Anthropomorphic skull phantom using quantitatively accurate bone mimic material

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Objectives

Quantitative accuracy of PET in PET/MRI studies is hindered, especially in the head, due to challenges in bone identification in current MR-based attenuation correction methods. Bone offers a unique challenge for MR based attenuation correction as it has low MRI signal due to its rapid relaxation rate and low proton density, though it also has the highest attenuation to PET annihilation photons. Using various doped plasters, 3D printing, and a casting process, we were able to construct a skull phantom for MR that can be used to test novel attenuation correction methods that include bone and are suitable for PET/MRI.

Methods

Plaster is a common building material in the form of a dehydrated powder that when mixed with water sets to form the mineral gypsum ($CaSO_4 2H_2O$). The similar mineral composition and density compared with bone make it a good candidate for a bone mimic in imaging phantoms. In order to achieve proper MR and attenuation properties we determined the MR T_1 and T_2^* relaxivity and attenuation of plaster, both undoped and doped with copper sulfate. We then casted undoped and doped (3% $CuSO_4$ by mass) plaster in a skull mold to build an anthropomorphic MR-compatible skull phantom. The positive prototype for creating the mold was generated via 3D printing using PLA plastic. The negative mold was produced by matrix molding using a quick-curing silicone rubber compound. Quantification of T_2^* was done using a 3D ultrashort TE sequence with 32 echo times ranging from 24 to 5000 μsec. MR scans were acquired at 3T with an acquisition matrix of 112x112x114 and 2mm isotropic voxels.

Results

In small vials, undoped plaster has an average T_2^* of 1364 microseconds, plaster doped with 2.8% copper sulfate has a T_2^* of 414 microseconds, closer to the T_2^* of bone (~300-500 microseconds). Corresponding average CT attenuation values were 1380 HU and 1182 HU for doped and undoped plaster respectively, which are within the range of typical HU values observed in humans. Using the cast skull models we measured undoped plaster to have an average T_2^* of 1132 microseconds, and 3% copper sulfate doped-plaster had shortened the average T_2^* to 858 microseconds.

Conclusion

Plaster doped with copper sulfate is a promising candidate for a bone mimic in PET/MRI phantoms with appropriate MR and attenuation values and potential to be cast into an anthropomorphic phantom shape. Differences in the absolute quantitative values of T_2^* between the cast plaster phantom and the vial experiment may be due to differences in uniformity and composition of the final plaster, also differences in the drying and crystallization process. With refinement of the casting process and adjustment of the doping this process can be used to construct a quantitatively accurate and geometrically anthropomorphic plaster phantom to mimic bone in MRI over multiple scanning paradigms, including for evaluation of MR-based attenuation correction methods.

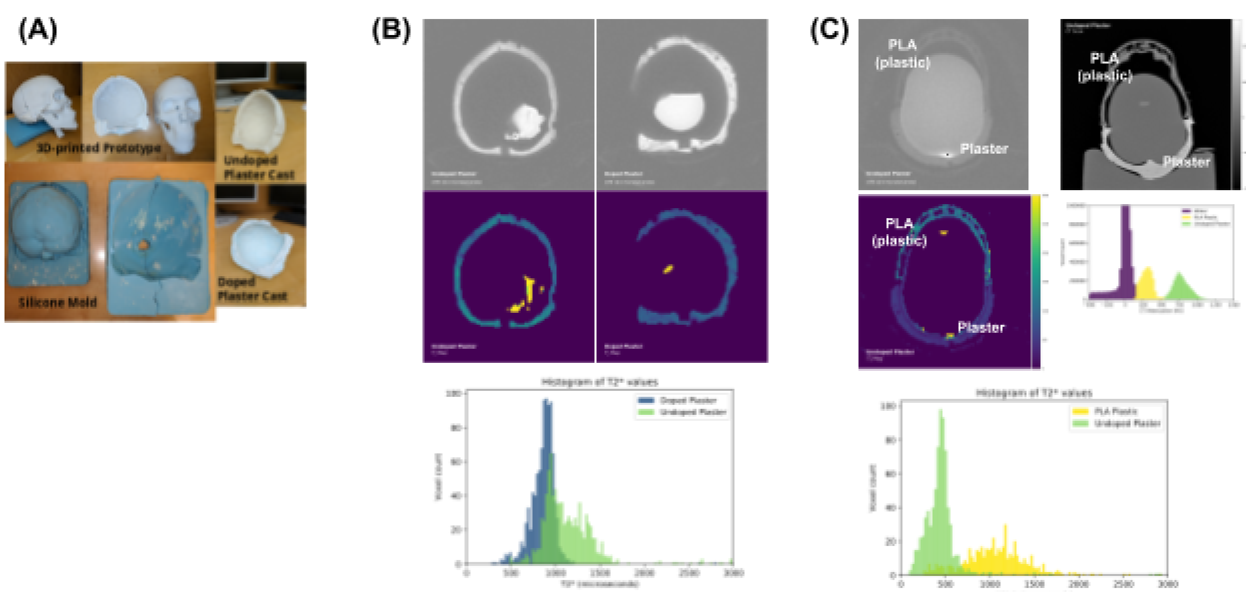

Figure 1: Proof of concept anthropomorphic skull cast using plaster. **(A)** A 3D-printed PLA skull was used to create a silicone mold from which a plaster cast was created. **(B)** In Experiment #1, an undoped and a copper sulfate doped (3.0 %wt CuSO4) plaster cast of the posterior skull half were compared. **(C)** In Experiment #2, an undoped plaster cast of the posterior skull half and the original PLA printed anterior skull half were imaged.