to our study (not about wound care), not in English, or which did not compare a silver-containing product to another product. We also excluded clinical studies with fewer than 20 patients. The articles were manually screened and duplicates were excluded. The remaining articles were analyzed in detail qualitatively, to extract answers to our study questions. The articles analyzed in this study are shown in **Table 1**.

RESULTS

Quality of the Evidence

We found a total of 490 published studies using our PubMed searches. Four hundred and thirty-one articles were excluded for the following reasons: 149 were not relevant to our topic, 31 were not in English, 34 were duplicate articles across searches, and 196 did not have a nonsilver comparison group. We were thus left with 59 relevant studies. This included 8 basic science or animal studies (no level of evidence), 33 randomized-controlled trials (level 1 evidence), 1 retrospective study (level 3 evidence), 1 case series (level 4 evidence), 14 systematic reviews of randomized-controlled trials (level 1 evidence), and 2 qualitative review articles (no level of evidence).

Most prior reviews found that the quality of the published data on the use of silver in wound care is poor.[8,9] This is due to the fact that these studies use inconsistent, and sometimes subjective, outcomes measures, such as pain with dressing change, days until reepithelialization, number of dressing changes until reepithelialization, wound size reduction at various time points, presence of infection, etc. In addition, many of the published studies are funded,[10,11] or even written, by manufacturers of silver-containing dressings.[12]

Silver Formulations, Effectiveness, and Toxicity

While the silver ion is a very powerful bactericidal agent, it also has toxic systemic and local effects. The systemic toxic effects are due to silver absorption through the wound, leading to argyria, which manifests as irreversible gray skin discoloration and loss of night vision.[13–15] However, systemic toxicity is rare because serum silver is rapidly excreted in urine and feces.[14]

The local toxic effects of silver are more likely to occur, and are due to the cytotoxicity of the silver ion against keratinocytes and fibroblasts. Poon et al found that in monolayer cultures of keratinocytes and fibroblasts, silver became toxic to cells at a concentration of 33 ppm or greater.[16] However, when fibroblasts were cultured in a collagen lattice, replicating more closely in vivo conditions, the toxic concentration increased to 60 ppm. On the other hand, for the silver ion to have effective bactericidal activity, a concentration of 30 to 40 ppm is needed.[1]

Therefore, the ideal silver-containing dressing would maintain a *sustained (several days), therapeutic (≥30 ppm)* silver ion concentration in the wound without causing *systemic* or *local (≤60 ppm)* silver toxicity.

SSD contains silver, glycols, alcohols, and sulfadiazine (an antibiotic).[1] SSD has been found to release an extremely high initial silver concentration into the wound (up to 3,176 ppm),[17] which rapidly decreases to below therapeutic levels. SSD can therefore have high local toxicity, without providing the sustained silver levels necessary for microbicidal activity. In addition, propylene glycol, which is part of the SSD formulation, is known to cause bone marrow toxicity and leukopenia.[5,18]

Newer dressings contain silver in a nanocrystalline state and elute silver into the wound in a sustained fashion, maintaining a concentration of up to 70 ppm for several days (slightly above the toxic threshold for keratinocytes and fibroblasts).[16] These newer formulations include Silverlon (silver-coated nylon, Argentum Medical, Geneva, Ill.), Acticoat (silver-coated polyethylene, Smith & Nephew, London, UK), Mepilex Ag (silver-coated foam, Mölnlycke Healthcare, Norcross, Ga.), Mepitel Ag (silver-coated silicone, Mölnlycke Healthcare, Norcross, Ga.), Aquacel Ag (silver-coated cellulose hydrofiber, ConvaTec, Reading, UK), Promogran Prisma Ag (KCI, San Antonio, Tex.), and V.A.C. GranuFoam Silver (silver-coated polyurethane sponge, KCI, San Antonio, Tex.), amongst others. There are advantages and disadvantages to each of these formulations: Acticoat tends to adhere to the wound bed and can be painful upon removal,[19] unlike Mepitel Ag and Mepilex Ag, both of which have a silicone interface, allowing them to adhere to the surrounding normal skin, but not to the wound itself (**Table 2**).[19] Promogran Prisma contains collagen, which acts as a sacrificial substrate for matrix metalloproteinases, enhancing wound healing.[20,21] The silver-coated polyurethane negative-pressure wound therapy (NPWT) sponge combines the advantages of NPWT with a sustained release of 20 to 40 ppm of silver,[22,23] which is below the toxic threshold to keratinocytes and fibroblasts.

