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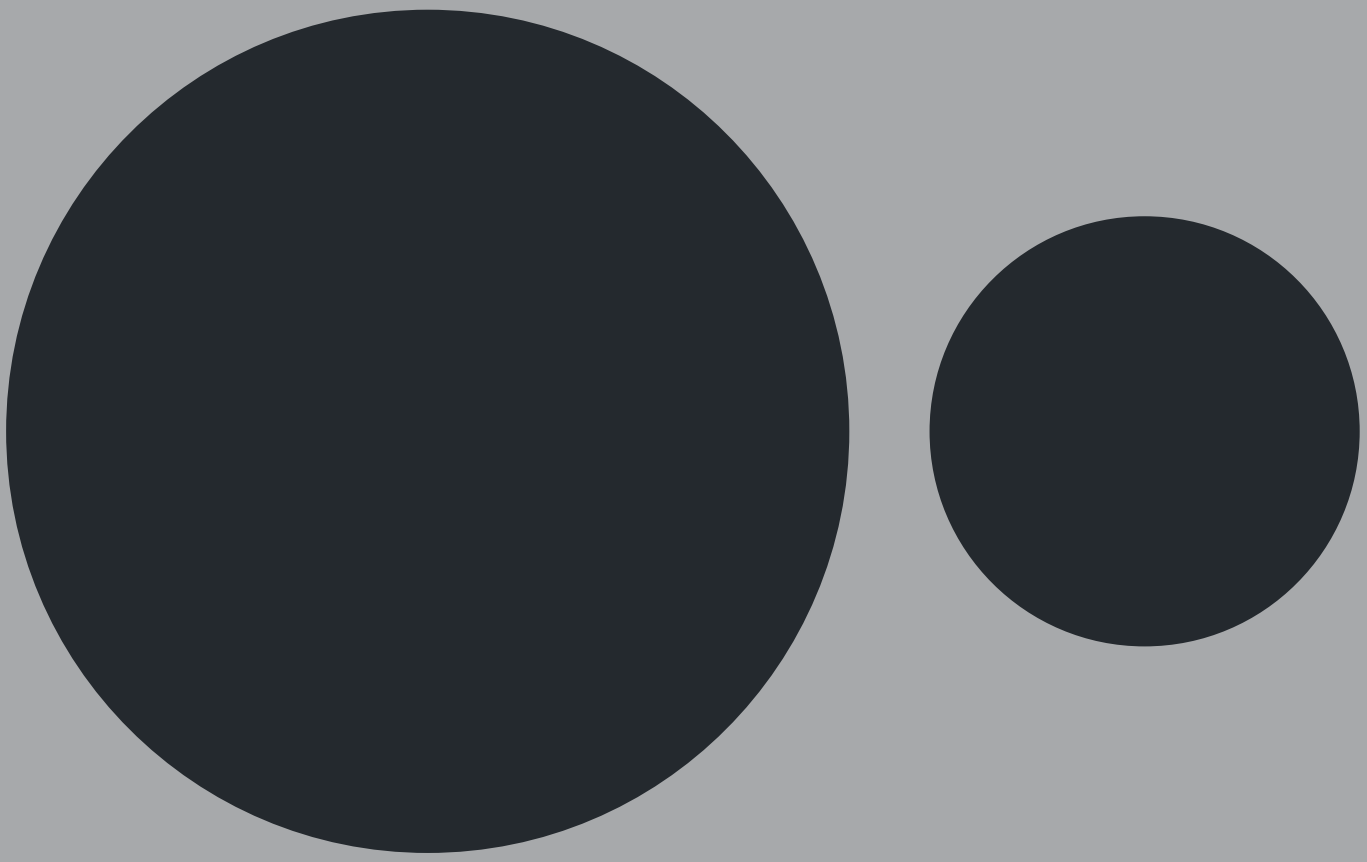

EPIDERMAL TATTOO POTENTIOMETRIC SODIUM SENSORS WITH WIRELESS SIGNAL TRANSDUCTION FOR CONTINUOUS NON-INVASIVE SWEAT MONITORING

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Epidermal tattoo potentiometric sodium sensors with wireless signal transduction for continuous non-invasive sweat monitoring

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ABSTRACT

This article describes the fabrication, characterization and application of an epidermal temporary-transfer tattoo-based potentiometric sensor, coupled with a miniaturized wearable wireless transceiver, for real-time monitoring of sodium in the human perspiration. Sodium excreted during perspiration is an excellent marker for electrolyte imbalance and provides valuable information regarding an individual's physical and mental wellbeing. The realization of the new skin-worn non-invasive tattoo-like sensing device has been realized by amalgamating several state-of-the-art thick film, laser printing, solid-state potentiometry, fluidics and wireless technologies. The resulting tattoo-based potentiometric sodium sensor displays a rapid near-Nernstian response with negligible carryover effects, and good resiliency against various mechanical deformations experienced by the human epidermis. On-body testing of the tattoo sensor coupled to a wireless transceiver during exercise activity demonstrated its ability to continuously monitor sweat sodium dynamics. The real-time sweat sodium concentration was transmitted wirelessly via a body-worn transceiver from the sodium tattoo sensor to a notebook while the subjects perspired on a stationary cycle. The favorable analytical performance along with the wearable nature of the wireless transceiver makes the new epidermal potentiometric sensing system attractive for continuous monitoring the sodium dynamics in human perspiration during diverse activities relevant to the healthcare, fitness, military, healthcare and skin-care domains.

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1. Introduction

Wearable chemical sensors, capable of real-time on-body monitoring of chemical constituents, can yield significant additional insights into the overall health status and performance of individuals, compared to that obtained by monitoring physical variables alone (Morris et al., 2008). Roger's group introduced epidermal sensors for measuring physical physiological parameters (Kim et al., 2011). Electrochemical devices offer considerable promise for such continuous non-invasive on-body monitoring (Windmiller et al., 2012). Particular attention has been given recently to printed electrochemical sensors on flexible substrates and textiles (Windmiller and Wang, 2013). Recently our group introduced the first tattoo-like electrochemical sensors, capable of adhering and conforming to the epidermis, for amperometric biosensing of lactate in human perspiration (Jia et al., 2013a) or potentiometric sensing of sweat pH (Bandodkar et al., 2013a) and ammonium (Guinovart et al., 2013a). Continuous monitoring of sweat lactate and pH dynamics during exercise events has thus been demonstrated. Extending this attractive platform towards continuous non-invasive monitoring of key sweat electrolytes should benefit diverse healthcare, fitness, and military applications.

The present article describes the design and analytical performance of a temporary-transfer tattoo solid-contact ion-selective electrode (ISE) for the continuous non-invasive monitoring of sweat sodium concentration directly on the human epidermis. Sodium is the most abundant electrolyte present in human sweat (Harvey et al., 2010). It is an excellent marker for electrolyte imbalance and provides valuable information regarding an individual's physical and mental wellbeing. Replenishing the sodium level in the body is important since it is essential for regulating water balance, pH, and osmotic pressure. This is especially true for athletes (Rosner and Kirven, 2007), people working in hot and humid environments (Ladell, 1955) and patients suffering from Cystic Fibrosis (Stern, 1997), since, in these cases, the amount of

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