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Sensors and imaging for wound healing: A review

Tim R. Dargaville [a,*], Brooke L. Farrugia [a], James A. Broadbent [a], Stephanie Pace [b], Zee Upton [a], Nicolas H. Voelcker [b]

[a] Tissue Repair and Regeneration Program, Queensland University of Technology, Institute of Health and Biomedical Innovation, 60 Musk Avenue, Kelvin Grove, Queensland 4059, Australia
[b] Mawson Institute, University of South Australia, GPO Box 2471, Adelaide, South Australia 5001, Australia

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ABSTRACT

Wound healing involves a complex series of biochemical events and has traditionally been managed with 'low tech' dressings and bandages. The concept that diagnostic and theranostic sensors can complement wound management is rapidly growing in popularity as there is tremendous potential to apply this technology to both acute and chronic wounds. Benefits in sensing the wound environment include reduction of hospitalization time, prevention of amputations and better understanding of the processes which impair healing. This review discusses the state-of-the-art in detection of markers associated with wound healing and infection, utilizing devices imbedded within dressings or as point-of-care techniques to allow for continual or rapid wound assessment and monitoring. Approaches include using biological or chemical sensors of wound exudates and volatiles to directly or indirectly detect bacteria, monitor pH, temperature, oxygen and enzymes. Spectroscopic and imaging techniques are also reviewed as advanced wound monitoring techniques. The review concludes with a discussion of the limitations of and future directions for this field.

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* Corresponding author. Tel.: +61 7 31386174; fax: +61 7 31386030.
E-mail address: t.dargaville@qut.edu.au (T.R. Dargaville).

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1. Introduction

In the last century, there have only been a handful of technical advances that have contributed to changes in the discipline of wound management. One of the most important was in the 1960s when it was found that keeping a wound moist accelerates the healing processes. This was reported in the pivotal study by Winter in 1962 (Winter, 1962) and later became accepted practice and indeed a key design parameter in the development of dressings (Wu et al., 1995). The other crucial developments have been the management of infections in wounds through the use of anti-microbial agents, most notably, silver and iodine (Mertz et al., 1999; Wright et al., 2002), the use of compression pressure therapy (for chronic venous leg ulcers) (Wong et al., 2012), skin grafts (Rizzi et al., 2010) and hyperbaric oxygen therapy (breathing 100% oxygen at elevated pressure) (Malda et al., 2007). Each of these breakthroughs has resulted in new commercial products. For instance, there are now numerous different hydration-controlling dressings available (Queen et al., 1987, 2004); while for infection control dressings impregnated with silver have become ubiquitous in wound management (Wright et al., 2002) (Fig. 1). Despite these advancements and the wide range of dressings available, wound management is still extremely challenging due to its subjectivity, the complexity of the wound healing process itself, and patient variability.

There is now growing evidence to suggest that we are currently on the verge of the next significant advance in wound care where sensors will be used as diagnostic tools in wound healing to revolutionize wound care practice. The main types of wounds which will benefit most from sensor technology are chronic ulcers, and to a lesser extent infected acute wounds and large full-thickness burns. Chronic ulcers can be especially difficult to treat, highly susceptible to infection and can cause long-term suffering for the patient. Sensor innovation in the management of these wounds has the potential to impact clinical practice, patient outcomes and economic policy.

Chronic ulcers are a substantial cause of morbidity and societal burden worldwide. Foot ulcers, for instance, occur in approximately 25% of diabetics and are the leading cause of non-traumatic amputation in developed countries (Turns, 2011). In United States, chronic wounds as a whole are estimated to affect approximately 1–2% of the population during their lifetime (Gottrup, 2004), translating to an estimated morbidity of 6.5 million sufferers at a cost of US$25 billion per annum (Crovetti et al., 2004; Singer and Clark, 1999). Equally concerning is the rate at which chronic wound incidence is increasing due to lifestyle changes and the aging population. Together these phenomena pose a substantial threat to the future of health provision and the management of national economies (Sen et al., 2009). Wound management technologies and strategies are underdeveloped and need to evolve to meet this present and increasing challenge. Accordingly, reflecting on current practice may identify avenues for innovation and improvement.

Currently, when a patient presents with a wound there are a series of standard steps that will be followed by the clinician. Initially, their past medical history, including cardiovascular

Fig. 1. Current commercial products for wound management. Clockwise from top—Acticoat silver dressing (Acticoat (wound.smith-nephew.com)), Mepilex moisture control dressing (http://www.molnlycke.com), Woundcheck™ Protease Status diagnostic (http://www.systagenix.com/our-products/lets-test).