Harnessing Bioengineered Magnetic Nanoparticles for Advanced Theranostics

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Magnetic nanoparticles are invaluable for theranostics, integrating multiple diagnostic and therapeutic applications, such as targeted drug delivery, magnetic hyperthermia, and imaging. Mostly prepared ex vivo via wet chemical methods, their biocompatibility and solubility under physiological conditions require critical evaluation. A promising alternative is the use of biological nanocompartments for synthesis via biomineralization, enabling nanoparticles tailored for in vitro and in vivo applications while minimizing adverse effects. Naturally occurring nanocompartments like ferritin (diameter 8 nm) and encapsulin (diameter 30 nm) facilitate biomineralization of Fe and other 3d metal ions, forming Fe oxides, hydroxides, and ferrites with tunable properties [1,2]. Their size and anisotropy can be tuned, though some exhibit reduced performance due to polycrystallinity and defects.

We investigated ferritin-based and encapsulin-derived nanoparticles offering innovative strategies for precise magnetic control in biological systems. Ferritin nanoparticles, with a genetically tunable protein cage, enable controlled biomineralization. Doping of 7% Co for Fe enhances their magnetic blocking temperature from 35 K to 137 K and thus, improve inductive heating and enabling rapid, reversible spatial manipulation within cellular environments at high intracellular stability and traceability. Similarly, encapsulin nanocompartments enable fully genetically controlled biomineralization of 30 nm iron oxide cores (Fig. 1), forming quasicrystalline structures with mixed para- and ferrimagnetic behavior. These nanoparticles generate magnetic moments (10–15 $A \cdot m^2$ per cell), comparable to conventional exogenous labels, facilitating magnetic-activated cell sorting (MACS) and precise cell manipulation. Their ability to enable magnetic control without external agents makes them valuable for advanced biomedical applications.

The presented works are highly interdisciplinary with contributions from Biologists, Chemists, and Physicists. The contributions M.A. Abakumov, I.B. Alieva, I. Beer, S.-V. Bodea, F. Curdt, M.V. Efremova, M. Farle, T. Feggeler, J. Franke, A.S. Garanina, P. Hagemann, N.P. Ivleva, N. Josten, D.A. Kuckla, R. Lavrijsen, R. Meckenstock, A. Neusch, C. Monzel, I.P. Novoselova, H. Ohldag, L.N. Panzl, S. Sadik, A.S. Semkina, F. Sigmund, N. Tetos, G.G. Westmeyer, M. Winklhofer, S. Wintz are highly acknowledged.

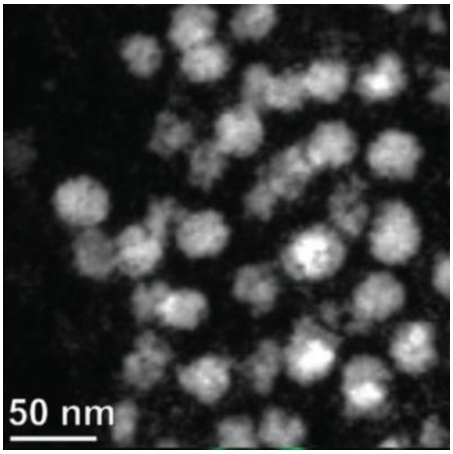

Figure 1. Dark field scanning transmission electron microscopy image of encapsulin-derived 30 nm Fe oxide nanoparticles [2].

References

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