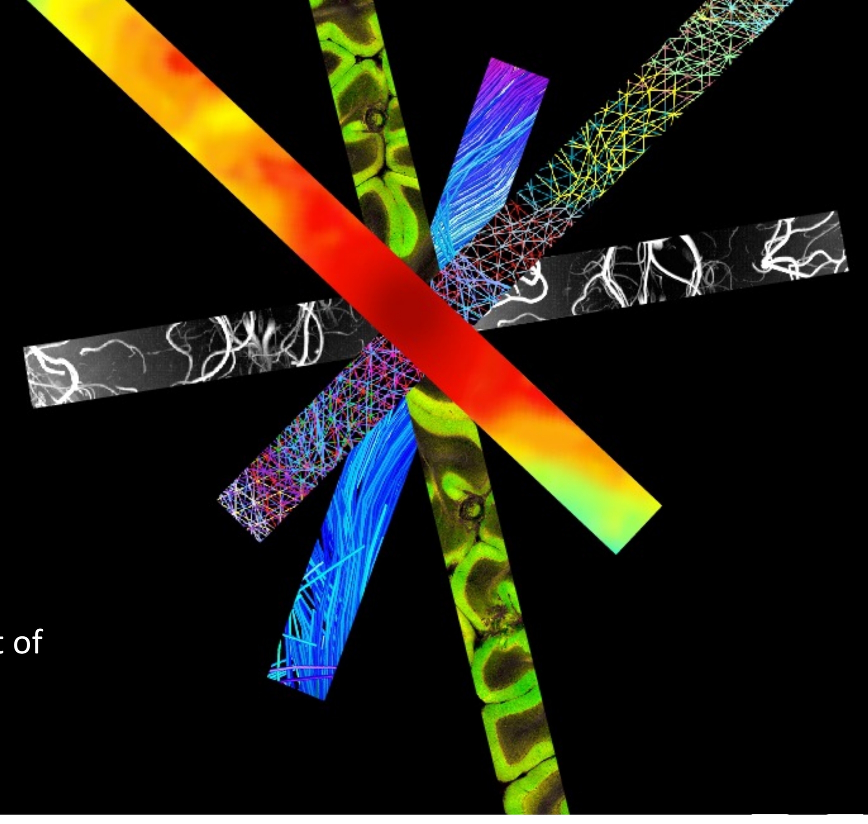

Concept 0.13 T bedside MRI for early brain imaging in the neonatal intensive care unit

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Introduction

Goal: to design and optimize an MRI system for the neonate bedside capable of early evaluation of brain conditions, such as Hypoxic Ischemic Encephalopathy (HIE).

Purpose: The neonatal brain is susceptible to various insults, particularly in preterm births. Such injuries can result in long-term neurological deficits and even mortality but could potentially be better managed with point-of-care imaging. HIE results from a lack of blood flow and oxygen at the time of birth and stands out as a primary contributor to neurological problems in children[1,2] and deaths among neonates[3,4]. It is responsible for about 23% of all deaths in newborns[5] and is the most common cause of cerebral palsy[3,6]. MRI offers distinct advantages over other imaging modalities for diagnostic brain imaging in these patients (see Fig. 1)[7]. Diffusion-weighted MRI (DWI), for instance, provides valuable prognostic information within the first 3-5 days of life, then pseudonormalization of the apparent diffusion coefficient (ADC) occurs thereafter[8,9]. The urgent need for timely imaging and the complexities associated with transporting these fragile patients to an MRI suite, or even within the NICU, drive the development of a bedside MRI scanner for neonatal brain imaging.

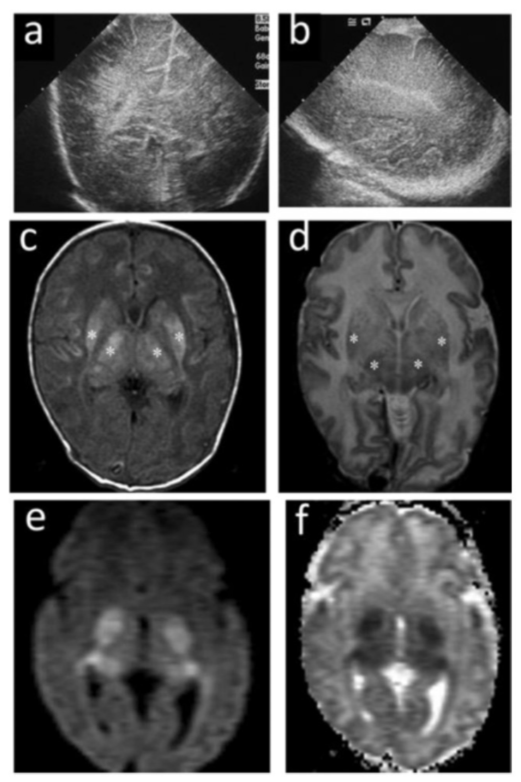

FIGURE 1 (adapted from [7]): Multimodal images of a neonate brain [7]. (a,b) Ultrasound images of the 1-day old suggests cerebral edema. (c-f) MR images obtained at 10 days of life show (c) abnormal T_1 hyperintensity and (d) T_2 hypointensity. Lesions are more pronounced in (e) DWI and (f) ADC images.

