Magneto-Enzymatic Microgels for Precise Hydrogel Sculpturing

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The incorporation of channels in artificial tissues has become an attractive strategy to facilitate the delivery of nutrients and oxygen to the cells within the material, thereby ensuring their viability and functionality for the repair process. However, the most commonly used methods for creating these channels heavily rely on microfabrication techniques that typically require substantial resources, lengthy fabrication times, complex chemistry protocols, and expensive, sophisticated equipment.

Herein, we propose a real-time, cost-effective, and easily implementable approach to sculpt channels in large-scale hydrogels, providing precise control over their trajectory, number, width, and formation timing throughout the hydrogel volume. This approach relies on the combination of magnetic nanoparticles with an enzyme selected for its ability to degrade the specific hydrogel matrix, resulting in magnetically responsive, enzyme-based microgels capable of sculpting channels in response to an externally applied magnetic field. The rate, number, width, and direction of channel formation can be controlled by adjusting the magnetic field parameters, nanoparticle concentration, and the number and size of the microgels.

The potential of this system was further demonstrated by its ability to sculpt hydrogels in the presence of cells, which remained viable due to medium perfusion through the formed channels. Moreover, the open channels generated within the hydrogel supported endothelial cell adhesion, mimicking key aspects of native vascular structures.

Overall, this approach offers an innovative and accessible alternative to conventional microfabrication techniques for developing functional *in vitro* tissues. This versatile approach can be applied to different hydrogel–enzyme systems, enabling precise, minimally invasive channel formation in complex soft biomaterials for the delivery of cells, drugs, or biomolecules.

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FIGURE 1
Magnetically guided microgels sculpt channels in a cell-laden hydrogel, forming user-defined paths, as shown in micros.

FIGURE 2
Live/dead assay showing cell viability around the channel; and endothelial cells' adhesion to channel walls, followed by hydrogel invasion.