Evaluating the collective dispersion of magnetic-enzymatic nanomotors

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Many treatments are based on the systemic administration of high amounts of therapeutic drugs, which leads to side effects and limited accumulation at the target side. Therefore, methods to efficiently administer, penetrate and locally release the drugs such as smart nanoparticles (NPs) for precision medicine are highly needed. For this, NPs with self-propelling properties, which are called nanomotors, have been proposed as drug delivery systems able to overcome these limitations [1].

However, the fundamental understanding of the collective movement i.e. swarming behavior of these nanomotors is still lacking. And many nanomotor approaches are either showing high velocities or directional steering abilities, but not both at once.

Here, we present nanomotors with dual functionalities: they can be enzymatically powered and magnetically steered. These properties are being investigated as a novel strategy to deliver drugs with high precision.

METHODS & MATERIALS

Our nanomotors are 500 nm polymeric nanoparticles carrying superparamagnetic nanoparticles (SPIONs) on their surface giving the nanoparticles their magnetic properties. The nanoparticles were functionalized by using urease as activating enzyme [2].

To apply different magnetic field configurations, a permanent magnet array, a so called Halbach-ring, has been developed, able to apply homogeneous and gradient magnetic fields [3,4]. A magnetic particle, carrying a magnetic moment $\vec{m}$ is experiencing a force of the form

$$\vec{F} = \nabla(\vec{m} \cdot \vec{B})$$

which is pulling the nanomotors towards higher magnetic field strength $\vec{B}$. The direction of the force and therefore the direction of movement can be chosen as desired, by rotating the permanent magnet ring.

The movement behavior was analyzed using image analysis tools (Matlab) of the recorded videos of swarming nanomotors. This allows for a better understanding and quantification of the collective dispersion under different experimental conditions, such as the concentration of fuel (urea) or magnetic field configuration.

RESULTS

The results show swarming behaviors in the presence of the fuel for nanomotors due to their enzymatic activation, meaning they spread over a larger area and form pattern of higher and lower nanomotor concentrations. When applying a magnetic gradient field, the nanomotors showed directionality due to the presence of a magnetic force. The conducted image analysis gains an insight into these combined movement behaviors.

References

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Figures

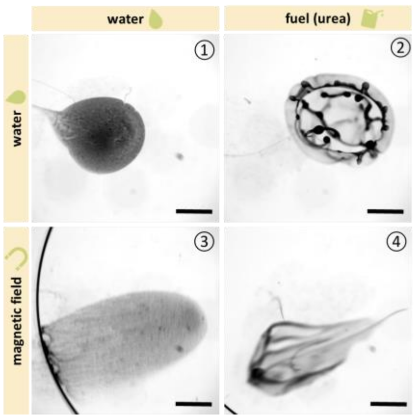

Figure 1. Representative snapshots from the recorded videos for each condition: 1) control, nanomotors in water show passive diffusion and sedimentation 2) fuel, nanomotors in urea show active propulsion and pattern formation 3) nanomotors in water and magnetic gradient field show directional pulling, but also sedimentation 4) fuel and magnetic field, nanomotors show active propulsion and a fast directional movement. Scale bar 2 mm.