Table 1. Summary of the Articles Included in This Study

Article	Type of Study	Level of Evidence	No. Subjects (for Human Studies)	Purpose	Results
Infected wounds					
Abarca-Buis, 2014	Basic science	-	-	Evaluate silver ion elution from silver-coated polyurethane NPWT sponge	Silver ion concentration in wound exudate rises over several days
Ellenrieder, 2015	Basic science	-	-	Evaluate effectiveness of polyurethane versus silver-coated polyurethane NPWT sponges at reducing MRSA colony counts	NPWT with silver-coated polyurethane sponge decreases MRSA colony counts more than NPWT with polyurethane sponge
Ngo, 2012	Basic science	-	-	Compare biofilm formation with polyurethane NPWT sponge versus silver-coated polyurethane NPWT sponge	NPWT with polyurethane sponge reduces biofilm NPWT with silver-coated polyurethane sponge reduces biofilm even more
Sachsenmaier, 2013	Basic science	-	-	Compare activity of polyurethane NPWT sponge versus silver-coated polyurethane NPWT sponge against *S. aureus* and *S. epidermidis*	Silver-coated polyurethane NPWT sponge achieves a larger zone of bacterial inhibition than plain polyurethane sponge With silver-coated polyurethane NPWT sponge, wound silver level reaches a peak at 5 days
Stinner, 2011	Basic science	-	-	Compare activity of polyurethane NPWT sponge versus silver dressing and polyurethane NPWT sponge against *S. aureus* and *P. aeruginosa*	The addition of a silver dressing to polyurethane sponge enhances the antimicrobial activity of NPWT
Meekul, 2017	RCT	1	39	Compare healing, pain, and cost with silver alginate versus gauze	Silver alginate reduces pain compared to gauze, but does not accelerate healing or decrease cost
Vermeulen, 2007	Systematic review	1	847	Compare healing and odor with silver-containing dressing versus plain foam	Silver-containing dressing does not accelerate healing, but improves wound odor
Gunal, 2015	Retrospective	3	21	Compare polyurethane to silver-coated polyurethane sponges for NPWT for infected diabetic foot ulcers	NPWT with polyurethane sponge accelerates the healing of diabetic foot ulcers NPWT with silver-coated polyurethane sponge accelerates healing even more.
Qian, 2017	Basic science	-	-	Compare healing with SSD versus plain cream for chronic wounds	SSD slows epithelialization and increases hypertrophic scar formation
Applewhite, 2018	Review	-	-	Evaluate healing with NPWT and promogran prisma in chronic wounds	Promogran prisma accelerates healing due to its collagen component acting as a sacrificial substrate for proteases in the wound. NPWT promotes granulation tissue formation
Innes, 2001	RCT	1	17	Compare epithelialization with Acticoat versus occlusive, silver-free dressing for skin graft donor sites	Occlusive, silver-free dressing leads to faster epithelialization and better scar than Acticoat
Krasowski, 2015	RCT	1	80	Compare epithelialization with silver-containing dressing versus octenidine for lower-extremity ulcers	Octenidine leads to faster healing and less pain than silver-containing dressing
Michaels, 2009	RCT	1	213	Compare healing with nanocrystalline silver versus non-silver-containing dressings for lower-extremity venous ulcers	Nanocrystalline silver does not accelerate healing of lower-extremity venous ulcers
Norman, 2016	Systematic review	1	576	Compare healing with silver-containing dressings versus gauze for pressure ulcers	Silver-containing dressings do not accelerate pressure ulcer healing
O'Meara, 2014	Systematic review	1	4,486	Compare healing with silver-containing dressings versus standard dressings for lower-extremity venous ulcers	Silver-containing dressings do not accelerate lower-extremity ulcer healing
Storm-Versloot, 2010	Systematic review	1	2,066	Compare infection rates with silver-containing dressings versus non-silver-containing dressings for chronic wounds	Silver-containing dressings do not reduce infection rates
Bergin, 2006	Systematic review	1	0	Evaluate effectiveness of silver-containing dressings for diabetic foot ulcers	There are no good RCTs evaluating silver for diabetic foot ulcers

