Innovative Journal of Medical Imaging
Volume-1, Issue-1, Page Number: 9-12
Website: https://spjmhs.com/index.php/ijmi
Review Article **ISSN: XXXX-XXXX**

REVIEW ARTICLE ON MAGNETIC PARTICLE IMAGING (MPI)

[1]Himal Rai, [1]Avinash Chaubey, [1]Prashant Kumar Jha*, [1]Debasis Roy, [1]Rupam Gayen, [2]Satish Kumar Jha, [1]Supriyo Roy

[1]Brainware University Kolkata, India.
[2]Bhaikaka University, Karamsad, Gujarat
Corresponding Author: Prashant Kumar Jha

DOI: https://doi.org/10.62502/ijmi/3njqg492

ABSTRACT

Due to concerns regarding the complications associated with gadolinium-based contrast agents (GBCAs) in MRI scans, the field of radiology is shifting towards saferoptions such as superparamagnetic iron oxide nanoparticles (SPIONs) and Magnetic Particle Imaging (MPI). MPI, an innovative tomographic technology, employs SPIONtracers to achieve real-time, high-definition imaging without the use of ionizing radiation, thereby ensuring safety by operating at excitation frequencies below 25 kHz. The chemical and physical characteristics of MPI highlight its safety compared to otherimaging modalities, utilizing the nonlinear magnetization curve of SPIONs for radiation-free imaging. Tracers like Resovist and Feraheme influence spatial resolution and signal intensity in MPI. Applications of MPI encompass effective cell tracking, promising advancements in vascular imaging, and potential uses in oncologyand functional imaging. The assessment concludes that MPI is a low-risk approach, particularly benefiting patients with chronic kidney disease and those susceptible to iodinated contrast, with future directions focusing on refining techniques, creating more advanced nanoparticles, and broadening applications across various medical domains.

Keyword: Magnetic Particle Imaging, Contrast Media, SPION

Article Received: Feb-16, 2024	Acceptance: Feb-28, 2024	Published: March-20, 2024

Introduction

The realm of radiology is evolving swiftly, and this is particularly evident with the use of gadolinium-based contrast agents (GBCAs) in magnetic resonance imaging (MRI) due to their safety profile. However, recent findings have highlighted potential complications of these agents, particularly for patients with nephrogenic systemic fibrosis (NSF), especially those withstage 4 or 5 renal disease (known as chronic kidney disease or CKD, with a glomerular filtrationrate below 30 ml/min per 1.73 m2). Avoiding the risk posed by GBCAs is crucial, especially for vulnerable patients. As an alternative, superparamagnetic iron oxide nanoparticles (SPIONs) have emerged, with Magnetic Particle Imaging (MPI) being a notable advancement in this domain. MPI is a novel tomographic technology that utilizes a tracer called a superparamagnetic iron oxide nanoparticle (SPION), consisting of a surface coating (typically polyethylene glycol, carboxy dextran, or dextran) surrounding a core of magnetite (Fe3O4) or maghemite (Fe2O3). This technique enables real-time, high-resolution, and highly sensitive imaging without ionizing radiation, making it safer for specific applications compared to otherimaging methods. By adjusting the magnetic properties of an iron oxide nanoparticle with a magnetic field gradient, which is generated by the nonlinear magnetic properties of thenanoparticle, MPI can achieve exceptional image clarity. This unique approach allows MPI excitation frequencies to remain below 25 kHz, independent

of wavelength, while achieving a resolution that is more than six orders of magnitude finer than the wavelength, typically in millimeters [1,2,3].

Spatial coding in MPI is achieved through external magnetic gradient fields, while signal production involves periodically changing external magnetic fields. By employing sophisticated tracers and optimized scanner configurations, MPI can achieve a spatial resolutionof approximately 1 mm. The essence of MPI lies in leveraging small magnetic particle technology, which is not only widely employed for its non-destructive nature but also for its ease and speed of deployment. Its radiation-free characteristic makes it patient-friendly, utilizing the nonlinear magnetization curve of superparamagnetic nanoparticles, particularly SPIO.

The breakdown of these particles in the liver post-imaging is standard since they are already part of clinical MRI practices. Signal creation involves the use of periodically changing externalmagnetic fields, while spatial coding utilizes external magnetic gradient fields. Advanced tracers and optimal scanner setups contribute to achieving the desired spatial resolution of around 1 mm. Furthermore, the MPI scanner maximizes the unique properties of SPIOs by applying specific magnetic fields through a multi-layered coil topology, adapting its response accordingly. The primary signal for 3D visualization is the tracer response, which is amplifiedthrough receiving coils.

