International Journal on Magnetic Particle Imaging
Vol 8, No 1, Suppl 1, Article ID 2203064, 3 Pages

Infinite Science Publishing

Proceedings Article

Human-Sized Lightweight Head-Scanner Design

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Abstract

Brain imaging includes various techniques for direct or indirect imaging of the structure or function of the brain. Established clinical imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) require the referral of patients to specialized centres with stationary brain scanners in a shielded environment. However, these restrictions limit the accessibility for many people. For example, it may be difficult to assess time-critical neurological emergencies in a preclinical setting, or to monitor brain function of patients in intensive care units. Here we demonstrate the concept for a wearable brain scanner based on the magnetic particle spectroscopy technology with superparamagnetic iron-oxide nanoparticles (SPIONs) as contrast agent.

I. Introduction

An emerging experimental brain imaging technique is magnetic particle imaging (MPI) [1, 2, 3]. In contrast to conventional imaging modalities such as CT, magnetic resonance imaging (MRI), sonography and x-rays, MPI is a tracer-based imaging technique similar to Positron Emission Tomography (PET) or single photon emission computed tomography (SPECT). MPI uses magnetic fields to detect the spatial distribution of tracer agents composed of superparamagnetic iron oxide nanoparticles (SPIOs). Preclinical cardiovascular applications of MPI have been limited to small animal and phantom studies [4-10]. In a mouse model MPI has proven to be capable of detecting ischemic stroke with high sensitivity and high temporal resolution [11]. Recently, a first human-sized MPI scanner for monitoring of treated stroke patients on intensive-care units has been proposed [3]. Despite technical advances, MPI scanners remain heavy and immobile scanner units. Hence, MPI's potential clinical application would take place in a stationary setting, just like the established clinical brain imaging methods CT, MRI or PET.

In this context, magnetic particle spectroscopy (MPS), could be an interesting alternative. MPS is a measurement tool derived from MPI and has recently evolved into a versatile, highly sensitive, inexpensive platform for biological and biomedical assays, cell labeling and tracking, as well as blood analysis [12].

Here, we present a portable brain scanner-array concept based on the MPS technology for the quantitative assessment of brain perfusion. The MPS array has low technical requirements and is designed for fast and flexible deployment in an experimental setting. The scanner

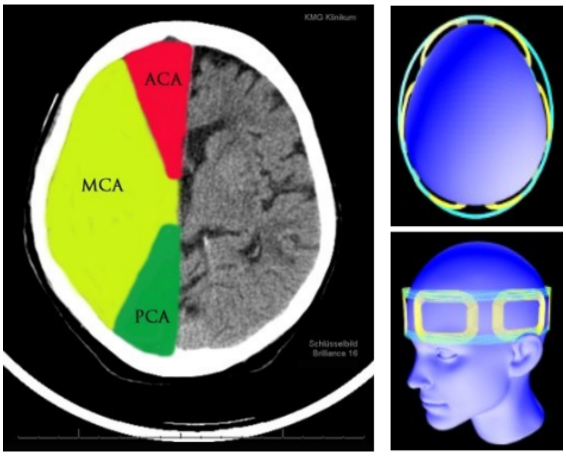

Figure 1: Left: In case of arterial ischemic stroke it is important to know the affected area within the brain depending on the supplying artery: MCA, ACA or PCA. Right: Simulated coil concept for MPS-based brain scanner.

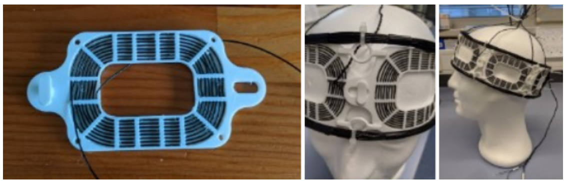

Figure 2: Left: Single flat coil made of highly flexible material. Middle&Right: Headband consisting of six individual flat coils for each brain area and two additional solenoids fitting around the head.

is dimensioned to conveniently fit on a human head.

II. Material and methods

Blood perfusion of the human brain is divided into a left and right hemisphere (see Fig. 1 left), each side is supplied by three main arteries: Anterior Cerebral Artery (ACA), Middle Cerebral Artery (MCA) and Posterior Cerebral Artery (PCA).

The conceptual design for a flexible transmit-receive (tx-rx) system utilizing MPS aims to detect the absence of blood flow for each area individually to distinguish a possible arterial ischemic stroke.

For that, six rectangular shaped flat coils have been hand-crafted (N=8 windings of litz wire, 45×0.1 mm, Rupol, Pack Feindrähte, Germany) on specific FDM 3D-printed holders (N2, Raise3D, USA) made of highly flexible material (Polyflex TPU95, Polymaker, USA). All single coil holders can be put together to form a flexible headband. Two additional solenoids (N=20 litz wire) fitting around the head stabilize the entire headband and provide additional flexibility in magnetic field generation as well as inductive signal measuring (see Fig. 2).

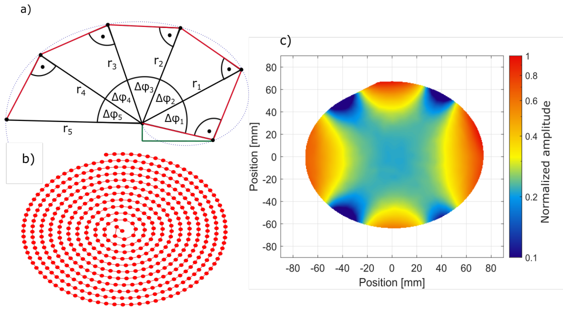

Figure 3: a&b: An optimized sampling trajectory covering the FOV within the scanner is proposed by approaching each spatial point p_{i+1} by a rectangular triangle with angle $\Delta\phi_i$ and the hypotenuse r_i. It is used to investigate the magnetic field distribution (c) of different coil settings.

Each coil (6+2) can be used either as transmit coil or receive coil, which allows multiple sequences, such as single area MPS, frequency mixing, as well as encoding for imaging.

III. Results and discussion

In a first test scenario, the magnetic field distribution within the system has been measured using a dedicated pick-up loop and a robot (Magician, DOBOT, China). The underlying trajectory follows a spiral form, which has been optimized to cover the elliptic FOV within the brain with evenly distributed points (see Fig. 3).

In the result, a field map for specific coil configurations can be measured and investigated to find optimal sequences for the given application.

IV. Conclusions

In a first concept study, the feasibility of a highly flexible and wearable MPS-based head scanner has been shown. With six flat coils arranged as a headband and two additional coils surrounding the head, each area of the brain can be measured. The individually drivable coils provide multiple sequences depending on the desired application.

Acknowledgments

Research funding: The work was partially funded by the German Research Council (DFG) (grant number: VO-2288/1-1, VO-2288/3-1, BE 5293/2-1).

Author's statement

Conflict of interest: Authors state no conflict of interest.

10.18416/ijmpi.2022.2203064

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