(*Continued*)

Table 1. (*Continued*)

Article	Type of Study	Level of Evidence	No. Subjects (for Human Studies)	Purpose	Results
Chambers, 2007	Systematic review	1	1,108	Evaluate effectiveness of silver-containing dressings for lower-extremity ulcers	Silver-containing dressings do not accelerate lower-extremity ulcer healing Quality of evidence for silver is poor
Dumville, 2015	Systematic Review	1	336	Evaluate effectiveness of silver alginate for pressure ulcers	Silver alginate does not accelerate pressure ulcer healing Quality of evidence for silver is poor
Karr, 2013	Case series	4	20	Compare healing with polyurethane NPWT sponge versus Silverlong + polyurethane NPWT sponge for chronic wounds	Adding Silverlon to NPWT reduces healing time and cost
Toussaint, 2015	Basic science	-	-	Compare epithelialization with Mepilex Ag versus triple antibiotic ointment	Triple antibiotic ointment achieves faster epithelialization and less scarring than Mepilex Ag
Selcuk, 2012	Basic science	-	-	Compare activity of SSD, mupirocin, Acticoat, and octenidine against *Acinetobacter baumannii*	Highest antimicrobial activity is achieved by Acticoat, followed by octenidine, then mupirocin, then SSD
Khorasani, 2009	RCT	1	30	Compare epithelialization with SSD versus aloe vera	SSD leads to slower epithelialization
Shahzad, 2013	RCT	1	50	Compare epithelialization and pain with SSD versus aloe vera	SSD leads to more pain and slower epithelialization
Baghel, 2009	RCT	1	78	Compare epithelialization and infection with SSD versus honey	SSD leads to more infections and slower epithelialization
Shah, 2013	RCT	1	78	Compare epithelialization and infection with SSD versus honey	SSD leads to more infections and slower epithelialization
Sami, 2011	RCT	1	50	Compare epithelialization and infection with SSD versus honey	SSD leads to more infections and slower epithelialization
Mujalde, 2014	RCT	1	110	Compare epithelialization, cost and infection with SSD versus honey	SSD leads to more infections, higher cost, and slower epithelialization
Mashhood, 2006	RCT	1	50	Compare epithelialization, pain and infection with SSD versus honey	SSD leads to more infections, more pain, and slower epithelialization
Varas, 2005	RCT	1	47	Compare pain with SSD versus Acticoat	SSD leads to more pain
Muangman, 2006	RCT	1	50	Compare pain with SSD versus Acticoat	SSD leads to more pain
Huang, 2007	RCT	1	98	Compare epithelialization with SSD versus Acticoat	SSD leads to slower epithelialization
Caruso, 2006	RCT	1	84	Compare epithelialization and cost with SSD versus Aquacel Ag	SSD leads to slower epithelialization and higher cost
Muangman, 2010	RCT	1	70	Compare epithelialization and cost with SSD versus Aquacel Ag	SSD leads to slower epithelialization and higher cost
Barret, 2000	RCT	1	20	Compare epithelialization, hospital length of stay and cost with SSD versus Biobrane	SSD leads to slower epithelialization, longer hospital stay, and higher cost
Gerding, 1988	RCT	1	30	Compare epithelialization, number of dressing changes and cost with SSD versus Biobrane	SSD leads to slower epithelialization, more dressing changes, and higher cost
Bugmann, 1998	RCT	1	76	Compare epithelialization and number of dressing changes SSD versus Mepitel	SSD leads to slower epithelialization and more dressing changes
Subrahmanyam, 1998	RCT	1	50	Compare epithelialization with honey versus SSD	Honey achieves faster epithelialization than SSD
Shahzad, 2013	RCT	1	50	Compare epithelialization and pain with aloe vera versus SSD	Aloe vera achieves faster epithelialization and less pain than SSD
Silverstein, 2011	RCT	1	101	Compare epithelizaliation, pain and cost with Mepilex Ag versus SSD	Mepilex Ag achieves faster epithelialization, less pain, and less cost than SSD
Yarboro, 2013	RCT	1	24	Compare epithelialization with Aquacel Ag versus SSD	Aquacel Ag achieves less pain and requires fewer dressing changes
Adhya, 2015	RCT	1	54	Compare epithelialization with nanocrystalline silver-containing hydrogel versus SSD	Burn epithelialization is faster with nanocrystalline silver-containing hydrogel than with SSD

