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A novel method for magnetic particle optical imaging

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Abstract

A novel method for magnetic particle optical imaging that exploits the change in transmitted light intensity of magnetic nanoparticles in the presence of a magnetic field allows for high resolution and sensitive imaging of magnetic nanoparticles. Since the method uses direct optical imaging, the theoretical resolution is no longer governed by the properties of the material, but depends on the optical diffraction limit. In future work, it is expected that high-resolution magnetic nanoparticle imaging in vivo will be achieved by selecting wavelengths of light that have a high penetration capacity into biological tissue.

I. Introduction

Magnetic particle imaging (MPI) using magnetic nanoparticles as tracers was introduced in Nature in 2005 and the first device was developed to demonstrate its feasibility [1]. MPI can effectively improve contrast and enable 3D functional imaging of a wide range of tissues, including vascular perfusion imaging, tumour imaging and targeted drug monitoring [2–4]. However, the imaging resolution of MPI is always dependent on the magnetic nanoparticles, and particles with narrower full width at half maximum intensity (FWHM) of the magnetisation conductivity can effectively improve the resolution of imaging. In addition, the particles are accompanied by relaxation effects which are detrimental to the imaging resolution. The resolution of optical imaging is generally close to the diffraction limit and can be further improved to tens of nm by super-resolution imaging techniques [5]. Therefore, if optical imaging is used to image magnetic nanoparticles specifically, not only can high contrast be maintained, but the resolution of the imaging will no longer be constrained by the nature of the material.

We proposed a novel magneto-optical imaging method for magnetic nanoparticle by exploiting its unique superparamagnetic properties as well as the optical properties. And its imaging capability has been validated in vitro experiments, and further work is in progress.

II. Methods and materials

Magnetic nanoparticle is approximately a few tens of nanometres in diameter and therefore undergo Rayleigh scattering when exposed to monochromatic light. Furthermore, due to their superparamagnetic properties, magnetic nanoparticles in the colloidal state are in thermal equilibrium and well dispersed in the absence of a magnetic field [6]. Under the influence of an applied

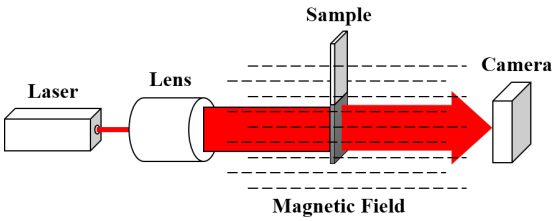

Figure 1: Schematic diagram of the magneto-optical imaging device for magnetic nanoparticles.

magnetic field, these particles can quickly aggregate and orient themselves into magnetic chains, which greatly reduces the scattering effect and thus improves the penetration of light [7, 8]. By controlling the magnetic field, the intensity of the transmitted light can be varied, and the magnetic nanoparticles can be detected by varying the intensity of the transmitted light before and after the magnetic field.

The schematic diagram of the experimental setup is shown in Fig. 1. Experiments were carried out using diluted 10 μg/mL of water-based iron oxide magnetic nanoparticles MHP-50 (Ocean NanoTech) as magneto-optical markers, with a laser generating monochromatic light through the sample after extended beam collimation and finally image acquisition using a camera. The effective resolution depends on the image element size of the complementary metal oxide semiconductor (COMS) chip when the target is magnified without the use of a lens set, so that a resolution of at least 10 μm can be achieved with this method.

It is assumed that the transmitted light intensity is I_0 before the magnetic field is applied and the transmitted light intensity is I_B after the magnetic field is applied. The noise generated using the COMS is I_{Noise}, which mainly includes plot noise, dark current noise, and readout noise. The difference in light intensity before and after the application of a magnetic field by a magnetic nanoparticle can be expressed as the signal of a magnetic nanoparticle S_{MNP}, is given by:

$$S_{MNP} = I_B - I_0 - I_{Noise} \tag{1}$$

III. Results and discussion

The transmitted light intensity is enhanced by the magnetic field and is restored after the field is removed. Throughout the process the background does not change with the magnetic field and therefore there is a strong contrast. The results are shown in Fig. 2, where the magnetic nanoparticle reagent and a 30 μm copper wire are multiplied in a 10 mm wide cuvette as can be clearly seen in the original image I_0.The brighter parts of image $I_B - I_0$ are the light from the magnetic nanoparticles,

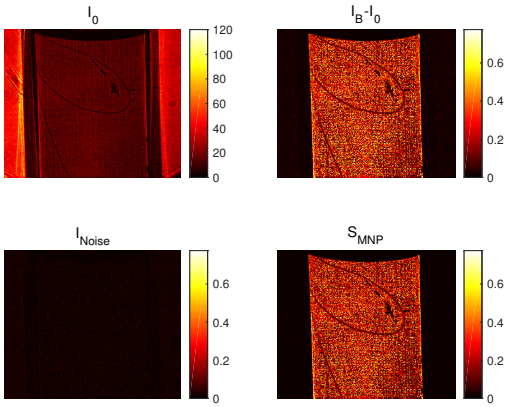

Figure 2: Results of optical imaging of magnetic nanoparticles in vitro.

while the darker parts are the colorimetric tube and the surrounding background. It is important that the 30 μm copper wire can still be clearly distinguished, which indicates that the imaging resolution is at least below 30 μm. Comparing the images I_{Noise} with S_{MNP}, the magnetic nanoparticles can be specifically detected with a signal to background ratio (SBR) of approximately 18.3 dB.

Different materials transmit different light intensities due to different transmittances, so both the magnetic nanoparticles and surroundings can be observed by image I_0; while specific imaging of the magnetic nanoparticles can be achieved before and after the application of a magnetic field, with high contrast.

The ability to detect light penetration into the human body is fundamental to achieving optical imaging of magnetic nanoparticles, and human tissue has good transmission near the near-infrared band of 700-1000 nm, which can act as an optical window [9]. The temporal resolution of this imaging method is one frame per second, and the available references confirm that optical imaging of biological tissues can be achieved in the NIR window from μm to mm depth [10, 11]. Thus rapid imaging of magnetic nanoparticles using optical means becomes possible within a certain thickness.

IV. Conclusion

The magnetic particle optical imaging technique proposed in this paper can effectively improve the resolution compared to conventional magnetic nanoparticle imaging techniques, and high contrast detection of magnetic nanoparticles in vitro has already been achieved using this method. Future work is expected to enable imaging of magnetic nanoparticles in vivo by selecting the right wavelength of light.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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