# Supporting Information

# Improving extracellular matrix penetration with biocatalytic metal-organic framework nanoswimmers

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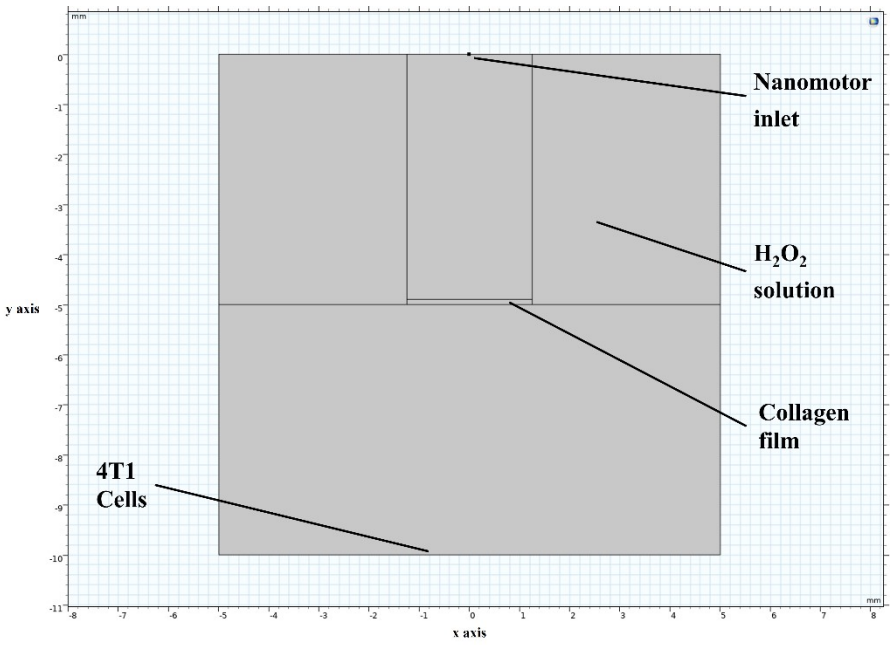


***Figure S1.*** *Schematic representation of the model geometry. The experimental setup is depicted with a container filled with $H_2O_2$ solution, modeled as a rectangular domain. The collagen film is represented as a thin rectangular region positioned at the bottom of an internal support structure within the container.*

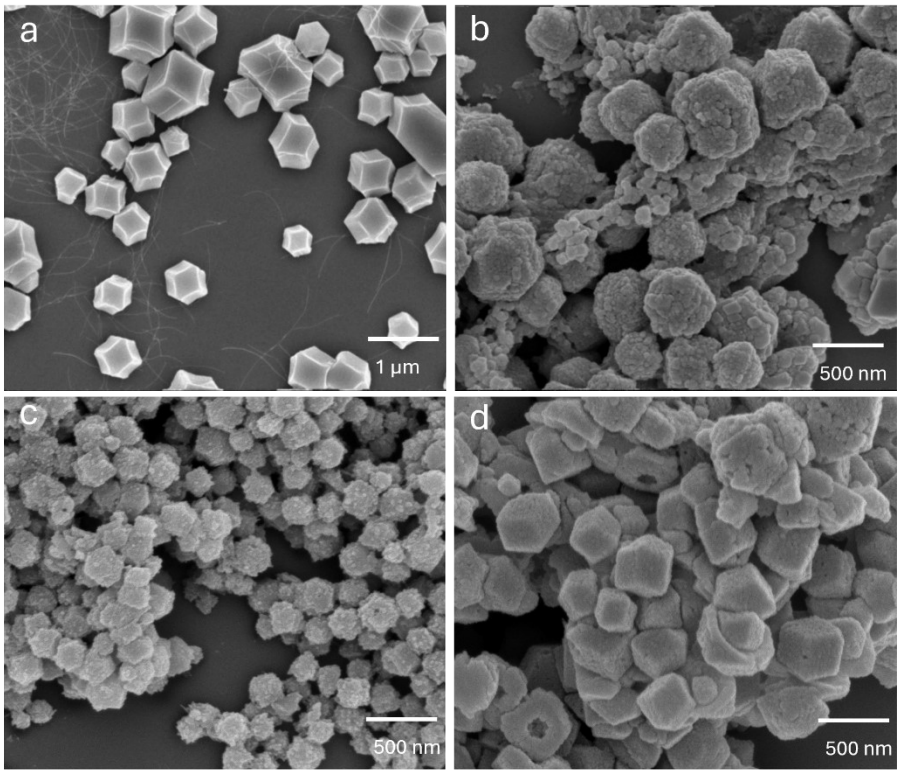


***Figure S2.*** *SEM images of different ZIF-90 nanoparticles.(a) ZIF-90. (b) Catalase@ZIF-90. (c) Collagenase@ZIF-90. (d) Catalase-Collagenase@ZIF-90-DOX.*

