3D Bioprinting Magnetic Bacterial Flagella-Inspired Micro Swimmers for Biomedical Applications.

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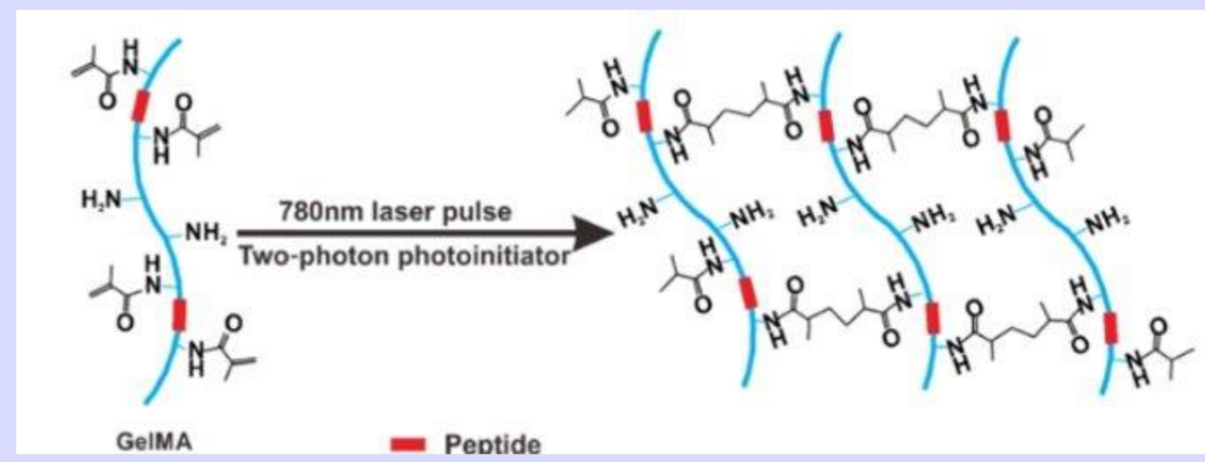
Introduction

3D bioprinting is a powerful tool for creating microscale devices for biomedical applications. Magnetic micro swimmers, inspired by the helical structure of bacterial flagella, offer a new promising approach for navigating complex biological environments and enabling targeted drug delivery and diagnostics.

Specifically in this project, helical micro swimmers containing magnetic nanoparticles are created using a two-photon polymerization 3D printing. Our current efforts focus on optimizing the printing conditions to produce intact, free-standing structures with reliable shape and motor function. This work advances fabrication methods for biomedical robotics and demonstrates the possibilities of 3D bioprinting to create functional microdevices

Methods

- To prepare the matrix, magnetic nanoparticles (MNPs) are mixed into the resin using a ThinkyMixer.
- **For printing in the resin:**
  - A small chamber is made using PDMS. This chamber is placed on top of a clean microscope slide.
  - Resin is pipetted into the PDMS chamber, and a microscope cover slip is placed on top of the chamber.
  - The prepared slide is placed inside the UpNano 3D printer. For this design, helices are printed in a 3D grid pattern. The structures are printed layer by layer from top to bottom of the resin.
- **For printing directly on the slide:**
  - Resin is poured directly onto a clean microscope slide, and the slide is placed inside the UpNano 3D printer.
  - 2D print design is used, printing helices along the x and y axes.
- Printed helices are developed in a PGMA (Propylene glycol monomethyl ether acetate) solution. After development, they can be pipetted onto slides for observation.
- To visualize "swimming behavior" of helices, a Nikon advanced optical microscope was used, and a rotational magnetic field was applied using a magnetic field generator.

