Towards the development of personalized drug delivery systems using 3D printed magnetically triggerable elastomers

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Introduction

- Conventional drug delivery methods (oral, intravenous) are convenient but have drawbacks such as reduced efficacy and off-target side effects.
- Controlled drug delivery systems (DDS) offer precise regulation of drug release in terms of location and rate.
- Porous soft materials in DDS respond to external stimuli (e.g., ultrasound, temperature, electric and magnetic fields) for targeted drug release [1].
- Magnetic fields are particularly advantageous due to their efficiency, safety, and contactless control.
- In this study we present the development of an externally and magnetically triggered 3D printed scaffold embedded in a 3D printed capsule for drug delivery applications. [3].
- The approach can potentially be used to develop wearable drug delivery technologies, paving the way for personalized treatments for achieving improved patient treatment outcomes.

Methodology

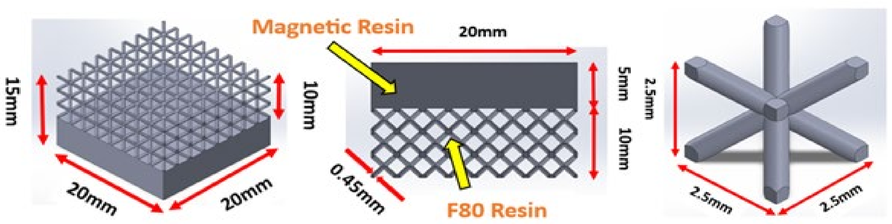

Fig. 1. CAD design details, including three distinct views: the overall structure diagram (left), the left side view highlighting the geometric features and dimensions (center), and an enlarged view of a single lattice unit detailing its precise dimensions and design (right)

- Scaffold designed in SolidWorks using a Uniform Body-Centered Cubic (UBCC) lattice for optimal compression [2].
- The structure consists of a 20 mm × 20 mm × 10 mm cubical block with 256-unit cells (2.5 mm size, 0.45 mm diameter) and a 20 mm × 20 mm × 5 mm dome on top.
- Fabricated with 40 w/w% printing slurry for the dome and pure F80 UV resin for the scaffold [4].

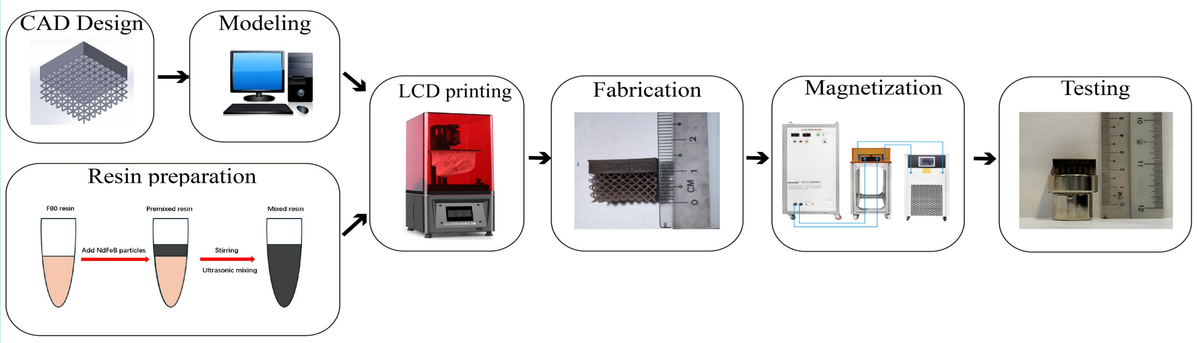

Fig. 2. Flowchart illustrating the process for the preparation of the magnetic soft compressible scaffold. The key steps include CAD design, resin preparation(involving the mixing of NdFeB particles with resin), 3D printing using LCD technology, scaffold fabrication, magnetization, and testing.

Experiments and Results

Experimental setup:

a. A scaffold loaded with NdFeB magnetic microparticles is placed in a 3D-printed capsule with a drug delivery aperture on the proximal side (Fig. 1a-top).
b. A micrometer-controlled high-precision linear stage holds an N-52 neodymium magnet (350 mT).
c. A magnetic field meter measures the magnetic field on the scaffold's surface, with distances from the magnet ranging from 0 to 10 mm.
d. Two CMOS cameras capture scaffold deformation to calculate compression ratios under varying magnetic fields (Fig. 1a-c top).
e. A digital scale beneath the capsule aperture measures droplets released under different magnetic field strengths.

