Summary

Transdermal Drug Delivery Technology Using a Microneedle Patch Combined with Diagnostics for Veterinary Medicine Applications

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The doctoral dissertation entitled "Transdermal Drug Delivery Technology Using a Microneedle Patch Combined with Diagnostics for Veterinary Medicine Applications" focuses on the development, fabrication, and experimental validation of two modern, complementary technological solutions with implementation potential in veterinary medicine:

(1) dissolvable microneedle patches for transdermal delivery of active substances, manufactured using 3D printing and micromolding techniques,

(2) a portable point-of-care (POC) diagnostic system based on isothermal nucleic acid amplification using the RT-LAMP method, carried out in chips also fabricated using 3D printing.

The dissertation is interdisciplinary in nature and integrates issues from microsystems engineering (MEMS), 3D printing technologies, optoelectronics, and molecular diagnostics. The primary motivation for undertaking this research was the need to develop low-cost, mobile, easy-to-use, and customizable diagnostic and therapeutic tools that could be applied directly at the site of animal care, without requiring access to specialized laboratories.

In the part of the work concerning microneedle patches, various microneedle geometries (including conical and pyramidal) were designed and then printed as array structures using DLP (digital light processing) 3D printing. Based on these structures, a technological process for fabricating dissolvable microneedles was developed using micromolding with silicone PDMS molds. Mixtures of biodegradable and biocompatible polymers, polyvinylpyrrolidone (PVP) and polyvinyl alcohol (PVA), were used as the carrier materials.

A detailed dimensional conformity analysis of the dissolvable microneedles relative to the master structures was conducted, demonstrating small, geometry-dependent deviations within a few percent. Subsequently, functional studies were performed, including microneedle dissolution tests, assessment of mechanical stability, and analysis of the release kinetics of a model substance (rhodamine B) under conditions simulating skin contact. It was shown that a PVP 10% / PVA 5% composition provides a favorable compromise between mechanical strength and the speed and repeatability of active substance release. Complete release of the model compound occurred within approximately 120 to 150 seconds, depending on the microneedle geometry.

The studies were complemented by in vitro tests evaluating biocompatibility and cytotoxicity, which confirmed the biological safety of the developed structures. The obtained results indicate that dissolvable microneedle patches may constitute a viable alternative to conventional injections in veterinary practice, enabling safe, minimally invasive, and controlled administration of drugs or vaccines.

In the diagnostic part of the dissertation, RT-LAMP reaction conditions dedicated to the detection of animal viruses were developed. An optoelectronic setup enabling fluorescent readout of the reaction (end-point detection and, ultimately, real-time monitoring) was designed and assembled, allowing objective assessment of amplification and increasing the automation potential of the system compared

to colorimetric methods. Subsequently, a microfluidic chip enabling RT-LAMP reactions in an on-chip format was designed and fabricated using DLP technology.

The system was experimentally validated using the detection of genomic RNA of feline calicivirus (FCV), a highly contagious virus widely distributed among cat populations. High reaction specificity was achieved, with no amplification observed in control samples, and a limit of detection (LOD) of 2.3 $\times 10^3$ RNA copies per reaction was obtained. Although the sensitivity of the on-chip system was lower than that of conventional tube-based reactions performed under laboratory conditions, these results were considered sufficient for veterinary applications and typical for prototype microfluidic systems manufactured using additive technologies.

The dissertation confirms that 3D printing is an effective tool for rapid prototyping and customization of diagnostic and therapeutic systems. The developed solutions form a coherent platform with high implementation potential, suitable for further development toward integrated next-generation diagnostic and therapeutic devices for veterinary medicine.

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