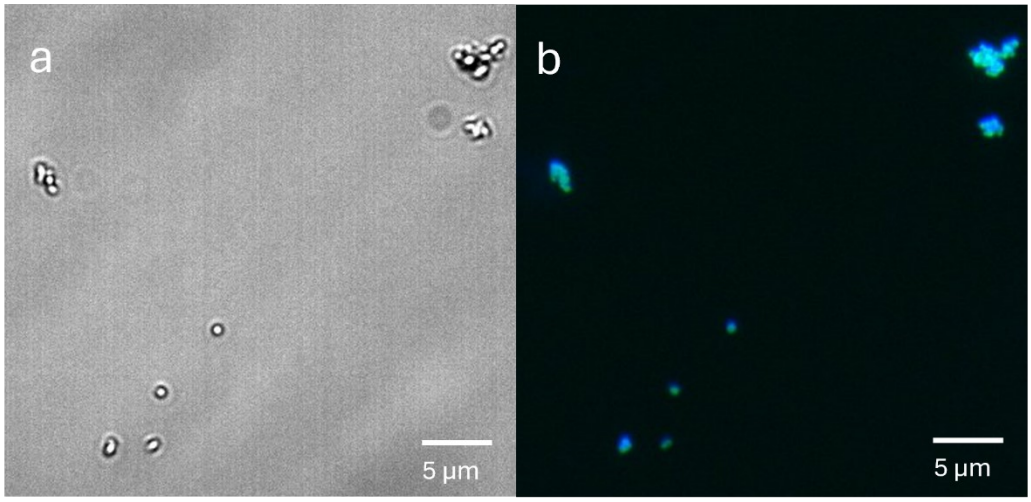


***Figure S3***. *CLSM Images of CAT-COL@ZIF-90 containing* (a) bright-field image, and (b) fluorescence overlay image. (green = FITC-catalase, blue = atto633-collagenase)

