Design and Fabrication of Hydration Based Biosensor for Flare-up Detection in Chronic Psoriasis

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Key points:

- Skin hydration and increased trans-epidermal water loss (TEWL) serve as quantifiable biomarkers for monitoring chronic inflammatory skin disorders.
- Psoriasis is characterized by profound stratum corneum dehydration, elevated TEWL, and Th17-driven keratinocyte hyper-proliferation.
- A non-invasive wearable patch utilizes a four-polymer nanocomposite (rGO, PVA, Chitosan, and silk fibroin) optimized via CAD for skin attachment.
- Tracks impedance changes across the stratum corneum via Electrochemical Impedance Spectroscopy (EIS) to detect early-stage flare-ups.

Introduction

Skin hydration plays an important role in maintaining the epidermal barrier and overall skin health, therefore it can be used as a measurable biomarker. Abnormal hydration and increased trans-epidermal water loss (TEWL) are common biomarkers across various dermatological conditions, including atopic dermatitis, urticaria, seborrheic dermatitis and psoriasis. In particular, psoriasis is characterized by extremely reduced level of hydration in stratum corneum and increased TEWL level, and keratinocyte hyper-proliferation that is driven by autoimmune pathways, that causes the disease severity.

This project aims to explore skin hydration as an objective, non-invasive biomarker for monitoring and diagnosing dermatological disorders, with a primary focus on psoriasis. By correlating hydration levels with disease lesion activity and its severity, this study aims to establish hydration as a reliable diagnostic tool that can diagnose flare-up in Psoriasis.

This research will investigate hydration imbalance in psoriasis and analyze the relationship between skin impedance and hydration. This study is designed to provide a scientific basis for the development of real-time skin hydration monitoring systems that could enable earlier detection of flares and improve the quality of patient's life.

Skin Disorders

There are different skin disorders such as Atopic Dermatitis, Seborrheic Dermatitis, Urticaria, Psoriasis and many more. Hydration plays a significant role in all of the skin inflammatory disorders.

Atopic Disorders

Atopic Dermatitis (AD) is predominantly characterized by eczema, dry skin, and itching. The hydration level of the SC lowers while the TEWL level increases than normal. Main protein named filaggrin, it's deficiency occurs in AD.[1,2]

Urticaria

Urticaria is a disease characterized by erythematous and edematous urticarial plaques. IgE-mediated activation of mast cells occurs that releases histamine due to which vasodilation occurs which leads to wheal formation.

Seborrheic Dermatitis

Seborrheic Dermatitis is a chronic relapsing skin condition characterized by patches of greasy scaly skin, often appearing in regions rich in sebaceous glands such on the scalp, face, and chest. Increase TEWL level and reduced production of epidermal lipids, creates a favorable environment for microbial overgrowth. In SD increased activity of *Malassezia* yeast takes place that causes an inflammatory response on oily skin sites.[3,4]

Psoriasis

Psoriasis is a chronic inflammatory skin disease with a strong genetic predisposition and autoimmune pathogenic traits. Psoriasis is not contagious and transmittable. The hydration level of Stratum Corneum is extremely low as compared to the normal skin while the TEWL level increases in psoriasis. In Psoriasis keratinocyte hyper-proliferation takes place that is driven by Th17 cells.[2,5,6]

Role of Hydration in Psoriasis

Hydration is most significant at the barrier dysfunction stage (keratinocytes). Poor hydration worsens barrier defects which eventually triggers immune activation and results in the manifestation of Psoriasis. So maintaining hydration helps stabilize the barrier, reduce flare-ups, and complement immune-targeted therapies.[7]

Mainly focusing on Psoriasis due to Koebnerization phenomenon, that is if a psoriatic patient's skin damages due to a scratch or cut, there are high chances of new plaques formation which increases the total affected body surface area. This flare-up should be controlled to avoid plaque formation which can be done with the help of real-time monitoring of skin hydration level.[8]

For this purpose, a biosensor is designed that consists of a four polymer nanocomposite (rGO, PVA, Chitosan and silk fibroin). An electrode will be designed and coated with the desired nanocomposite which will be tested for monitoring of hydration level through impedance measurement.[9,11]

Designing a Biosensor

Electrode Designing

In the first step, the electrode geometry and configuration are designed on CAD (Computer Aided Designing). They are designed in a coplanar configuration to ensure uniform current distribution and adequate penetration depth across the stratum corneum to the dermis. The inter-electrode spacing (1–2 mm) and trace width (5 mm) are optimized to achieve a penetration depth of approximate 5 mm, corresponding to full skin thickness.

Nanocomposite Synthesis

A nanocomposite is prepared by reducing graphene oxide (rGO) and combining it with polymers such as polyvinyl alcohol (PVA), chitosan (CS) and silk fibroin (SF) through sonication. The nanocomposite is stored at room temperature.

Electrode Printing

A conductive ink is prepared and coated on to the substrate which will act as a transducer (signal converter) in our biosensor. The goal is to fabricate a

flexible, thin, and reproducible electrode suitable for skin attachment. Screen printing will be used to deposit the electrode layer on flexible substrate that is thermoplastic polyurethane (TPU).

Device Characterization

Before biological testing, the fabricated electrode is characterized to confirm its electrical and structural properties. SEM, XRD, FTIR are used. Where SEM ensures the morphology while FTIR/XRD checks for the nanocomposite synthesis.

Electrochemical Impedance Spectroscopy

EIS is performed using an impedance analyzer with an AC excitation amplitude of 1 V and frequency from 1 Hz to 100 kHz. Hydrogels are made in such a way that it varies hydration levels by controlled drying or soaking in saline. The impedance spectra are recorded for each hydration condition, and equivalent circuit fitting is conducted to extract surface and bulk parameters.[12,14]

Conclusion

This study will contribute to the scientific community by advancing understanding of hydration as a quantifiable biomarker for skin disorders, particularly psoriasis. Establishing hydration as a diagnostic tool will add objectivity to dermatological assessments. It will also open pathways for the development of non-invasive sensor technologies and standardized hydration-based diagnostic protocols. For society, this research has the potential to improve patient care by enabling earlier detection, better monitoring of disease progression, and personalized treatment strategies. It will also affect the quality of life of psoriatic patients by reducing the susceptibility to comorbidities such as arthritis, cardiovascular disorders, depression etc.

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