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Microfluidic Microneedle Platform for Real-time Transdermal Muscle Injury Monitoring

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ABSTRACT

Muscle injuries, particularly those of the shoulder, can progress into chronic conditions if not properly monitored, requiring extensive medical intervention. Today's standard practice involves medical imaging for diagnosis, followed by a treatment plan of rest and physiotherapy, with progress assessed through pain and functionality. Unlike pain reporting and static imaging, biomarkers provide continuous tracking of tissue repair and recovery, enabling precise, personalized treatment and objective injury assessment. The muscle injury panel (MIP) is a set of biomarkers that can help detect muscle damage. Within this panel Fatty acid-binding protein 3 (FABP3) is a key biomarker, specifically linked to muscle cell membrane damage. Continuous biomarker tracking can provide real-time feedback during injury, enabling personalized rehabilitation and preventing long-term muscle damage. The goal of this research is to develop a continuous monitoring microdevice that integrates microneedles, microfluidics, and biosensors for painless real-time muscle injury monitoring. The fabrication of the microneedle platform is based on a novel method combining 3D printing fabrication methods, including two photon polymerization (TPP) and selective laser induced etching (SLE). A glass 3D printer (LightFab GmbH, Germany) was used to fabricate the microfluidic devices using 500 µm thick fused silica wafers. The CAD model, designed in Fusion360 for SLE, features channels with depths of 450 µm, 80 µm inlets, 22 µm inlet channels, a 100 µm outlet, a 5 mm analysis chamber, and alignment markers for TPP fabrication. IP-n162 resin was then used to print 600 micron tall hollow microneedles, precisely integrated atop the fabricated microfluidic channels. Pilot experiments have successfully demonstrated fluid intake at a flow rate of 20 µL/min, via microneedles, through the microfluidic system. The next phase involves integrating an aptamer-based biosensor within the microchamber. The biosensor will consist of a gold electrode functionalized with immobilized aptamers, specifically designed to detect FABP3. Experimental results of FABP3 real-time monitoring with the microsystem will be presented at the conference. The design of the system was changed multiple times to combat over etching, create proper piece alignment and adhesion, and avoid cracking during printing. This research highlights the advancements in microsystem fabrication, demonstrating the integration of microfluidic and biosensing components for continuous biomarker monitoring. The ability to continuously monitor FABP3 levels can be pivotal in tracking muscle injury progress over time, allowing for visualization of the muscle cell membrane healing timeline. This research paves the way for the development of novel wearable devices for continuous muscle injury monitoring.