Method: Overview

FIGURE 2: The proposed bedside neonatal MRI scanner design without (top) and with (bottom) paneling. A key feature of this design is the dipolar Halbach magnet shown in green. Entire MRI system weighs < 500 kg. Field strength is 135.1 mT and varies by 0.29 mT (~12 kHz) peak-to-peak over a 20 cm diameter spherical volume.

Method: Magnet Design

- **Magnets[13,14]:** 1848 N40UH NdFeB 1-inch blocks in a Halbach cylinder array. High intrinsic coercivity (≥1990 kA/m). High remanence (~1.2 T).
- **Simulation[13,14]:** finite element method (FEM) based software (Opera3d, Dassault Systemes, France). Measured BH curves used in simulation.
- **Optimization:** genetic algorithm (GA) with FEM. Variables = Halbach ring diameters and spacings.
- **Future shimming:** Customizable inner and outer shim arrays.

Method: Magnet Construction

- 3D printing of magnet formers using polylactic acid (PLA) which is inexpensive and lightweight as well as fabricated to have high tensile strength[14].
- Assembled ring-by-ring and compressed coaxially using brass rods/nuts.

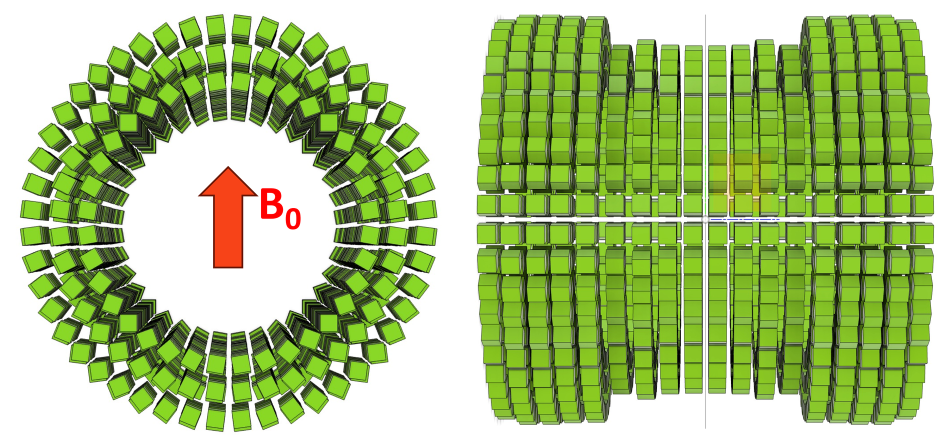

FIGURE 3: Model of the optimized block positions.

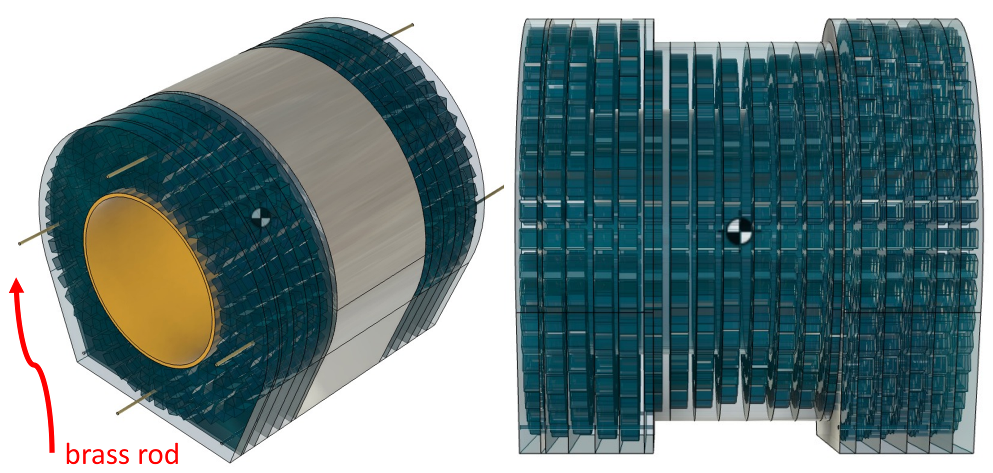

FIGURE 4: Model of the former for the main magnet's 18 rings (blue) as well as a customizable inner shim (yellow) and outer shim (gray).