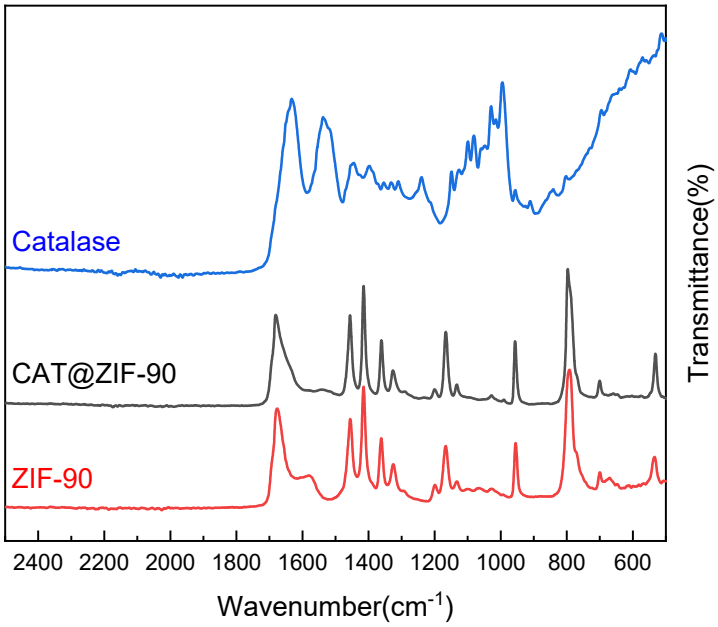


***Figure S4.*** *FTIR spectra of ZIF-90 before and after the addition of catalase.*

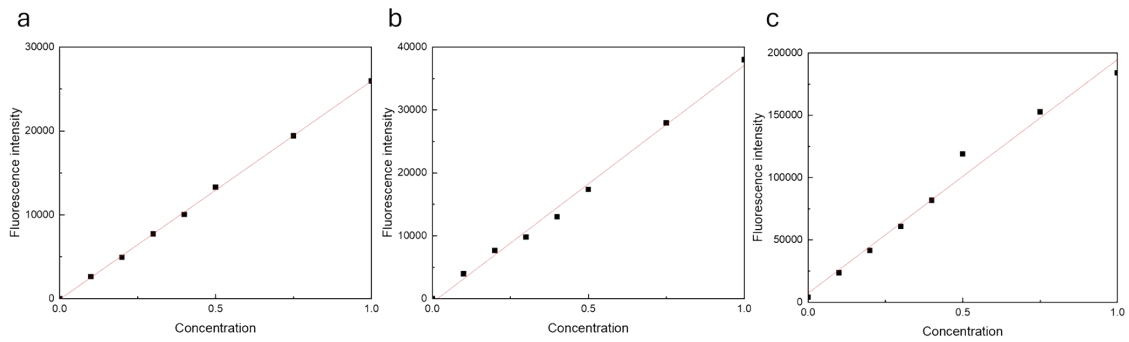


***Figure S5.*** *Standard curves used for calculating (a) catalase, (b) collagenase and (c) DOX loading.*

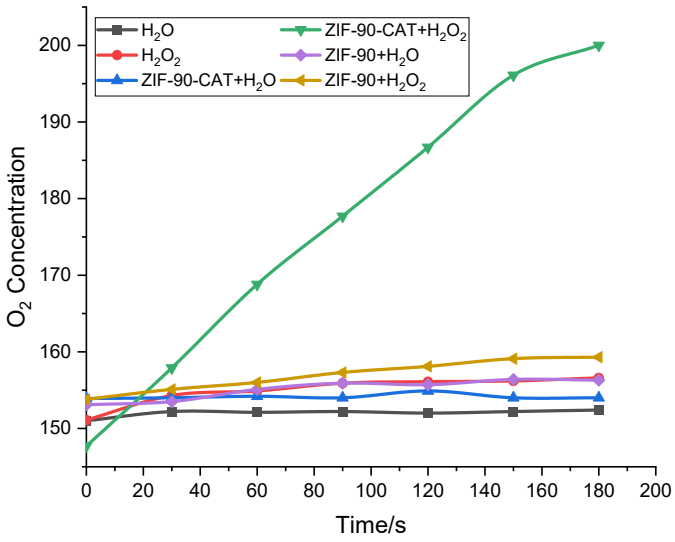


***Figure S6.*** *Changes in oxygen concentration in different solutions after the addition of various ZIF-90 samples.*

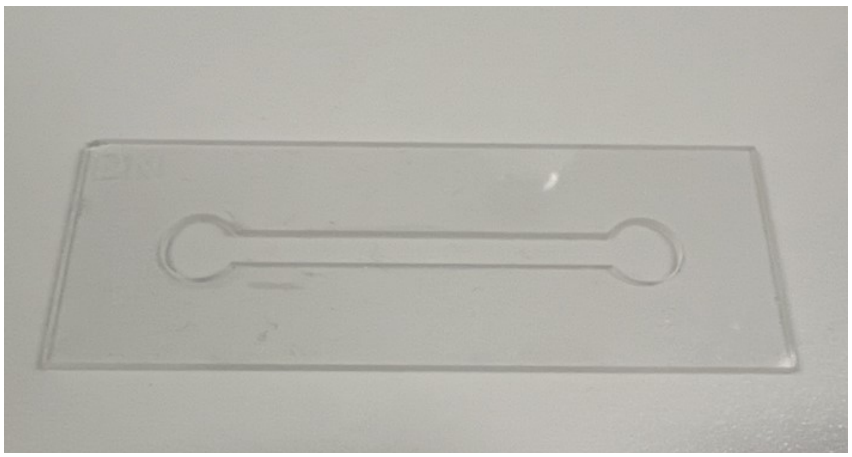

***Figure S7.*** *Glass slide used for motion tracking.*

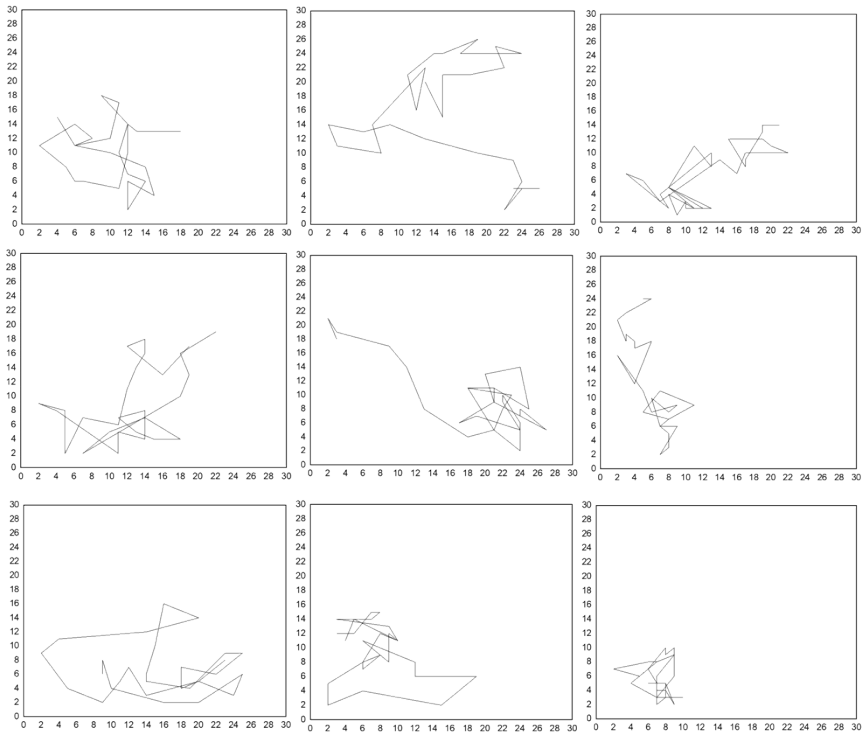

