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Interlaboratory comparison of static magnetization measurements using two commercial SQUID devices

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Introduction

Magnetic nanoparticles (MNP) are widely used in in-vitro and in-vivo biomedical applications. However, there exists no internationally accepted protocol for reliable and reproducible determination of their magnetic properties. Static magnetization measurements using higly sensitive superconducting quantum interference devices (SQUIDs) are commonly used to characterize MNP. While the continuous verification of the proper operation of SQUID devices within one laboratory is state of the art, interlaboratory comparisons are rarely reported. Within the EMPIR project “MagNaStand” (16NRM04), we conducted a comparison of static magnetization measurements of MNP on two commercial SQUID devices of the same type using a palladium (Pd) calibration reference sample at IMFM and PTB.

Methods

Initial magnetization curves and hysteresis loops of a Pd reference sample were recorded at 298K using identical SQUID devices (MPMS-XL-5, Quantum Design Inc). The Pd measurement data were used to recalculate (calibrate) the true external field values. With these corrections the static magnetization measurements of an identical MNP sample on both devices were corrected and compared to assess the accuracy of magnetic moment determination.

Results

The analysis of the paramagnetic Pd curves reveal non-linear deviations of the external magnetic field values from the nominal field experienced by the sample leading to implausible effects like inverted hysteretic behavior. This is found for both devices but to varying degrees. Applying the field correction on MNP measurements resulted in a reduction of the total difference between the MNP magnetization curves measured in the two laboratories. In the low field region, the differences in the magnetic moment decreased from about 15% down to about 1.5 % after field correction.

Conclusion

The corrections validated by our interlaboratory comparison help to harmonize magnetic measurement techniques for the characterization of magnetic nanoparticles and demonstrate the importance of interlaboratory comparisons between different laboratories operating identical (or even different) SQUID device types.

Development of a Guidance System made of permanent magnets in Halbach configuration

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Introduction

Drug delivery through the blood brain barrier (BBB) is a current field of research in many different areas. There are various approaches to deliver a drug through the BBB into the brain by opening it, for example with chemical substances or hyperthermia. Another approach is to push drugs through the BBB with the force of magnetic fields. The proposed Halbach setup is capable of generating steep magnetic gradient fields, which will be used to force magnetic particles through an in vitro model of the BBB.

Construction

The setup, which generates high magnetic gradient fields, consists of permanent magnets in a nested Halbach ring configuration. Two quadrupoles each generate the same gradient fields, so a change in magnetic field strength of 0 Tm^{-1} to ~5 Tm^{-1} can be achieved by rotating the rings in opposite directions. The field created by the dipole ring is homogeneous and has a maximum strength of about 0.37 T in the center. The superposition of the fields lead to a gradient field that has a changeable direction and strength. The complete setup includes 78 neodymium magnets. A petri dish with a diameter of 5.5 cm can be placed in the center of the setup for the experiment.

Experiment

An in vitro model of the BBB will be used to determine the required magnetic field strength and size of the magnetic particles. Since magnetic particles are always attracted to higher magnetic fields, a directed steering of the particles can be achieved. Magnetic particles of bigger sizes are more suitable for manipulation. We consider to use magnetic particles with a size of about 200 nm for this experiment.

Magnetic Drug Targeting Simulations of a 3D Tumor Vessel Network

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Introduction

Magnetic Drug Targeting (MDT) is a most promising therapeutical approach which uses magnetic nanoparticles (MNP) as drug carriers. These are accumulated at the tumor site by using external magnetic fields, where the drugs can be then released, e.g. by local MNP heating via excitation in alternating magnetic fields. To optimize the carrier accumulation many experimental and numerical investigations were described in literature before, however, only for a few branched vessels to mimick a tumor. In this, work a 3D multibranched vessel model is used for MNP accumulation simulation.

Methods

We developed a 3D FEM-based MDT simulation model with the software Comsol Multiphysics® which allows the quantification of MNP accumulation in silico for various configurations of magnetic field. In this simulations, the MNP properties of self-synthesized MNP (e.g. magnetic moment, size) and a multibranched 3D vessel network model, the so-called ArtiVasc, were implemented. This model exists also in a printed version allowing for experimental validation of the simulations. The printing procedure was multiphoton polymerization.

