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Electrodeposited Polymers In Electrochemical Sensors For Health Applications – Aging And Chronic Pain

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Abstract

Electrochemical sensors are emerging as indispensable tools for point-of-care diagnostics due to their ability to rapidly and sensitively detect analytes in bodily fluids by transducing chemical interactions at an electrode surface into quantifiable electrical signals. The incorporation of advanced nanomaterials has significantly enhanced their performance, particularly by increasing surface area, improving conductivity, and facilitating efficient analyte recognition. Among the most promising approaches is the use of electrodeposited polymers, which provide precise control over the sensing interface. By forming uniform, nanostructured films directly on electrode surfaces, these polymers promote efficient electron transfer, improve analyte binding, and ensure long-term stability under physiological conditions. Conductive polymers such as polyaniline (PANI), poly(3,4-ethylenedioxythiophene) (PEDOT), and polypyrrole (PPy) enhance signal transduction, while functional polymers like Eriochrome Black T (EBT) and Chromotrope 2R (C2R) introduce versatile recognition sites through multiple functional groups.

This keynote presentation situates these material advances within the broader context of aging and chronic pain diagnostics, two areas where reliable biomarkers remain difficult to monitor. In Canada, the number of people aged 85 and older is projected to triple by 2046, while chronic pain already impacts 1.5 billion people worldwide, including 8 million Canadians. Chronic pain is often accompanied by diabetes, PTSD, and depression, complicating diagnosis due to its subjective nature and reliance on patient-reported scales. Electrochemical biosensors hold the potential to transform this landscape by enabling objective, real-time monitoring of pain- and aging-related biomarkers in saliva, blood, sweat, urine, and breath. Through measurable electrochemical signals—currents, voltammograms, or potentials—such devices classify health states more consistently than traditional methods.

A central focus is the integration of molecularly imprinted polymers (MIPs) as selective recognition elements in electrodeposited films. MIPs are synthesized by arranging functional monomers around a template molecule and fixing the structure through polymerization. Template removal creates specific binding cavities that allow selective rebinding of the target biomarker. Case studies demonstrate the effectiveness of this approach. A PANI-based MIP sensor for bovine serum albumin (BSA) achieved a detection limit of 2.3 pg/mL with wide dynamic range in clinical and food matrices, while a poly(o-phenylenediamine)-based MIP for Interleukin-6 (IL-6) demonstrated exceptional sensitivity down to 1.74 pg/mL and reliable performance in human serum. Similarly, glutamate, a small and electro-inactive biomarker, has been targeted using poly(o-phenylenediamine)/resorcinol systems, although challenges in template removal remain. These findings highlight how polymer choice, conductivity, and binding interactions—hydrogen bonding, electrostatic, covalent, and π–π stacking—directly impact sensitivity, selectivity, and reproducibility.

Despite their promise, challenges persist in transitioning MIP-based electrochemical sensors to real-world applications. Large biomolecules often leave incomplete cavities after template removal, while small molecules can be difficult to extract due to solubility issues. Variability in polymer stability, electrode reproducibility, and performance in complex biological fluids also limit broader adoption. Addressing these challenges through advances in polymer chemistry, electrode modification, and removal strategies will be key to scaling these sensors into practical devices. Looking ahead, electrodeposited polymer-based sensors show strong potential for integration into wearable, saliva-based, and multi-analyte platforms that continuously track inflammation and pain biomarkers. Such systems will not only provide clinicians with objective diagnostic tools but also empower patients with real-time health insights, ultimately reducing costs and improving management of aging and chronic diseases.

Keywords: Electrochemical sensors, Electrodeposited polymers, Molecularly imprinted polymers, Biomarkers, Chronic pain, Aging