***Figure S8.*** *Representative nanomotor motion trajectories at a hydrogen peroxide concentration of 0 mM.*

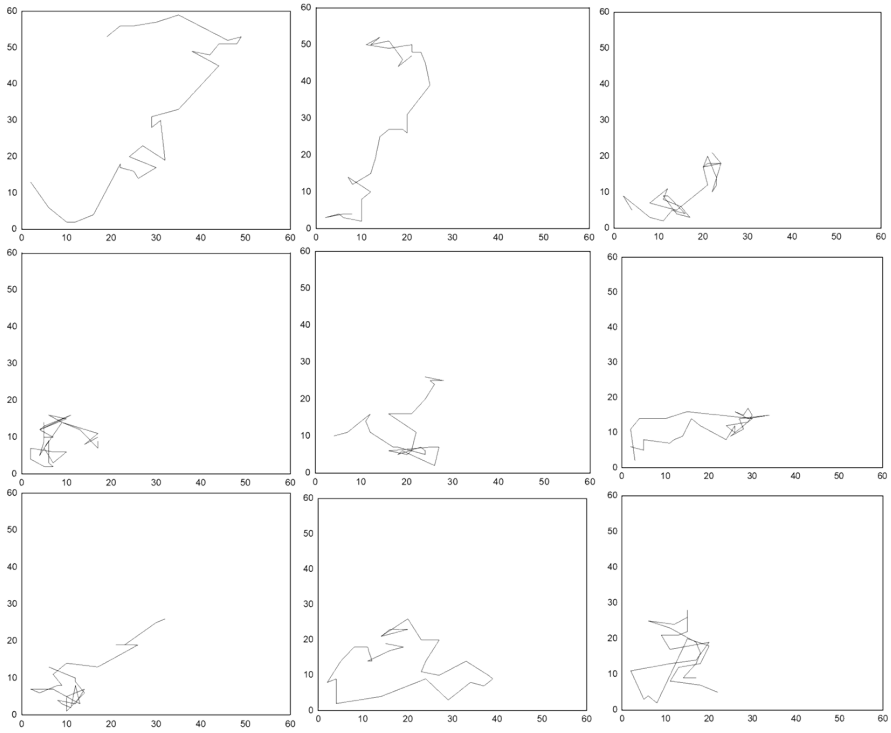

***Figure S9.*** *Representative nanomotor motion trajectories at a hydrogen peroxide concentration of 50 mM.*

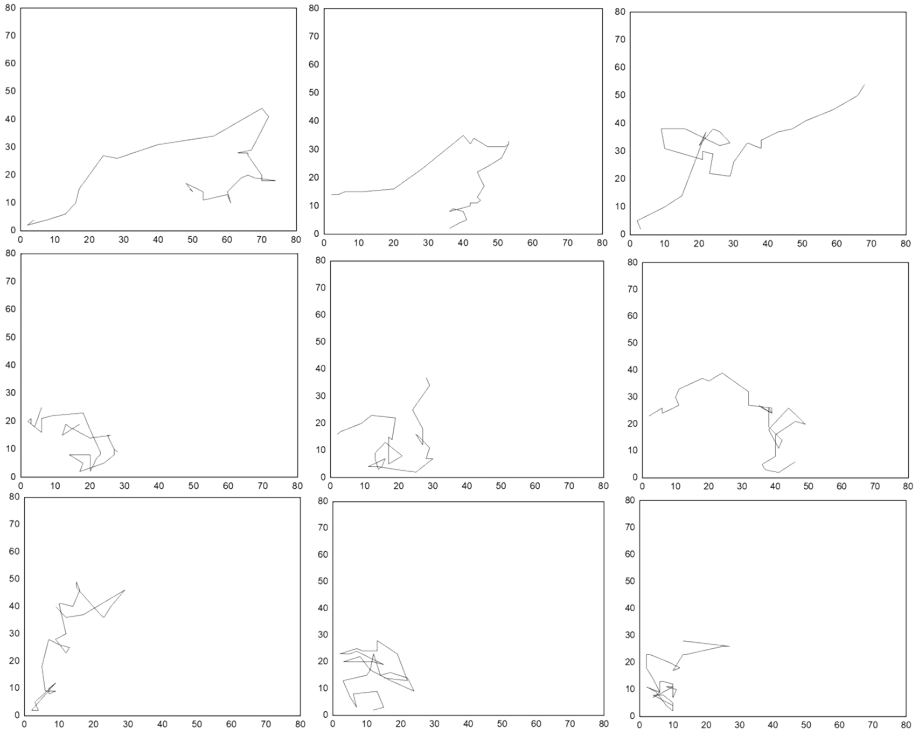

***Figure S10.*** *Representative nanomotor motion trajectories at a hydrogen peroxide concentration of 100 mM.*

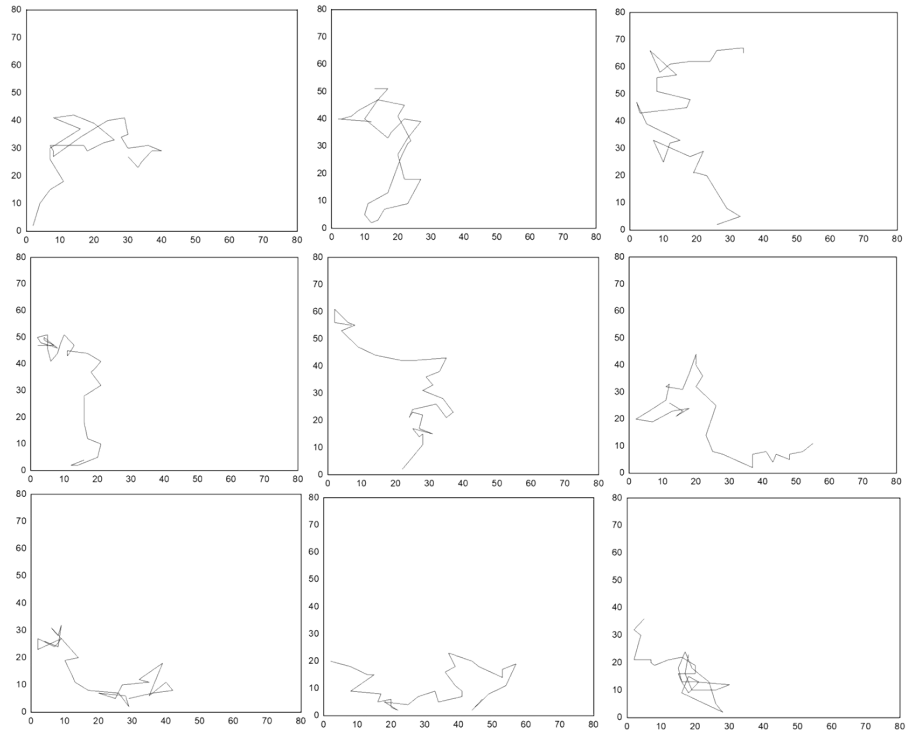

***Figure S11.*** *Representative nanomotor motion trajectories at a hydrogen peroxide concentration of 200 mM.*

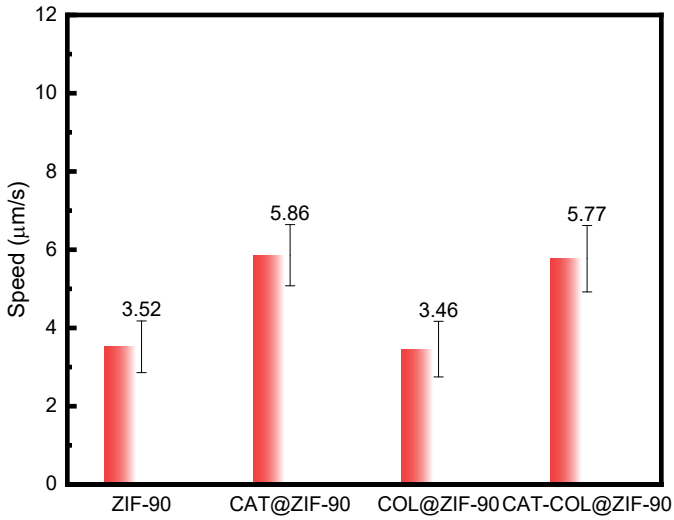