The core essence of Magnetic Particle Imaging (MPI) hinges on the utilization of SPION (Superparamagnetic Iron Oxide Nanoparticle) tracers, which are vital components enabling thetechnique. These tracers consist of iron oxide nanoparticles exhibiting spontaneous magnetization under the influence of an applied magnetic field, facilitating the identification ofbodily fluids like blood. Unlike the human body, which lacks a magnetic interface for magneticfield imaging, even a minor magnetic field can induce a directional shift. Notably, the propertiesof SPIONs significantly impact the resolution and signal intensity achievable with MPI.

Current MPI tracers in use, such as Resovist and Feraheme, are not developed solely based onMPI physics but rather employ imaging principles. For instance, the T2 relaxation time is shortened in MRI by incorporating Nano magnetic material, which introduces magnetic micro- gradients to external magnetic fields, causing a loss of phase coherence in resonance protons and resulting in signal voids in the MR image.

MPI finds diverse applications, notably in cell tracking. Feraheme, following its FDA approval, has demonstrated efficacy due to its small size and easy absorption by body cells, making it suitable for cell tracking. Notably, there are no known side effects even for individuals with kidney issues receiving iodinated sensitive contrast.

Innovative approaches have been explored to tailor tracers compliant with MPI physics theory. Modifications in particle size and shape have yielded tracers with significant saturation magnetization, excellent resolution, and sensitivity in MPI, surpassing commercially availableoptions like VivoTrax. These bespoke tracers have proven effective in real-time and extended monitoring of stem cells in vivo. Additionally, MPI holds promise in vascular imaging, surpassing the standard CT perfusion method, which carries ionizing radiation risks. MPI's capabilities have been demonstrated in measuring cerebral blood flow in live mice and imagingstroke-related perfusion changes in rodents.

Moreover, MPI's potential extends to cancer imaging by leveraging the enhanced permeability and retention (EPR) effect, allowing for tumor detection even in early stages. Functional imaging applications of MPI include assessing organ function and monitoring therapies through dynamic SPION distribution imaging, demonstrating high sensitivity and reduced scan duration. In conclusion, MPI stands as a low-risk diagnostic imaging method, benefiting patients with chronic kidney disease and those at risk with iodinated contrast. Its non-invasive, radiation-free nature coupled with high resolution and sensitivity is revolutionizing diagnostic imaging, with ongoing advancements focusing on refining tracer properties

and expanding applications across diverse medical fields. Future trends in MPI entail optimizing imaging techniques, developing advanced MNPs, and integrating with other imaging modalities for comprehensive diagnostic approaches. Efforts to address safety concerns and standardize protocols are expected to drive wider adoption of MPI in research and clinical settings, pavingthe way for breakthroughs in medical imaging and diagnostics.

References:

