Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.elsevier.com/locate/burns

Antimicrobial efficacy of a novel silver hydrogel dressing compared to two common silver burn wound dressings: Acticoat™ and PolyMem Silver®

Benjawan Boonkaew [a,b], *Margit Kempf* [a], *Roy Kimble* [a], *Pitt Supaphol* [b], *Leila Cuttle* [a,*]

[a] *Centre for Children's Burns and Trauma Research, Queensland Children's Medical Research Institute, The University of Queensland, Brisbane, Queensland, Australia*

[b] *The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok, Thailand*

ARTICLE INFO

Article history:
Accepted 20 May 2013

Keywords:
Silver
Dressing
Antimicrobial
Live/Dead
Disc diffusion
Broth culture

ABSTRACT

A novel burn wound hydrogel dressing has been previously developed which is composed of 2-acrylamido-2-methylpropane sulfonic acid sodium salt with silver nanoparticles. This study compared the antimicrobial efficacy of this novel dressing to two commercially available silver dressings; Acticoat™ and PolyMem Silver®. Three different antimicrobial tests were used: disc diffusion, broth culture, and the Live/Dead® Baclight™ bacterial viability assay. Burn wound pathogens (*P. aeruginosa*, MSSA, *A. baumannii* and *C. albicans*) and antibiotic resistant strains (MRSA and VRE) were tested. All three antimicrobial tests indicated that Acticoat™ was the most effective antimicrobial agent, with inhibition zone lengths of 13.9–18.4 mm. It reduced the microbial inocula below the limit of detection (10^2 CFU/ml) and reduced viability by 99% within 4 h. PolyMem Silver® had no zone of inhibition for most tested micro-organisms, and it also showed poor antimicrobial activity in the broth culture and Live/Dead® Baclight™ assays. Alarmingly, it appeared to promote the growth of VRE. The silver hydrogel reduced most of the tested microbial inocula below the detection limit and decreased bacterial viability by 94–99% after 24 h exposure. These results support the possibility of using this novel silver hydrogel as a burn wound dressing in the future.

1. Introduction

The increase of multi-resistant bacterial strains and fungal infections in burn wounds requires the development of new burn wound medications. Various silver products have become efficient alternative agents in burn care instead of antibiotics [1] and there are a number of studies reporting their efficacy against a broad range of micro-organisms [2–4]. There are several mechanisms by which silver ions and their salts have antimicrobial effects. Silver is believed to interact with thiol groups of key respiratory enzymes [5] as well as interrupting the hydrogen bonding of microbial DNA [6] and it has been shown to damage bacterial cell membranes [7]. The powerful antimicrobial actions of silver nano particles (SNPs) have been previously reported [8,9]. The decrease in size and increase in surface area of SNPs increases their antimicrobial efficacy, but the mechanism of action is unclear due to the

* *Corresponding author at*: The University of Queensland, Centre for Children's Burns and Trauma Research, Royal Children's Hospital, Herston Road, Herston, Queensland 4029, Australia. Tel.: +61 7 3636 9067; fax: +61 7 3636 5578.
E-mail address: L.Cuttle@uq.edu.au (L. Cuttle).

0305-4179/$36.00
http://dx.doi.org/10.1016/j.burns.2013.05.011

difficulty in detection of the unstable silver nano form. Silver treatments used in burn care have also been reported to be toxic to human cells [10,11]. The balance between the cytotoxicity and antimicrobial properties of each dressing should always be considered for each wound environment.

Previously, our research group has developed a novel silver hydrogel dressing which is composed of 2-acrylamido-2-methylpropane sulfonic acid (AMPS) sodium salt and silver nano particles. Preliminary *in vitro* cytotoxic studies in mammalian cells indicate the novel dressing has less cytotoxicity compared to some commercial silver agents used in burn care.

This study compares the antimicrobial efficacy of the novel silver hydrogel dressing to two common dressings (Acticoat™ and PolyMem Silver®) used in our burn centre. The same silver hydrogel dressing that had been kept at room temperature for one year was also tested for efficacy. Three different antimicrobial assays were used, including; the disc diffusion method, broth culture and the Live/Dead® Baclight™ bacterial viability assay (Molecular Probes, Life Technologies, Australia).