***Figure S12.*** *Average speeds of different nanomotors under 200 mM $H_2O_2$.*

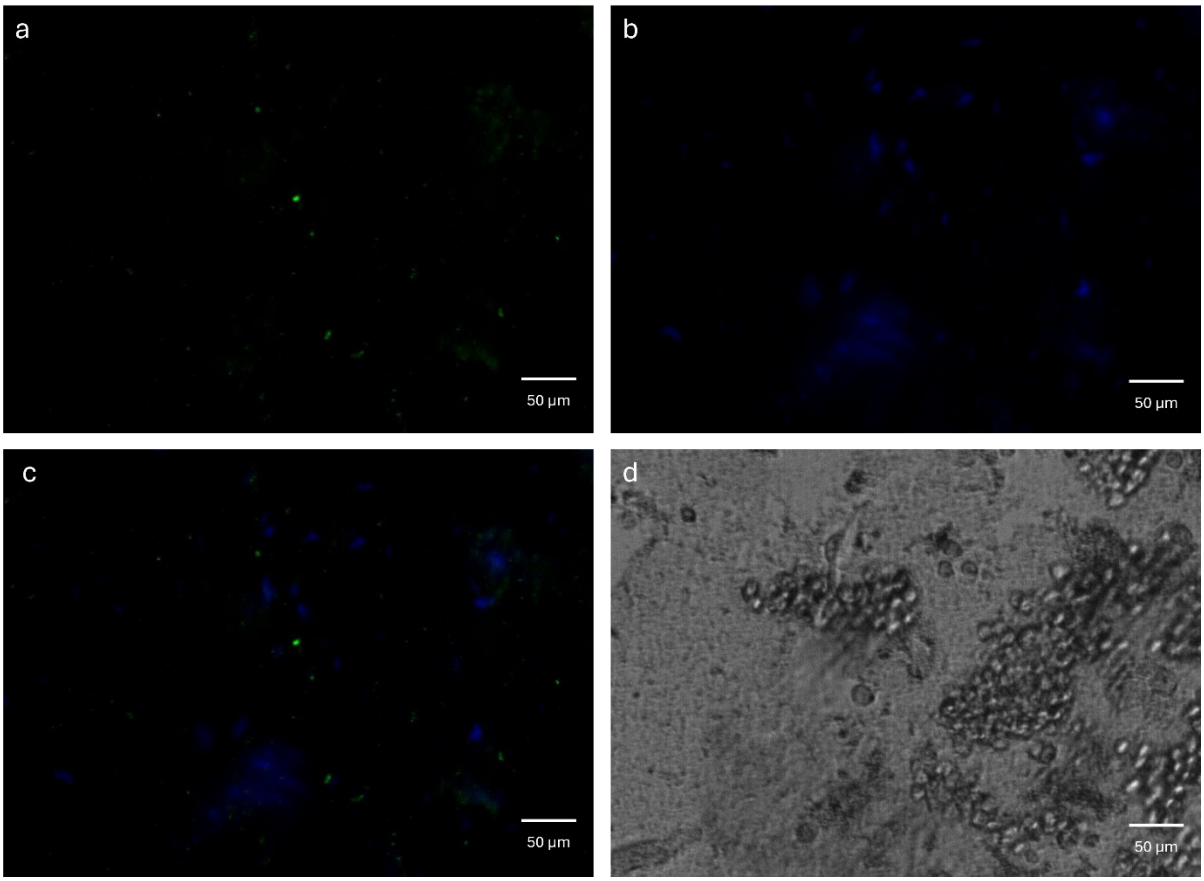


***Figure S13.*** *CLSM images of nanomotors co-cultured with 4T1 cells: (a) catalase fluorescence (green), (b) collagenase fluorescence (blue), (c) merged fluorescence image, and (d) corresponding bright-field image.*

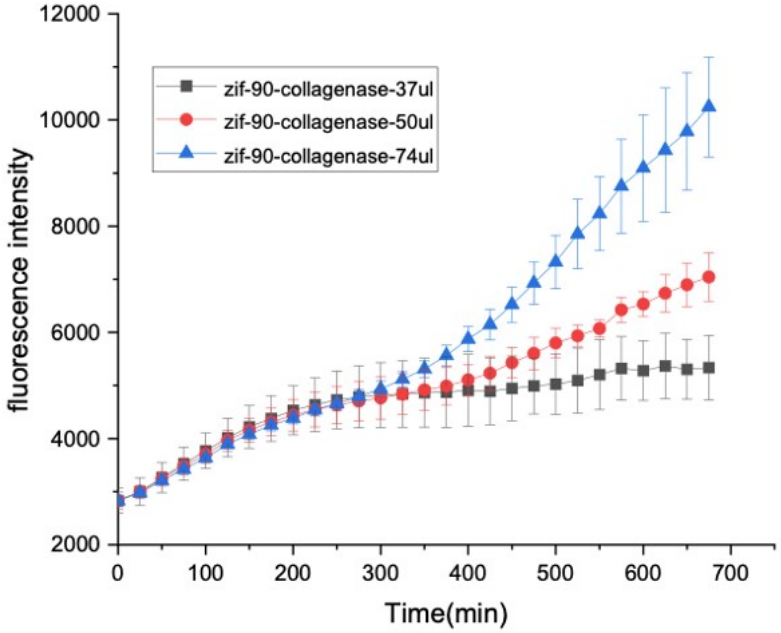


***Figure S14.*** *Fluroescence intensity change with time of FITC-labelled gelatin decomposition catalyzed by the nanomotors.*

