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Bandage-Based Wearable Potentiometric Sensor for Monitoring Wound pH

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Abstract: A new wearable electrochemical sensor for monitoring the pH of wounds is introduced. The device is based on the judicious incorporation of a screen-printed pH potentiometric sensor into bandages. The fabrication of this sensor, which uses an electropolymerized polyaniline (PANi) conducting polymer for pH sensing, combines the screen-printing fabrication methodology with all-solid-state potentiometry for implementation of both the reference and the working electrodes. The pH bandage sensor displays a Nernstian response over a physiologically relevant pH range (5.5–8), with a noteworthy selectivity in the presence of physiological levels of most common ions. The bandage-embedded sensor can track pH fluctuations with no apparent carry-over effect. The sensor displays good resiliency against mechanical stress, along with superior repeatability and reproducibility. The in vitro performance of the device was successfully evaluated using buffer solutions emulating the composition of a wound. The novel pH-sensitive bandages facilitate new avenues towards the realization of telemedicine.

Keywords: Embedded sensors · Chemical bandage sensors · Potentiometric sensors · Polyaniline

1 Introduction

The development of wearable sensors, embedded into different types of substrates, is a growing area of research [1]. For example, integrating sensing capabilities into textiles can provide significant benefits in diverse fields, such as sports performance [2], military applications [3], and healthcare [4,5]. Such wearable sensors can remotely monitor personal health status as well as the physical state of an athlete or soldier.

Wounds present a unique set of healthcare concerns that place a significant burden on the patient and entails significant costs for the healthcare provider, especially when such wounds become chronic and fail to heal properly. Wound healing is a complex process strongly influenced by environmental factors. Adhesive bandages are thus widely used for protecting wounds from debris and adhesion and ensuring a moist, unperturbed environment in order to be conducive to rapid healing processes [6,7]. Microbial growth is a major source of concern that has motivated the development of approaches – such as fluorescent dyes [8], anodized porous silicon [9], temperature [10] and pH [11] – to monitor the activity of bacteria during the healing process. Monitoring the pH of a wound has been the focus of several recent studies [12,13], since pH shifts at the wound site can provide useful information regarding wound evolution. While the pH of healthy skin is slightly acidic (approx. 5–5.5), an infected wound shows neutral or slightly basic (7–8.5) pH due to the presence of different types of enzymes and bacteria [12]. Interestingly, while evidence strongly suggests a correlation between pH and wound healing, the underlying relationship is still unclear. It is believed that different pH values may benefit healing at different stages [11], but the lack of suitable tools that can provide information at large scale is still a major limitation to unveil this relationship.

Several platforms have been proposed in recent years for sensing pH in wounds [14–18]. Puchberger-Enengl et al. developed a miniaturized optical reflectance sensor to monitor pH of wounds by immobilizing dyes on a organically modified silicate [14]. Also, a disposable screen printed pH voltammetric sensor for point-of-care (POC) applications, based on pH-dependent changes of the cyclic voltammetric response of uric acid present in the wound fluid, has been recently reported [15]. The development of textile-based sensing devices capable of pH monitoring represents a major progress within this field. A pH-indicator dye coupled to Raman spectroscopy [16] and a pH-responsive hydrogel in a multi-layer coated fiber using impedance spectroscopy [17] have been reported. Diamond et al. developed a wearable patch to monitor pH using spectroscopic techniques [18].

Evidently, to be usable in real-life scenarios, wearable sensing platforms need to combine suitable analytical per-

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