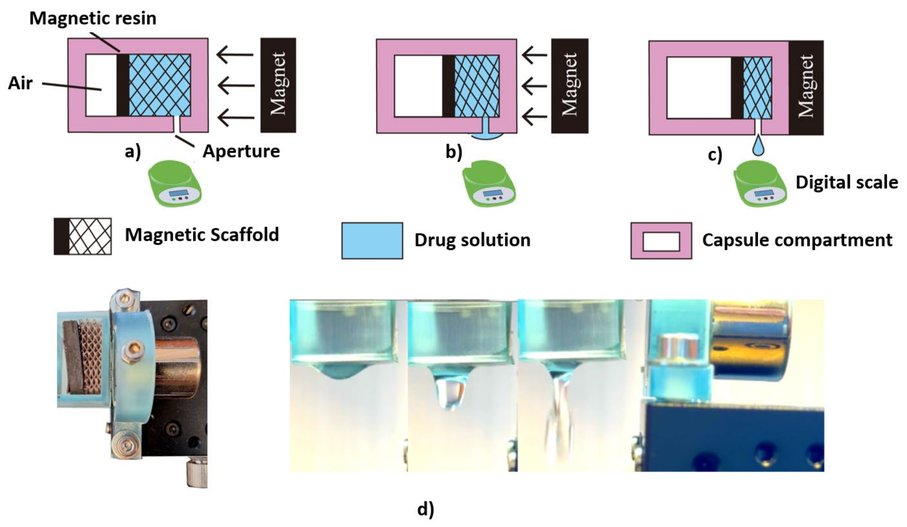

Fig. 3 shows the schematic of the magnetically controlled drug release setup. A) Uncompressed scaffold with the magnet 10 mm away, no droplet release. B) Partially compressed scaffold with the magnet at 5 mm, where droplet release is driven by surface tension. C) Scaffold compressed with the magnet ~0.2 mm away, showing increased compression and droplet release. Droplets were measured using a scale. D) The experimental setup, imaged with two CMOS cameras, captured scaffold compression and droplet release dynamics.

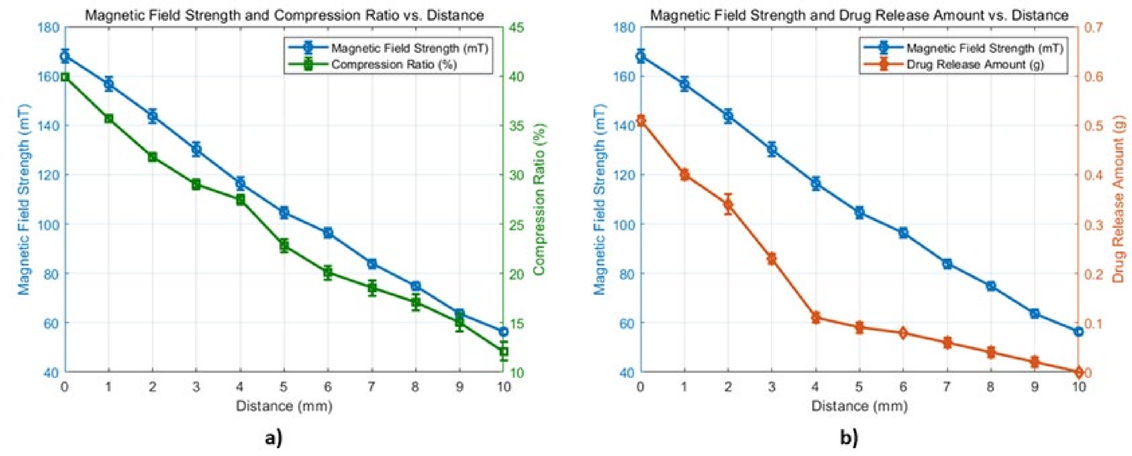

Figure 4. (a) Experimental results of magnetic field strength versus the distance variation of the neodymium permanent magnet and 3D printed scaffold compression ratio. (b) Experimental results of magnetic strength vs drug release mass resulting from the distances variation between the permanent magnet and the scaffold.

- A remote triggering system was developed based on a Neodymium permanent magnet considering the decay of the magnetic field as a function of distance producing magnetic fields in the range of 56.3 ± 1.25 mT to 167.9 ± 2.62 mT at the surface of the scaffold.
- This resulted in a precise drug delivery where the developed device was able to deliver precise drug quantities in the range of 20.7 ± 3.5 to 102.8 ± 21.7 µl/mm.

References

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Conclusion and future work

This study demonstrates the successful integration of NdFeB microparticles with photocurable resin to 3D-print soft, macro-porous scaffolds and to develop a magnetically activated, externally controlled scaffold inside a capsule for targeted drug delivery applications. This system enables precise dosage control up to 20.7 ± 3.5 to 102.8 ± 21.7 µl/mm, paving the way for patient-specific drug delivery solutions and advancing the field of personalized medicine with adaptable and wearable drug delivery technologies.

Future research will focus on a) Exploring the positioning and navigation of drug-loaded magnetic scaffolds to accurately reach target sites and b) Developing application scenarios for magnetic wearable devices, including personalized treatment plans for conditions such as diabetes and keratoconus.