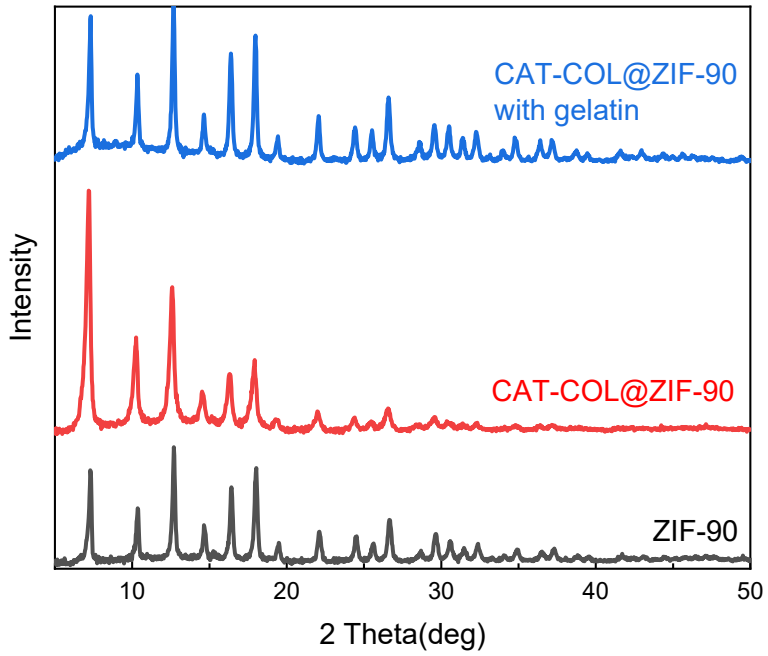


***Figure S15.*** *XRD patterns of the nanomotors before and after gelatin treatment.*

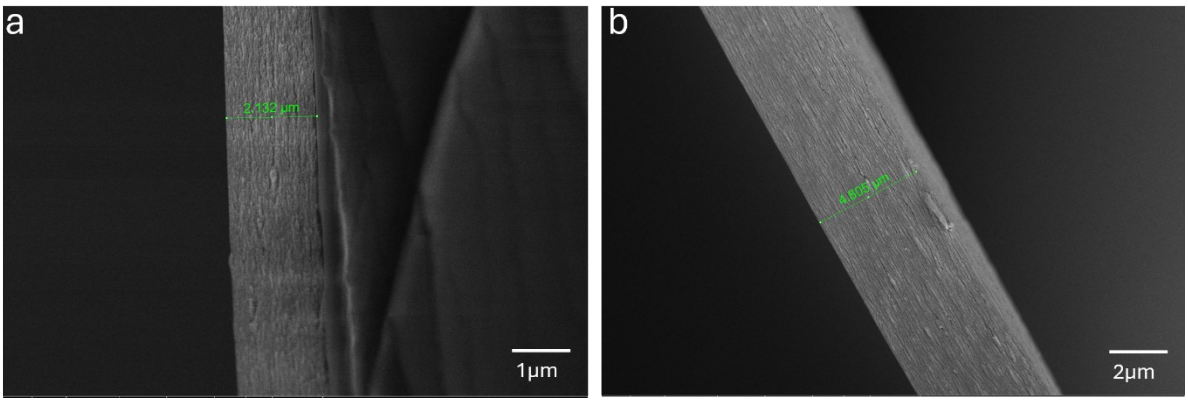


***Figure S16.*** *Crosssectional SEM images of collagen films prepared at different thicknesses. (a) 2 µm-thickness and (b) 5 µm-thickness.*

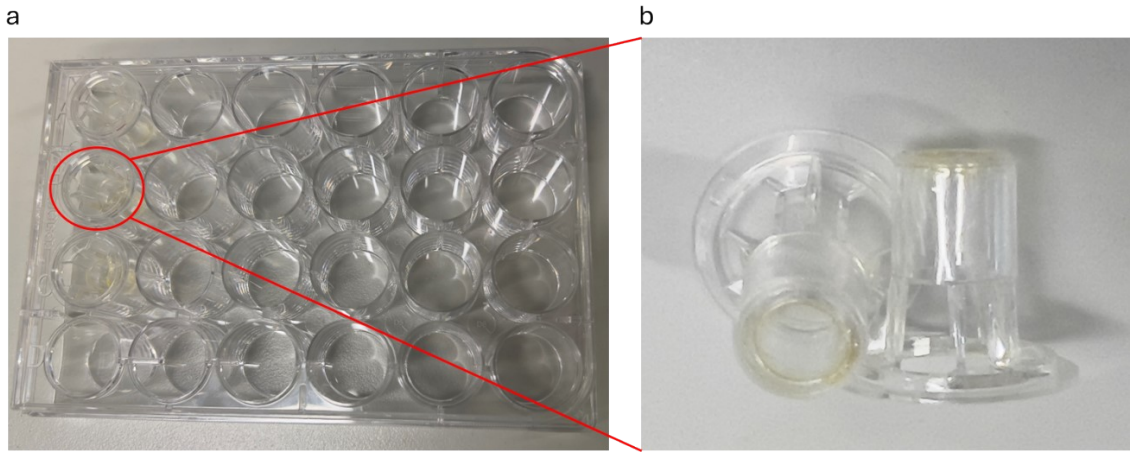


***Figure S17.*** *Photograph of the model used to test the nanomotor's ECM penatration ability (a) 24-well plate with Transwell; (b) Transwell with collagen film.*

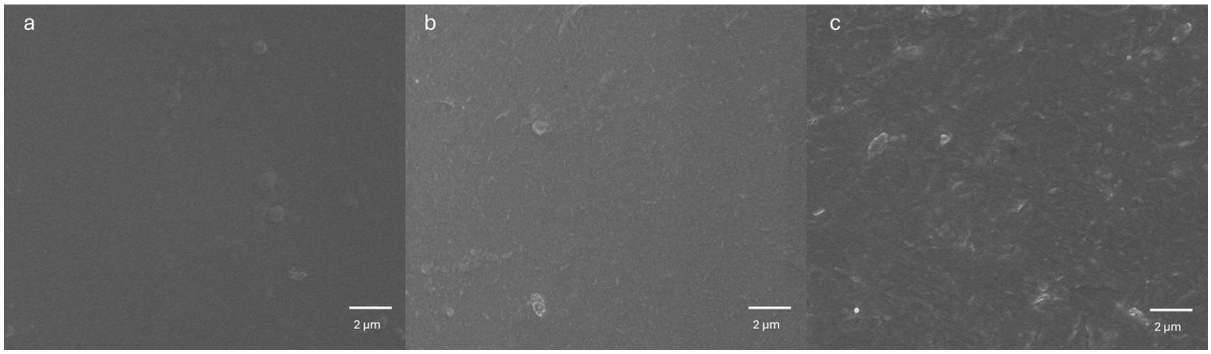


***Figure S18.*** *SEM images of collagen film re-hydrated with (a)$H_2O_2$ solution, (b) ZIF-90-DOX, (C) CAT@ZIF-90-DOX after drying.*

