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3D-Printed Mouthguard with Integrated Microfluidic Drug Dispenser for Oral Cavity Applications

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Summary:

This study introduces an innovative 3D-printed mouthguard incorporating an integrated microfluidic drug dispenser. Fabricated from biocompatible resin utilizing Digital Light Processing (DLP) technology, the device allows for facile redesign and customization to accommodate individual dental anatomy. The integrated microfluidic system is equipped with two check valves, enabling simple and repeatable refilling, and dispensing of liquids from the internal reservoirs.

Keywords: 3D printing, microfluidics, drug dispensing, dental health

Introduction

Over the past decade, 3D printing has significantly impacted the dental industry, enabling the development of customized dental splints and mouthguards tailored for conditions such as bruxism and malocclusion [1, 2]. These advancements utilize 3D scans of the oral cavity to create models for designing personalized dental appliances. In this study, we propose a solution that integrates a microfluidic delivery system with a dental mouthguard, facilitating the dispensing of liquids for intraoral healing and therapy.

Materials and methods

The device was manufactured using Digital Light Processing (DLP) technology (Asiga), commonly employed for producing orthodontic appliances. An FDA-approved UV-curable resin (Pro3Dure) served as the construction material. The mouthguard's design is based on a standard dental splint model (Fig. 1a) and incorporates two integrated microfluidic dispensers, each with a liquid reservoir capacity of 105 µL.

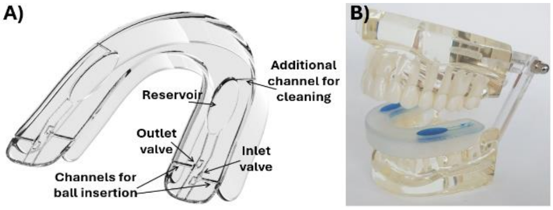

Fig. 1. 3D printed mouthguard: a) digital model containing two symmetrical drug dispensers, b) the mouthguard mounted in the human dental model (microfluidic system filled with a blue dye for contrast).

The upper and lower layers of the reservoir are designed as membranes that dispense the sample when compressed by teeth clenching. Each dispenser features two microfluidic channels with individual check valves operating in opposite directions, facilitating easy filling, and dispensing of the sample plug (Fig. 2). The dispenser's location can be customized according to a 3D scan of the dental structure (Fig. 1b).

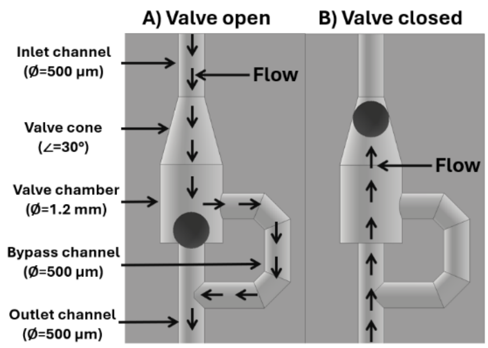

Fig. 2. schematic of the ball choke valve in open and closed mode.

Within the valve chamber, a steel microbead (Cospheric) was placed via an additional side channel, which was subsequently sealed after UV exposure to a resin droplet (Fig. 3). During compression, the microbead in the inlet valve moves toward its conical section, preventing flow, while the outlet valve remains open. In the refill stage, the valves operate oppositely, preventing the liquid from flowing back into the reservoir.

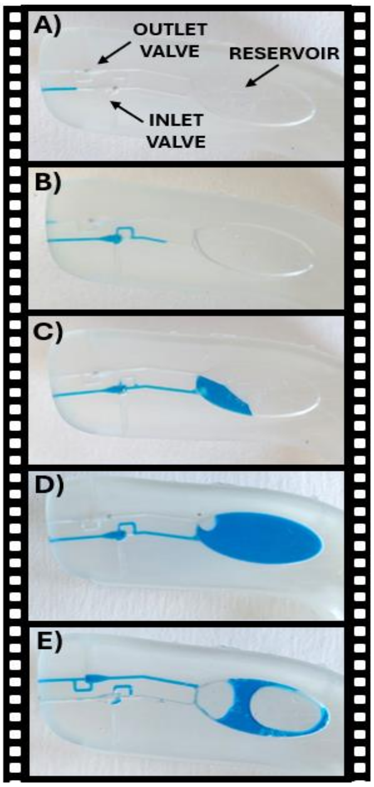

Fig. 3. Workflow sequence of the microfluidic drug dispenser: a) device empty, b) loading liquid through the input channel (inlet valve open, outlet valve closed), c) filling the reservoir with a liquid, d) device filled up, e) dispensing of the liquid from the reservoir forced by deflection of the membrane (inlet valve close, outlet valve opened.

Results

The design of the integrated microfluidic dispenser was optimized through a series of experiments using a pressure regulator, water tank, and measuring cylinder. Various microbeads with diameters ranging from 600 to 800 µm were tested, with the most extreme values of forward flow (open valve) and reverse flow (closed valve) observed for the 700 µm bead (Fig. 4a). The study identified that reverse flow (leakage) was caused by imperfections on the valve cone's surface, stemming from the printer's resolution limit of 35 µm. Nonetheless, the difference in flow between the open and closed modes was over 80 times greater. Additionally, it was confirmed that while forward flow increases linearly with pressure, reverse flow remains nearly constant (Fig. 4b).

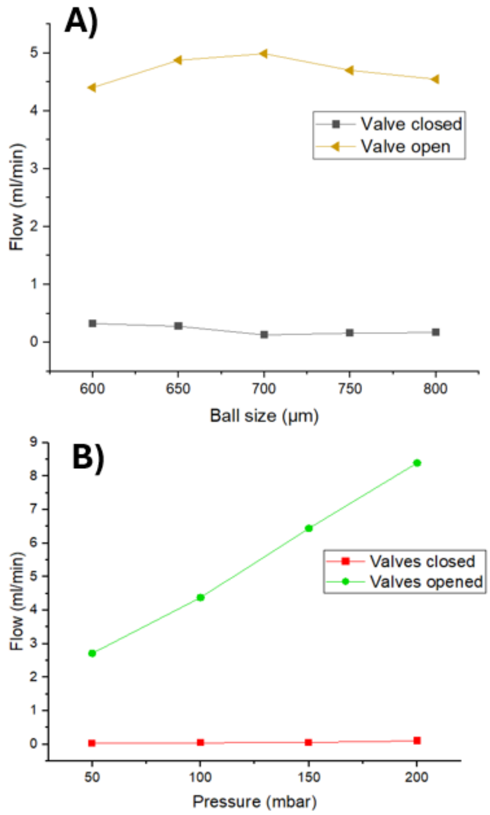

Fig. 4. Results of the forward (valve open) and reverse (valve closed) flow measurements of the microfluidic check valve: a) water flow in a function of ball size for constant pressure of 100 mbar, b) water flow in a function of applied pressure for ball size of 700 µm.

Summary

For the first time, a 3D-printed biocompatible mouthguard with an integrated microfluidic dispenser, equipped with a liquid refilling and distribution system, has been presented. The device can be easily replicated and customized to meet individual patient needs, paving the way for the development of 3D-printed intraoral microfluidic devices for personalized medicine.

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