Results

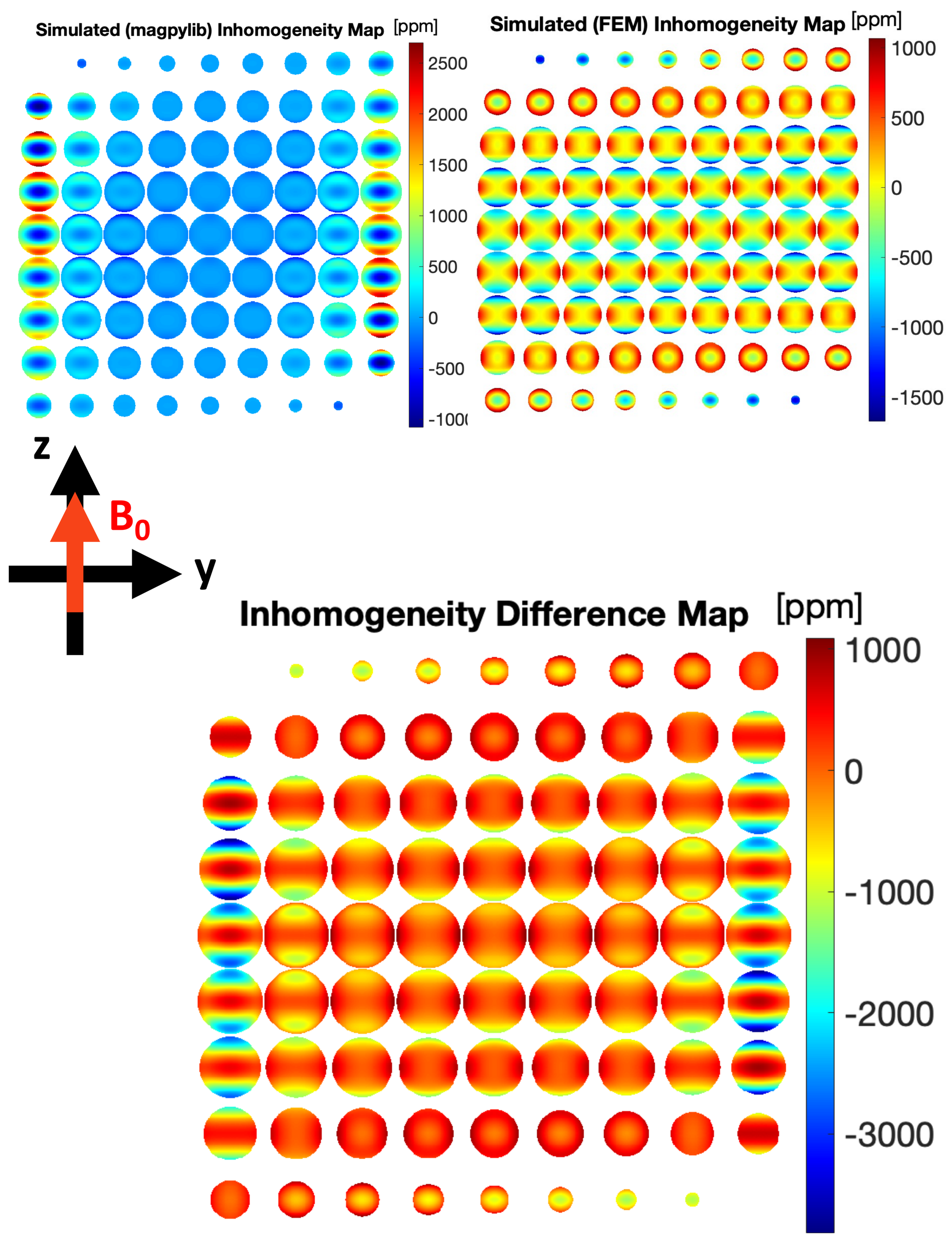

FIGURE 5: Simulated B_0 field inhomogeneity maps of the FEM-optimized design using N40UH grade and two different software packages, magpylib and Opera3d. Field inhomogeneity maps predicted by (top left) magpylib and (top right) FEM Opera3d. (bottom) The difference in predicted field homogeneity (FEM - magpylib). FEM considers demagnetization effects and interactions.

Conclusions

- FEM simulation is critical for accuracy in the optimization framework since demagnetization and interactions are considered. However, FEM is generally not used since it is often assumed to be too slow.
- Compared to other portable MRI systems, our new design is more than double the field strength[10-12,14-16], lighter[11,12] (by about 150 kg) and has similar overall dimensions[10-12,15].

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