(*Continued*)

Table 1. (*Continued*)

Article	Type of Study	Level of Evidence	No. Subjects (for Human Studies)	Purpose	Results
Gee Kee, 2015	RCT	1	96	Compare epithelialization with Mepilex Ag versus Acticoat	Acticoat has slower healing and more pain compared to Mepilex Ag
Genuino, 2014	RCT	1	50	Compare epithelialization with SSD versus petrolatum	Petrolatum leads to faster epithelialization than SSD
Godhi, 2017	RCT	1	60	Compare epithelialization with SSD versus sucralfate	Sucralfate leads to faster epithelialization than SSD
Brown, 2016	RCT	1	89	Compare epithelialization with Aquacel Ag versus Acticoat	No difference in epithelialization or infection between Aquacel Ag and Acticoat
Vloemans, 2014	Systematic review	1	266	Compare epithelialization, pain and length of hospital stay with SSD versus Biobrane	Biobrane achieves faster epithelialization, shorter length of stay, and less pain than SSD
Wasiak, 2013	Systematic review	1	1,307	Compare epithelialization and infection with various burn dressings	SSD has the worst epithelialization and infection outcomes in burns
Heyneman, 2016	Systematic review	1	-	Compare epithelialization with SSD versus nanocrystalline silver	Nanocrystalline silver dressings lead to faster epithelialization than SSD
Gravante, 2009	Systematic review	1	285	Compare infection and pain with SSD versus nanocrystalline silver	Nanocrystalline silver leads to less infection and pain than SSD
Aziz, 2017	Systematic review	1	717	Compare epithelialization and infection with honey versus SSD	Honey results in faster epithelialization and less infection than SSD
Vieira, 2018	Review	-	-	Evaluate the effectiveness of incisional NPWT in high-risk incisions	Incisional NPWT improves wound outcomes
Abboud, 2016	RCT	1	110	Compare pain with Silverlon versus Gauze	Silverlon reduces pain
Biffi, 2014	RCT	1	112	Compare infection with Aquacel Ag versus Gauze	Aquacel Ag does not decrease infection compared to gauze
Newman, 2019	RCT	1	160	Compare wound complications with incisional NPWT versus silver dressing	Incisional NPWT decreases wound complications compared to silver dressings
Ozaki, 2015	RCT	1	500	Compare infection with Acticoat versus Gauze	Acticoat does not reduce infection rates
Ruiz-Tovar, 2015	RCT	1	147	Compare infection with silver-containing dressing versus mupirocin versus gauze	Silver-containing dressings have more infections than mupirocin ointment
Dumville, 2016	Systematic Review	1	5,718	Compare infection with silver-containing dressings versus standard dressings	Silver-containing dressings do not reduce infection rates
Li, 2017	Systematic review	1	2,196	Compare infection with silver-containing dressings versus standard dressings	Silver-containing dressings do not reduce infection rates

Abbreviations: MRSA, Methicillin-resistant *Staphylococcus aureus*; NPWT, Negative-pressure wound therapy; RCT, Randomized control trial; SSD, Silver sulfadiazine

Table 2. Commonly Used Dressings Containing Nanocrystalline Silver

Product	Manufacturer	Composition	Properties
Silverlon	Argentum Medical, Geneva, Ill.	Silver-coated nylon	Highest silver concentration
Acticoat	Smith & Nephew, London, UK	Silver-coated polyethylene	Can adhere to the wound bed, causing pain with removal
Mepilex Ag	Mölnlycke Healthcare, Norcross, Ga.	Silver-coated foam with silicone interface	Adheres to normal skin and not to wound bed
Mepitel Ag	Mölnlycke Healthcare, Norcross, Ga.	Silver-coated silicone	Adheres to normal skin and not to wound bed
Aquacel Ag	ConvaTec, Reading, UK	Silver-coated cellulose hydrofiber	Absorbs exudate
Promogran Prisma Ag	KCI, San Antonio, Tex.	Oxidized regenerated cellulose, collagen, and silver	Contains collage, which acts as a sacrificial substrate
V.A.C. GranuFoam Silver	KCI, San Antonio, Tex.	Silver-coated polyurethane sponge	Combines advantages of NPWT and silver

Infected Open Wounds

Wound infection in the form of planktonic organisms or biofilm is known to impair wound healing. Foreign microorganisms in an open wound deplete local micronutrients and oxygen, and produce toxins that impair healing mechanisms.[24] Therefore, eradicating infection is a prerequisite to obtaining a healed wound.