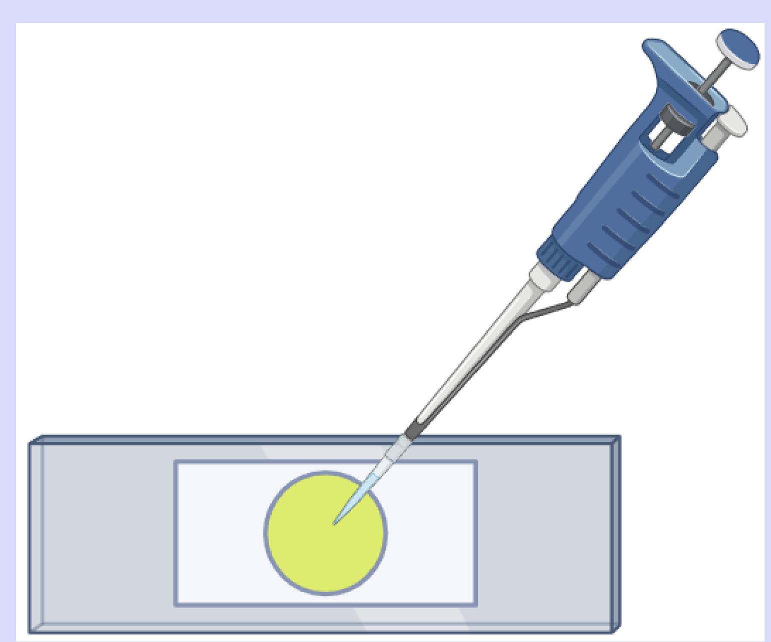


Microhelices Fabrication Using 2PP

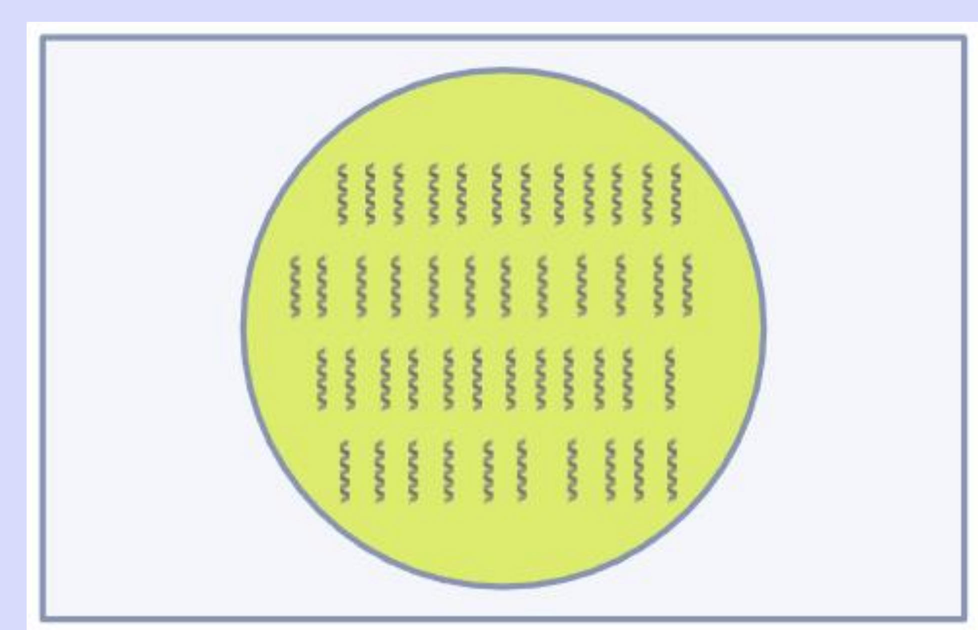
- ***Two-Photon Polymerization (2PP)***: 2PP uses a laser to trigger the absorption of two photons, enabling the 3D printing of nanoscale structures

Results

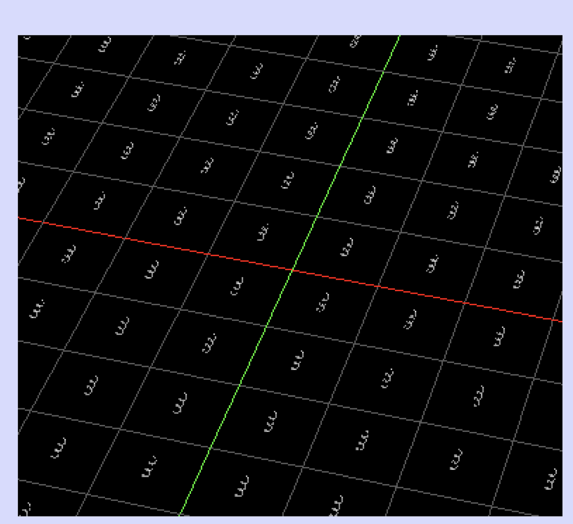
- Successfully fabricated helical micro swimmers using two-photon polymerization and produced structures on both a glass substrate surface and within the resin.
- Achieved true volumetric printing across X,Y and Z axes.
- Helical geometry preserved under optimized printing parameters such as laser power and speed. The modified parameters for different concentration of MNPs improved recovery of intact helices.
- Isolated swimmers remained stable after separation from printing medium.
- The rotational magnetic field induces torque on the swimmers and makes them spin and move forward.