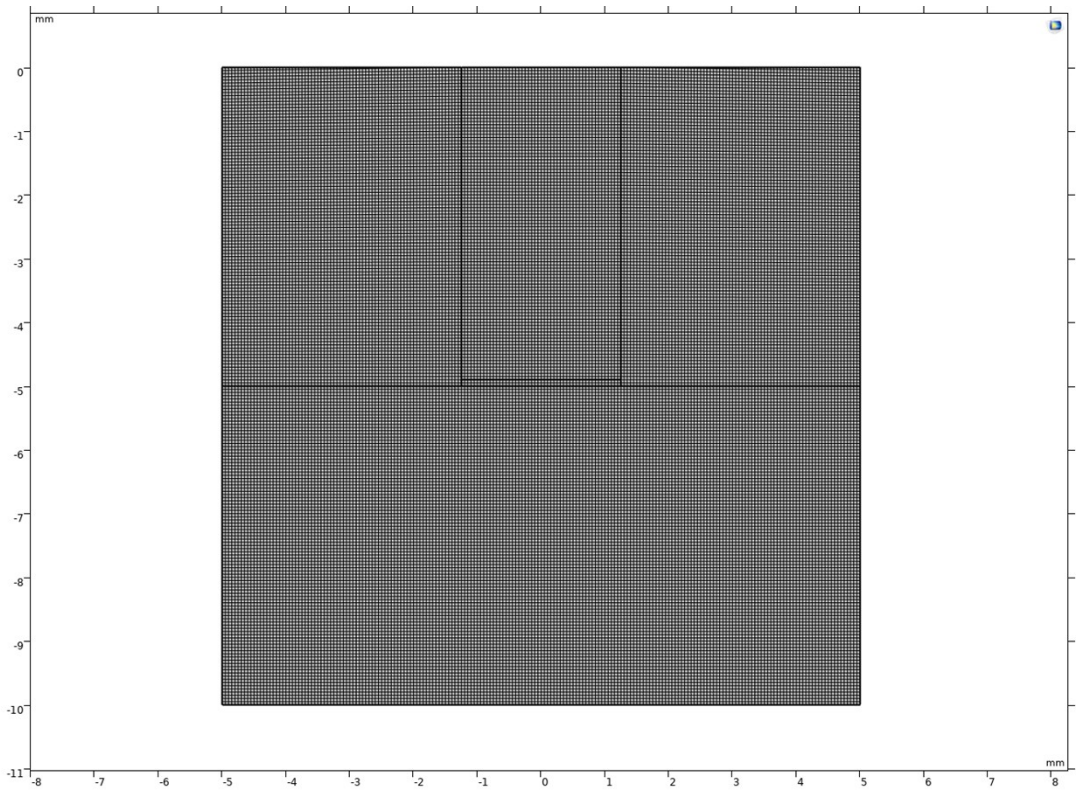


***Figure S19.*** Example of the model mesh.

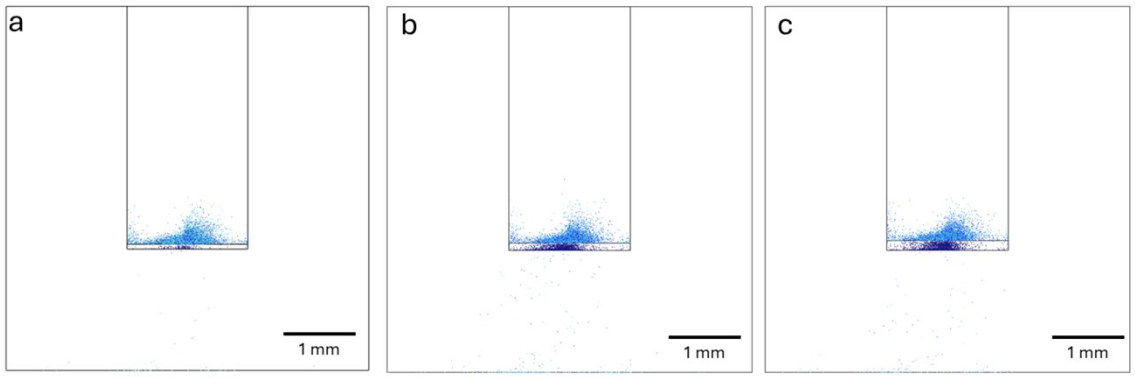


***Figure S20.*** *Simulated nanomotor penetration through the collagen film in COMSOL Multiphysics environment. (a) ZIF-90-DOX with 1 µm-thickness collagen film; (b) CAT-COL@ZIF-90-DOX with 2 µm-thickness collagen film; (c) CAT-COL@ZIF-90-DOX with 4 µm-thickness collagen film.*

