Intelligent Wound Dressing for Wound Infection Management and Diagnosis at Point of Care


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Abstract

Here we present the development of a prototype wound dressing that can detect the infection in wounds. The dressing is made of a hydrated agarose sheet in which a mixture of fluorescent dye containing vesicles and agarose are dispersed within the hydrogel matrix. The release of dye is triggered by the interaction of vesicles with virulence factors, secreted within the biofilm by population-density-dependent quorum sensing, from clinical pathogens of Staphylococcus aureus, Pseudomonas aeruginosa and Enterobacteriaceae (SPE pathogen group). The dressing only activates when in contact with wound biofilm of pathogenic bacteria in infected wounds, but not to the biofilms of non-pathogenic bacteria.

Introduction

Wound infection is a global problem and approximately 13,000 patients with burns require treatment in hospitals in England and Wales every year. 1, 5 Burn wound infection is currently diagnosed by clinical observation and judgement, and standard microbiological culture to identify causative pathogens usually take several days. 1, 5 There are evidences that the delayed healing due to persistent infection is closely related to wound biofilm formation. 1, 5 If pathogens present, this will cause tissue damage by further colonization, extensive infection and formation of difficult-to-treat biofilm in wounds which inevitably require aggressive antibiotic treatments. 2 Early indication of infection at point of care and ability to rapidly distinguish between infected and non-infected states of wound will help in clinical decision making, prevent over-management by inappropriate use of antibiotics, improve patient outcomes and reduce costs of treatment.

Methods, Results and Discussion

1) Vesicles and Mode of Actions Detection

Vesicles of 200 nm in diameter were made of 1,2-dipalmitoyl-sn-glycerol-3-phosphocholine (DPPC), cholesterol and 10,12-tricosadiyonic acid (TCDA) by extrusion. 2 Encapsulated inside vesicles were 50 mmol dm⁻³ self-quenched 5,6-carboxyfluorescein (CF) dyes, characteristic for pathogens, such as Pseudomonas aeruginosa, delta haemolysin and harrimolysid lysed vesicles and triggered the release of visible dyes (figure 3). 3, 4 Expression of such virulence factors as S. aureus and P. aeruginosa was demonstrated by growing them on the blood agar plate (figure 2).

2) Dressing Design and Prototype Development

The vesicles were mixed with molten 0.7% agarose and filled in the patterned wells of moulded 2% agarose dressing (figure 3a) . 5 This design allows the diffusion of toxins from infected wound to the dressing, following the fluorescent dyes release from vesicles within hydrogel matrices (figure 3c).

3) Clinical Assessment of Prevalent Burn Wound Pathogens

An independent assessment of 55 burn wounds at Queen Victoria Hospital (QVH) at East Grinstead, U.K. provided that more than 75% of “at risk” wounds were colonized by species of pathogenic bacteria, of which above 80% were identified as S. aureus, P. aeruginosa and E. faecalis strains (SPE pathogens) (figure 4).

4) in Vivo Colony Wound Biofilm Model

For the evaluation on prototype dressing performance, a model wound biofilm was developed by growing biofilms on a nano-porous polycarbonate membrane (200 nm in diameter) on top of nutrient agar, incubated at 37°C (figure 5a, b). Growth of biofilm was characterized by Scanning Electron Microscope (figure 5c).

5) Dressing Response to In Vivo Model Wound Biofilms

In vivo colony wound biofilms, produced from burn pathogens, S. aureus and P. aeruginosa, and control E. coli were grown for 24, 48 and 72 hours and tested with prototype dressings (figure 6a). Within 5 hours of incubation with biofilms, the fluorescent response was clearly observed in dressings (figure 6b).

6) Ex Vivo Porcine Burn Wound Model and Dressing Response

Using organic porcine skins, ex vivo burn wound, as a more realistic model, was further developed for the evaluation of the dressing performance. 11 Scaled burns were created with a hot metal block on disinsected pig skins (figure 7a) and infected with selected strains of SPE pathogens to establish biofilms allowing only burned tissues as a sole carbon source for infected bacteria (figure 7b). After 24 hours of growth at 37°C, each dressing was placed on the burn wounds and incubated up to 24 hours to test the dressing response (figure 7c). Fluorescent response was observed in all of the dressings except for the control biofilm of E. coli.

Conclusion

A prototype intelligent wound dressing is developed and the dressing performance is accessed by testing with in vitro and ex vivo porcine wound biofilm models of clinically important S. aureus, P. aeruginosa and E. faecalis (SPE) pathogens. Patterned vesicles in hydrogel dressing are lysed by virulence factors of pathogenic bacteria in mono biofilms only and triggered the release of fluorescent dyes which are visible to naked eyes. This study provides proof-of-concept for an advanced infection-detecting dressing for wound care, which could allow the targeted treatment of infections at the bedside and reduce the unnecessary use of antibiotics.

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