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IonSens: a Wearable Potentiometric Sensor Patch for Monitoring Total Ion Content in Sweat

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Abstract: A sensor for monitoring total ion activity is described, and its performance as a wearable device for monitoring the total ion levels of sweat is evaluated. The sensor works by tracking changes in the Donnan potential generated across a Nafion® membrane. This cation-exchange polymer was cast on a paper coated with carbon-ink, making the platform elegantly simple. Analytical parameters during calibration in aqueous solution include a sensitivity of 56.3±1.0 mV/dec.$a_{(Na+)}$ and a standard deviation between standard electrode potentials of 5.3 mV (N=5) for first time use. By integrating a paper-based pseudo-reference electrode, a miniature disposable electrochemical cell (the "IonSens" device) was created and demonstrated as a wearable sensor. Potentiometric measurements estimating the total ion activities were validated against conductivity measurements. Recoveries of eleven raw sweat samples were determined to be 95.2±6.6% (n=3). The perspiration conductivity profile of an athlete during exercise was monitored in real-time and visualized on a mobile phone application connected via Bluetooth®. The excellent reproducibility of the electrode without any conditioning is noteworthy and lends itself to applications including – but not limited to – the monitoring of total ion activity in sweat.

Keywords: Conductivity • ion-exchange membrane • solid contact potentiometry • wearable sensor

1 Introduction

The development of body sensing networks [1] using wearable sensors to monitor physiological parameters in real time and in real settings is becoming possible due to the exponential progress in electronics and communication technologies. These platforms may have a significant impact in areas such as medical care [2], sports performance [2], homeland security, etc. Today, a wide range of devices that can monitor and wirelessly transmit physical parameters (heart rate, body temperature, movements, etc.) are available. Tools to generate chemical and biochemical information have not progressed at the same pace, creating an increasing gap that is fueling the interest for the development of wearable chemical and biochemical sensors. For this reason, since the pioneering works of Diamond *et al.* and Wang *et al.* this topic has been receiving a continuously increasing amount of attention in analytical chemistry [1–5]. The challenge is multifaceted, since wearable devices must work under very stringent dynamic conditions- including mechanical stresses, vibrations, temperature changes, etc. – and must adapt to the end-users needs without interfering in their routines. Given these constraints, the analytical problem must be reframed beyond the traditional performance-focused parameters, in order to include other equally relevant factors such as simplicity of operation, low power consumption, robustness, size, ergonomics and cost. The need to simultaneously meet all these requirements may offset the advantages of many well-established lab-based techniques. Therefore, the search for alternative detection approaches is an essential task in order to develop truly wearable (bio) chemical systems.

A good example of the complexity of this challenge is the analysis of sweat, a biological fluid that provides opportunities for the non-invasive monitoring of physiological information [5–7]. Electrolyte levels in sweat can be correlated with physical activity, physiological processes and some health-related issues, such as cystic fibrosis. Traditional lab-based methods require sampling sweat using absorbing pads, a step that is not free from problems (contamination, evaporation and changes on sample composition, etc.) and that stresses the advantages of using wearable devices. Total electrolyte levels are usually estimated by monitoring the sweat conductivity due to the overwhelming simplicity of this technique. However, many of these advantages vanish when dealing with wearable systems. Conductimetric measurements strongly depend on the cell geometry (electrode distance, spatial arrangement, shape and size), a factor that is easy to control in a lab, but that is harder to maintain in a wearable, flexible environment. To overcome this problem, a miniaturized, rigid wearable conductivity cell, as reported by Liu *et al.* for the real-time monitoring of athletes' sweat during exercise [6], can be employed. While this solution is effective, it requires coupling to a sweat pumping and transport system. This increases the

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