1. Edward A. Neuwelt,1,2 Bronwyn E. Hamilton,3 Csanad G. Varallyay,4 William R. Rooney,5 Robert D. Edelman,6 Paula M. Jacobs,7 and Suzanne G. Watnick2,8 Ultrasmall superparamagnetic iron oxides (USPIOs): a future alternative magnetic resonance (MR) contrast agent for patients at risk for nephrogenic systemic fibrosis (NSF)?
2. L.C. Wu,a Y. Zhang,c G. Steinberg,b,d H. Qu,c S. Huang,c,h M. Cheng,b T. Bliss,b F. Du,b J. Rao,d G. Song,a L. Pisani,d T. Doyle,e S. Conolly,f K. Krishnan,g G. Grant,b and M. Wintermark c A Review of Magnetic Particle Imaging and Perspectives on Neuroimaging.
3. Patrick W. Goodwill, Kuan Lu, Bo Zheng, and Steven M. Conolly An x-space magnetic particle imaging scanner
4. Chandrasekharan, Prashant; et al, (November 2018). "A perspective on a rapid and radiation-free tracer imaging modality, magnetic particle imaging, with promise for clinical translation". The British Journal of Radiology. 91 (1091): 20180326. doi:10.1259/bjr.20180326. ISSN 1748-880X. PMC 6475963. PMID 29888968.
5. Panagiotopoulos N, et al, Magnetic particle imaging: current developments and future directions. Int J Nanomedicine. 2015 Apr 22; 10:3097-114. doi: 10.2147/IJN.S70488. PMID: 25960650; PMCID: PMC4411024.
6. URL https://www.onestopndt.com/ndt-articles/basic-principles-of-magnetic-particle-testing
7. https://www.imt.uni-luebeck.de/research/magnetic-particle-imaging
8. Goodwill, Patrick (2012). "X-Space MPI: Magnetic Nanoparticles for Safe Medical Imaging". Advanced Materials. 24 (28): 3870–7. Bibcode:2012AdM....24.3870G. doi:10.1002/adma.201200221. hdl:11693/53587. PMID 22988557. S2CID 554405.
9. Bulte J.W. Superparamagnetic iron oxides as MPI tracers: A primer and review of early applications. Adv. Drug Deliv. Rev. 2019;138:293–301. doi: 10.1016/j.addr.2018.12.007.
10. Yeh, T.-C.; Zhang, W.; Ildstad, S.T.; Ho, C. Intracellular labeling of T-cells with superparamagnetic contrast agents. Magn. Reson. Med. 1993, 30, 617–625.
11. Bulte, J.W.M.; et.al. Dextran-magnetite particles: Contrast-enhanced MRI of blood–brain barrier disruption in a rat model. Magn. Reson. Med. 1992, 23, 215–223
12. Bulte, J.W.M.; Ma, et.al Selective MR imaging of labeled human peripheral blood mononuclear cells by liposome mediated incorporation of dextran-magnetite particles. Magn. Reson. Med. 1993, 29, 32–37.
13. Yu, E.Y.; et.al Magnetic Particle Imaging: A Novel in Vivo Imaging Platform for Cancer Detection. Nano Lett. 2017, 17, 1648–1654.
14. Connell, J.J.; et al. Advanced cell therapies: Targeting, tracking and actuation of cells with magnetic particles. Regen. Med. 2015, 10, 757–772.
15. Song, G.; et.al Iron Oxides Semiconducting Polymer Nanoparticle Tracer for Cell Tracking by Magnetic Particle Imaging. Nano Lett. 2017, 18, 182–189.
16. Weizenecker J., Gleich B., Rahmer J., Borgert J. Micro-magnetic simulation study on the magnetic particle imaging performance of anisotropic mono-domain particles. Phys. Med. Biol. 2012;57:7317–7327. doi: 10.1088/0031-9155/57/22/7317.
17. Connell J.J., et al. Advanced cell therapies: Targeting, tracking and actuation of cells with magnetic particles. Regen. Med. 2015;10:757–772. doi: 10.2217/rme.15.36.
18. Wu Y, Zhao RC. The role of chemokines in mesenchymal stem cell homing to myocardium. Stem Cell Rev 2012;8:243–50 10.1007/s12015-011-9293-z

19. Harting MT, Jimenez F, Xue H, et al.. Intravenous mesenchymal stem cell therapy for traumatic brain injury. J Neurosurg 2009;110:1189–97 10.3171/2008.9.JNS08158.Intravenous
20. J Weizenecker1, J Borgert1 and B Gleich1 A simulatiom study on resolution and sensitivity of magnetic particle Imaging.
21. Prashant Chandrasekharan , et al Magnetic Particle Imaging in Vascular Imaging, Immunotherapy, Cell Tracking, and Noninvasive Diagnosis
22. Xiao Han et.al The applications of Magnetic Particle Imaging: From cell to body
23. Yu, E.Y.; Bishop, M.; Zheng, B.; Ferguson, R.M.; Khandhar, A.P.; Kemp, S.J.; Krishnan, K.M.; Goodwill, P.W.; Conolly, S.M. Magnetic Particle Imaging: A Novel in Vivo Imaging Platform for Cancer Detection. Nano Lett. 2017, 17, 1648–1654.
24. Weizenecker et.al Particle dynamics of mono-domain particles in magnetic particle imaging.
25. Song, G.; Zheng et.al Magneto-Optical Nanoplatform for Multimodality Imaging of Tumors in Mice.
26. B. Gleich and J.Weizenecker, Nature 435, no. 7046, pp. 1214–7, 2005.
27. Weizenecker et al., Phys. Med. Biol., vol. 54, no. 5, pp. L1–L10, 2009
28. C. Z. Cooley et al., Neuroimage vol. 178, pp. 713–720, 2018.
29. Bonnemain B. Superparamagnetic agents in magnetic resonance imaging: physicochemical characteristics and clinical applications—a review. J Drug Target 1998;6:167–74 10.3109/10611869808997890
30. Sun C, Lee JS, Zhang M. Magnetic nanoparticles in MR imaging and drug delivery. Adv Drug Deliv Rev 2008;60:1252– 65 10.1016/j.addr.2008.03.018