Resin being pipetted into the PDMS chamber on a microscope slide (not to scale).



Visual representation of one layer of the helices suspended in the resin after 3D printing (not to scale).



3D print design for helices printed within the PDMS chamber.

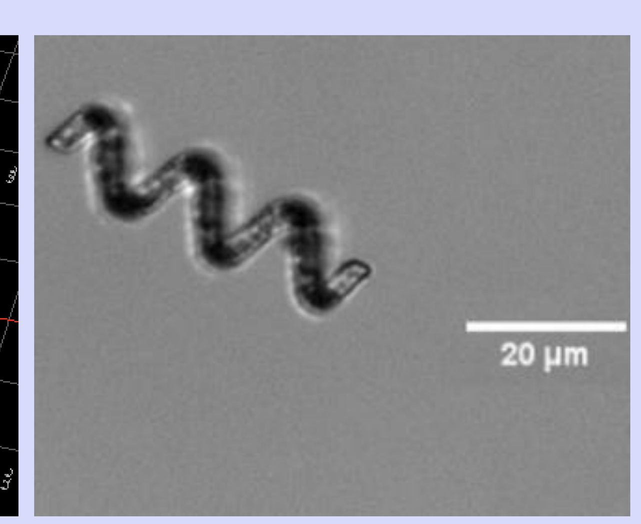
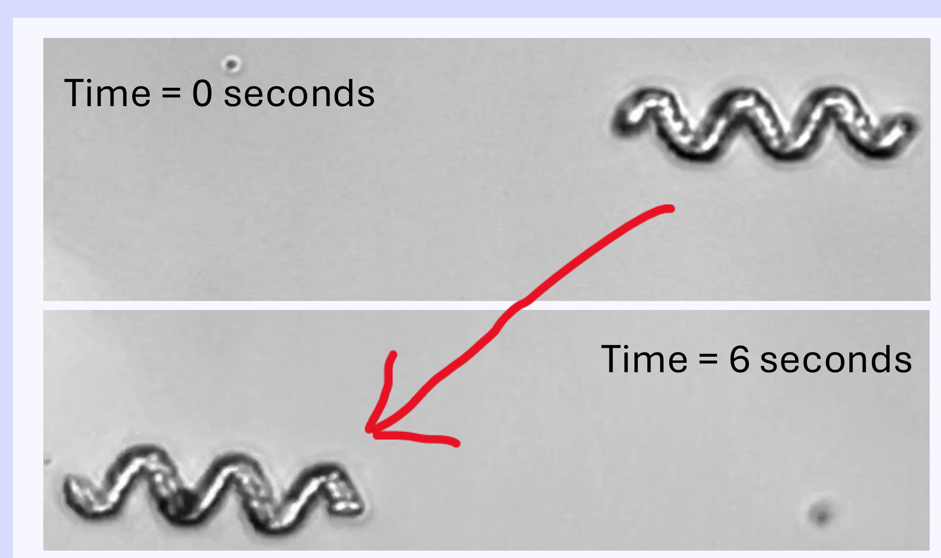


Image of one magnetic helices under Nikon microscope.



Images of helices movement in a 6-second period. From the start position (top image), the helices travelled at a speed of 10 µm/s with a rotation frequency of 5 Hz under a magnetic field strength of 15 mT to the end position (bottom image).

Discussion

- Successful fabrication of helical micro swimmers confirms that a two-photon polymerization can in fact produce complex, magnetically responsive microscale devices. However, structural integrity and recovery are dependent on printing conditions.
- Current work focuses on optimizing the MNPs concentration and adjusting printing parameters to improve how precise the structures can be printed, developments and clean separation. These parameters directly affect the devices stability and swimming behavior under magnetic actuation.
- Refining these fabrication conditions will allow consistent production of free-standing micro swimmers and improve their performance for future biomedical applications.

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References