Results

The 3D vessel network was successfully implemented into FEM simulations for MDT prediction. The most promising results were achieved for a linear array of magnets with same polarity facing each other showing approximately 20 % higher MNP accumulation compared to the one from simulations performed without external fields. The critical ratio between viscous drag force of the blood flow and magnetic force was determined for which the MNP accumulation increases significantly. This ratio is specific for each magnetic field configuration.

Conclusion

3D simulations based on a multibranched vessel model improve the prediction of MNP accumulation, as they allow for magnetic field configurations optimization in a realistic setup. High magnetic gradients are the key parameter for higher MNP accumulation in the tumor vessel network. In future, experiments will be conducted to validate the simulation results.

Velocity simulations of a magnetically steered swimmer

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Introduction

Magnetic manipulation enables to perform medical procedures in an untethered minimal invasive fashion. Hence, the importance of investigating such methods has acquired relevance. Numeric simulations were performed on the translational velocity of swimmers. It has been previously shown that these swimmers can be magnetically steered due to rotating magnetic fields. In the first study, the swimmer velocity is evaluated for different rotation frequencies in water. Consecutively, another study evaluates the velocity of a swimmer in media of different viscosities, to emulate conditions of different body fluids.

Methods

A numeric, time-dependent study was performed with Comsol Multiphysics to study the swimmer's velocity under different conditions. The swimmer has following dimensions in the first and second study, respectively: length of 3 mm and diameter of 1.2 mm, length of 4.5 mm and a diameter of 1.8 mm. The rotation of the swimmer is emulated with the Solid Mechanics interface. The frequency of rotation was varied for the first study (5,10,15 Hz) and fixed at 10 Hz for the viscosity study. The viscosity was varied between those of pure water and 22 mPa s. The laminar flow interface simulates the response of the medium (water) upon the movement of the swimmer. The mesh was selected to be physics-controlled, with a coarser size.

Results

Both swimmers reach velocities in the order of few mm/s. Simulations for the first study suggested an increase in the swimmer's velocity for higher values of the frequency of rotation. Moreover, the study on the viscosity of the medium showed a decrease in the swimmer's velocity with increasing viscosity.

Conclusion

Numerical simulations to study the velocity of a magnetically steered swimmer were successfully achieved. Two different studies were performed with Comsol Multiphysics to analyse the effects on the swimmer's velocity due to a variation in the frequency of rotation and the viscosity of the medium.

Evaluation of the Impact of Static Interference on an Empirical Data Based Static Magnetic Localization Setup for Capsule Endoscopy

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Introduction

Wireless capsule endoscopy (WCE) is less invasive than conventional endoscopy and should, therefore, be considered as an alternative diagnostic tool. Capsules for WCE are equipped with a camera to record a video of the GIT. For further diagnosis and treatment, it is essential that each video frame is correlated with the exact travelled distance of the capsule in the GIT to determine the location of interest. For this purpose, the static magnetic localization method is well-established.
Considering that it takes the capsule about 8 hours to travel through the GIT, the patient cannot be expected to remain in a fixed position during the examination. Therefore, the static magnetic sensor system must be wearable, compact and robust towards static interference of the geomagnetic field.

Methods

A static magnetic localization setup is proposed which consists of three elliptical sensor rings. The dimensions of those were determined by conducting a study in which the average abdomen size of 15 subjects was measured. Subsequently, different-sized magnets were used to examine the three components of the magnetic flux density at the sensor positions. The measured values were then compared with the geomagnetic flux density.

Results

The results revealed that elliptical sensor rings with a large diameter of 40 cm and a small diameter of 33 cm were appropriate for the proposed study population. Furthermore, for all evaluated magnet sizes, the three components of the magnetic flux density had the magnitude of the geomagnetic flux density.

Conclusion

An elimination of inference of the geomagnetic flux density is mandatory for all evaluated magnet sizes. A calibration of the sensors regarding the geomagnetic flux density is not suitable for a wearable system. Therefore, it was concluded that a differential measurement could eliminate inference of the geomagnetic flux density for the proposed wearable system.