Magnetic Particle Imaging Opportunities and Challenges on the Way to the Clinic

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Magnetic Particle Imaging is a rising medical imaging technique which visualizes the distribution of magnetic particles within the human body. Besides direct visualization of blood flow dynamics, the technique can exploit the particle magnetization dependence on micro-environmental physical parameters as microsensors to measure temperature, viscosity, or binding state. Furthermore, the particles can also act as heat generators when exposed to suitable high frequency fields enabling magnetic fluid hyperthermia and triggered drug delivery. This work reviews the opportunities offered by MPI and highlights the challenges on the way to becoming an established clinical imaging modality.

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I Introduction

Magnetic Particle Imaging (MPI) was first proposed in 2005 by Gleich and Weizenecker from Philips Reasearch Laboratories in Hamburg [1]. The technology uses the nonlinear magnetization curve of magnetic nanoparticles, which act as a tracer material, to determine their spatial distribution within the patient [2]. Particles suitable for MPI are well tolerated by the human body and suitable tracer systems are available on the market for MRI imaging [3]. In contrast to MRI, MPI only images the distribution of the tracer, therefore the anatomy of the patient remains unknown. This represents a challenge and an advantage at the same time, as it increases the contrast but makes the images harder to interpret.

The goal of MPI is not to challenge or replace established imaging technologies like MRI or CT, but it can offer the possibility to improve situations, where current solutions are not optimal or fail. After the first years focussed on the instrumentation research, many medical application scenarios were demonstrated to prove that MPI can solve currently unmet needs within the clinic. The application scenarios range from stoke imaging [4], cell tracking [5] to functional imaging [6] and many more.

As MPI has proven its clinical potential in preclinical studies, the technology must now progress towards clinical scale systems and the acquisition of the first human images [7, 8].

II Opportunities and challenges for clinical usage

MPI offers a specific set of imaging properties: it comes with realtime capability with a speed of more than 46 volumes per second [9], no penetration depth dependence, high sensitivity down to pMol iron per ml [7], good image resolution down to submilimeter range [10] and a very high contrast to noise ratio due to no background image. Although not all these values were achieved until now within the same system, the unique combination offers high potential for clinical practice. MPI offers some high potential fields, some of them are shortly described in the following:

1) As the particles react to their micro-environment, they can be exploited as micro sensors within the human body with suitable functionalization. By doing so, MPI might be a nonradiation alternative for PET imaging [11].
2) The systems can be built with low footprint, low power consumption and even mobile if the resolution is not the strongest requirement. For stroke detection for example, a resolution of below 1 cm is sufficient for the diagnosis and classification. With this a small, low cost, mobile system can be built that can work within the intensive care unit or even in emergency vehicles [7].
3) As the field generators in MPI are typically able to provide a large flexibility on the field topology, the system can be used to steer and guide magnetic devices as small-scale robots for microsurgery or drug delivery systems [8]. There are many more potential benefits for a clinical scale MPI system. However, the upscaling does not come without new challenges. The larger bore diameter requires larger coils which lead to high power consumption and high voltages due to self induction. While the latter can be handled with proper coil designs, the power consumption remains a challenge. The best way to solve the power problem is to shift the attention towards the particle system. The imaging resolution of an MPI device is influenced by the gradient strength and the particle magnetization curve. If the particle magnetization is steeper, ideally a step response, the gradient can be chosen smaller to achieve the same resolution. As the gradient strength is linked quadratically to the power consumption of the gradient field generator, the particle system has a strong impact on the total power consumption. Recent research by Tay et al. has shown that tailored particle system can improve the image resolution by a factor of 10 and the signal to noise factor by 40 [12]. This resolution benefit could be omitted to reduce the gradient by a factor of ten and reduce the power consumption therefore by a factor of 100.

III Conclusion

MPI is an evolving medical imaging technology that offers a unique set of imaging parameters. On the way towards an established clinical imaging technology many challenges for particles synthesis and instrumentation are active research fields, but

still need time and resources to be solved. The medical possibilities are various and can improve many clinical scenarios.

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