2. Materials and methods

2.1. Burn wound dressings

Novel burn wound dressings based on a 2-acrylamido-2-methylpropane sulfonic acid sodium salt (AMPS-Na^+) hydrogel were created in our laboratories. Silver nitrate was added to a concentration of 5 mM in 40% AMPS sodium salt aqueous solution (pH 7.0 ± 0.1) in the presence of *N*, *N*′-methylenebis(acrylamide) (MBA) crosslinker. The mixture (pH 7.0 ± 0.1) was loaded into a nylon bag and exposed to gamma irradiation at 25 kGy to form silver nanoparticle-infused hydrogel. Neat hydrogel was similarly produced without addition of silver nitrate. The physical and mechanical properties of the neat and silver hydrogels were assessed and found to support their use as potential burn wound dressings. The water vapor transmission rate (WVTR) showed that the hydrogels can be used to decrease body fluid loss and maintain a moist environment for burn wounds (97.5 ± 5.0 g/m^2/h for neat hydrogel, 95.2 ± 4.9 g/m^2/h for 5 mM hydrogel). The absorptive capacities of the hydrogels (neat hydrogel 7.3 ± 0.6 mL/cm^2, 5 mM hydrogel 6.7 ± 0.2 mL/cm^2) confirmed that the hydrogels could potentially absorb exudate from wounds. The silver content in the hydrogel dressing was 0.043–0.054 mg/cm^2 (Table 1) and the cumulative amount of silver released from the silver hydrogel when submerged in simulated body fluid solution (pH 7.4, 35 °C) for 72 h was 75.9%, indicating it can be used as a silver-releasing dressing for up to 72 h. Transmission Electron Microscope images of the silver released from the silver hydrogel indicated that the size of the nanosilver particles were in the range of 2.1–15.6 nm. Silver was incorporated into the hydrogel to help prevent wound infection and the antimicrobial efficacy of the dressing was assessed in this study. Two of the commonly used silver dressings at our burn centre (Acticoat™ and PolyMem Silver®) were used as a comparison to the novel silver hydrogel dressing (Table 1, Fig. 1). Silver hydrogel[a] kept at room temperature for 1 year was also tested to estimate its expiration timeframe as most commercial burn dressings are be able to be stored at room temperature. The neat hydrogel (containing no silver) served as negative control for the disc diffusion method.

2.2. Micro-organisms studied

This study focused on assessing the efficacy of silver dressings on two antibiotic resistant strains (methicillin resistant *Staphylococcus aureus* (MRSA) and vancomycin resistant *Enterococus* (VRE)). *Pseudomonas aeruginosa* was also included as it is one of the most common bacteria (as well as MRSA) found in infected burns. *Candida albicans* was included to observe the efficacy of silver dressings on fungi infected wounds. Methicillin sensitive *S. aureus* (MSSA) and *Acinetobacter baumannii* were added for study when *P. aeruginosa* and *C. albicans* could not be tested with the Live/Dead® Baclight™ bacterial viability assay (Table 2).

2.3. Dressing preparation

For the disc diffusion method, the size of each original dressing was optimized in order to obtain a 1.0 cm × 1.0 cm swelled dressing after 24 h treatment. Acticoat™ was activated by dipping in sterile water before the treatment. PolyMem Silver® and hydrogels were soaked in 0.85% saline solution to swell before being applied. The neat hydrogel was used as a negative control.

Similar to the disc diffusion method, for antimicrobial activity assays (broth culture and Live/Dead® Baclight™ bacterial viability kit), the size of each dressing was optimized

Table 1 – Burn dressings tested.

Product name	Manufacturer	Basic composition	Silver form	Silver content
Acticoat™	Smith & Nephew (Hull, UK)	An absorbent polyester core laminated between two outer layers of silver coated polyethylene mesh	Nanocrystalline silver	0.84–1.34 mg/cm^2
PolyMem Silver®	Ferris MFG Corp. (Burr Ridge, IL, US)	Polyurethane foam containing F68, superabsorbent starch	Silver nanoparticle	Minimum 0.124 mg/cm^2
Neat hydrogel	Developed in our lab	AMPS sodium salt hydrogel	None	None
Novel silver hydrogel	Developed in our lab	AMPS sodium salt hydrogel	Silver nanoparticle	0.043–0.054 mg/cm^2
Novel silver hydrogel[a]	Developed in our lab	AMPS sodium salt hydrogel	Silver nanoparticle	Maximum 0.054 mg/cm^2

[a] Denotes kept for one year at room temperature.