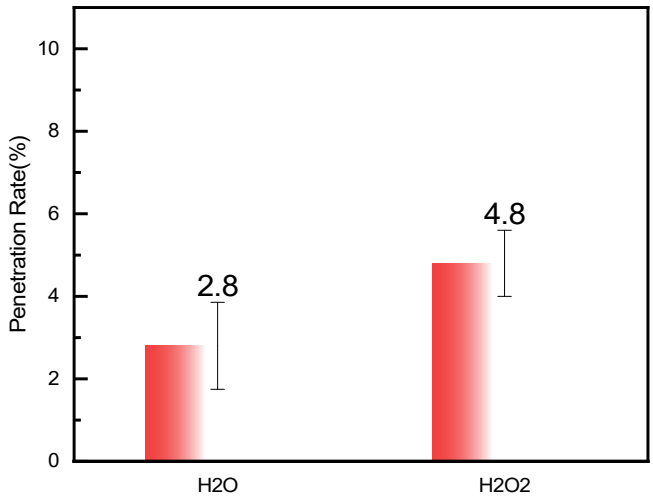


***Figure S21.*** Penetration efficiency of nanomotors in water and 100 μM $H_2O_2$ solution.

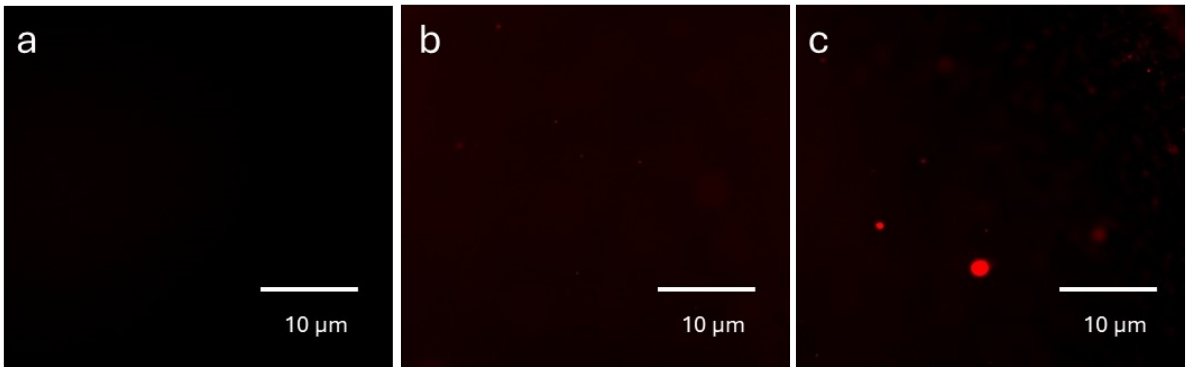


***Figure S22.*** *Confocal microscopy images after co-culturing the spheroids with (a) ZIF-90-DOX; (b) CAT@ZIF-90-DOX and (c) CAT-COL@ZIF-90-DOX.*

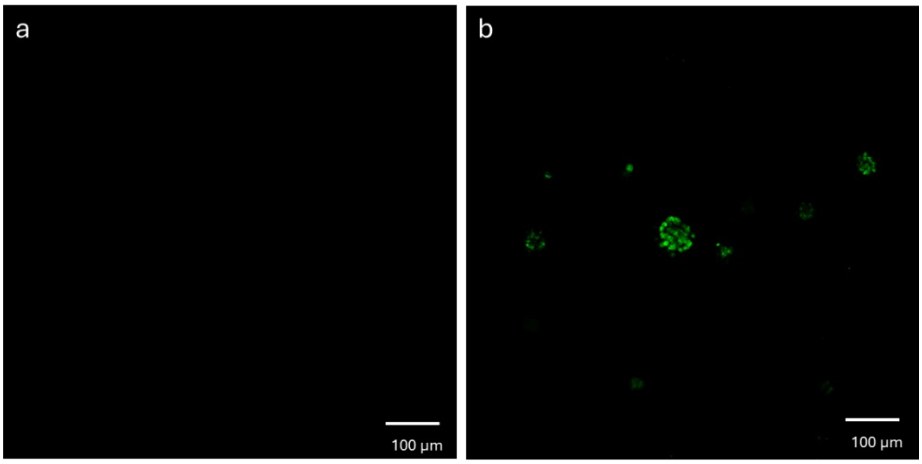

***Figure S23.*** *Confocal microscopy images of the spheroids with added ZIF-90: (a) dead cells; (b) live cells.*

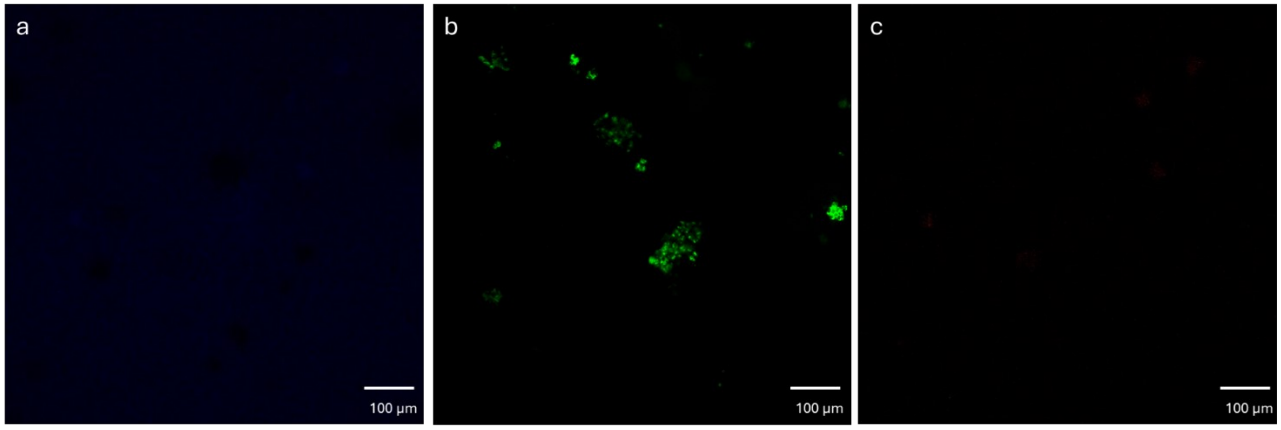


***Figure S24.*** *Confocal microscopy images of spheroids with added CAT@ZIF-90-DOX: (a) dead cells, (b) live cells and (c) DOX.*