Biofilm is especially difficult to treat, because it enhances bacterial recalcitrance to antimicrobials. This is due to molecules within the extracellular polymeric substance of the biofilm that interfere with antibiotic function[25] or physically shield the bacteria.[26] One strategy to combat biofilm and jumpstart healing is by disrupting the biofilm and displacing the bacteria into a planktonic (rather than sessile) state, where they are more susceptible to systemic antibiotics. This can be achieved with sharp debridement of the wound. However, even with adequate debridement, even a few remaining bacteria can recreate the biofilm within 48 hours.[27]

A combination of surgical debridement and long-acting topical antimicrobials has been used as an effective method to combat biofilm.[28] The ideal topical antimicrobial agent should be nontoxic to host tissue, have a broad antimicrobial spectrum, and maintain sustained levels in the wound until all infection is eradicated.

Nanocrystalline silver satisfies the above requirements. Several randomized-controlled trials and systematic reviews have demonstrated that dressings that contain nanocrystalline silver are beneficial for wounds that have high bacterial counts and bad odor.[29,30] Silver-containing dressings also have the advantage of requiring less frequent dressing changes than nonsilver-containing dressings, leading to lower pain levels.[31]

NPWT has been shown to decrease bacterial counts and accelerate healing in contaminated wounds.[32,33] The addition of silver to the sponge plays a synergistic role with NPWT. The use of silver-coated polyurethane sponges has been shown to reduce bacterial counts of biofilm-causing organisms, such as *Pseudomonas aeruginosa* and *Staphylococcus aureus*,[34,35] including MRSA,[36] more than plain polyurethane sponges, leading to faster healing in infected diabetic foot ulcers.[37] The synergistic effects of silver and NPWT can be achieved by using a silver-coated polyurethane sponge or by adding a silver layer under a plain polyurethane sponge.[38]

Noninfected Open Wounds

In contrast, there is very little evidence in favor of silver for noninfected wounds. Multiple meta-analyses and randomized-controlled trials found that nanocrystalline silver-containing dressings were no more effective than gauze for lower-extremity ulcers,[8,39–41] chronic noninfected wounds,[42] and pressure ulcers.[9,43] In fact, for noninfected, open wounds, silver-containing dressings have been found to increase cost[40] and delay epithelialization. In an animal study of clean burns, Mepilex Ag had slower healing than triple antibiotic ointment.[44] For skin graft donor sites, Acticoat has been found to delay epithelialization by more than 50% when compared to occlusive dressings.[45] As mentioned above, dressings containing nanocrystalline silver lead to silver ion concentrations in the wound of up to 70 ppm, which is above the toxic threshold for keratinocytes and fibroblasts.[16]

Burns

Even though SSD is widely used for the treatment of second-degree burns,[46] it has been shown to have some of the worst outcomes in burn treatment, in terms of infection and epithelialization.[47,48] It is less effective than aloe vera,[49,50] sucralfate,[51] petrolatum gel,[52] honey,[53–58,85,86] and Biobrane (nylon, silicone and collagen composite, Smith & Nephew, London, UK).[59–62] In addition to slowing epithelialization, SSD has been shown to increase the rate of hypertrophic scar formation.[63]

In contrast, dressings containing nanocrystalline silver have been found to be superior to SSD and to silver-free dressings for burns, in terms of epithelialization, infection, pain, and cost.[18,64–73] In addition, dressings containing nanocrystalline silver significantly reduce the cost of care when compared to SSD.[57,61,62,66,70,71,73] In an animal study examining several dressings for burns, Selcuk et al found that the most effective dressing against *Acinetobacter baumannii* was Acticoat, followed by octenidine, then mupirocin, with SSD being the least effective dressing.[74] Brown et al found that Aquacel Ag and Acticoat were equivalent for burn healing.[75]

Closed Surgical Incisions

One study found that the use of Silverlon as a dressing over closed surgical incisions resulted in less pain.[2] However, there is no evidence that the use of a silver-containing dressing to cover a closed surgical incision reduces infection or accelerates healing. This has been demonstrated in numerous randomized-controlled trials examining both clean and clean-contaminated operations.[76–80] One

surgical dressing that has been shown to reduce infection, wound healing complications, and reoperation is incisional NPWT, such as Prevena (Silver-impregnated foam, KCI, San Antonio, Tex.) or plain polyurethane foam with an NPWT machine.[81] Multiple studies have demonstrated the effectiveness of incisional NPWT in high-risk incisions.[82–84] Incisional NPWT is effective regardless of whether a plain polyurethane sponge or a silver-coated polyurethane sponge is used.[85]

Alternatives to Silver

There are several silver-free antimicrobial topical wound treatments that have been shown to be effective. Some of these dressings are widely used in Europe, but not in the United States.

Octenidine dihydrochloride (OCT) is a surfactant that can be used as a topical antimicrobial with a very broad spectrum. It has been shown to be less toxic to keratinocytes and fibroblasts than silver, leading to faster wound healing.[86] Polihexanide (PHMB) is also an antimicrobial with a very broad spectrum, which has been shown to have superior efficacy as a wound washing agent when compared to normal saline.[87] There is no resistance to either OCT or PHMB, and both have strong activity against MRSA, VRE, and *Candida albicans*.[3] Both OCT and PHMB have been used successfully as instillation solutions for NPWT in heavily contaminated wounds.[3]

Finally, medical-grade honey has been shown to be a valuable option for wound management. Honey has a low pH and generates a low, sustained concentration of hydrogen peroxide, which gives it broad antimicrobial activity against both Gram-positive and Gram-negative organisms, without toxic effects on tissue.[88] Honey leads to faster burn epithelialization than SSD.[89]

DISCUSSION

Our qualitative literature review on silver has limitations: it is not a quantitative systematic review. This is due to the heterogeneity of the outcome measures in the published literature, which makes it difficult to pool data and generate meaningful conclusions. However, from our qualitative analysis, we can provide the following strategies for the proper use of silver in wound care:

1) SSD slows healing, and should be avoided in wound care, including in burn treatment. In addition, it should not be used as the gold standard for burn research.
2) In infected wounds, dressings containing nanocrystalline silver are helpful in the early treatment phase (first 2–3 weeks) to reduce bacterial counts and mitigate wound odor. It is best used as an adjunct to surgical debridement. As the wound becomes cleaner, silver-free dressings should be used to minimize toxicity towards keratinocytes and fibroblasts.[90] Silver-containing dressings should not be used long-term.[3,10]
3) During the early phase of treatment, NPWT with a silver sponge is especially useful, because it combines the advantages of NPWT with the antimicrobial properties of silver. In addition, the silver ion concentration produced is in the wound is 20 to 40 ppm, which is bactericidal, but lower than the toxic threshold to keratinocytes and fibroblasts.[16,22,23]
4) In clean wounds, there is no role for the use of silver-containing dressings, as these can delay epithelialization. As discussed above, these dressings elute silver ion up to a concentration of 70 ppm, which is within the toxic range for keratinocytes and fibroblasts.5)Silver-containing dressings have not been shown to decrease the risk of infection when used over closed surgical incisions. One study found decreased pain when silver-containing dressings were used over a closed incision. For high-risk closed surgical incisions (in patients who smoke, who have diabetes, etc.), the use of incisional NPWT with a plain polyurethane sponge lowers the risk of wound healing complications.
6) Alternatively, lesser known topical wound treatments, such octenidine and polyhexanide, may produce good outcomes, especially when used as instillation solutions for NPWT.

CONCLUSIONS

The judicious and selective use of silver in wound care in the correct situation can help accelerate healing, primarily as an adjunct to surgical debridement in infected wounds. Silver-containing dressings, especially nanocrystalline silver, are most useful in infected wounds, but do not provide added benefit in clean, noninfected wounds, and may slow the healing of those wounds. Moreover, silver-containing dressings do not confer an added advantage when applied over closed surgical incisions. In burns, dressings containing nanocrystalline silver are beneficial, but SSD leads to slower epithelialization, higher cost, more infections, and more pain. Plastic surgeons must be familiar with these nuances to optimize patient outcomes.

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