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A Low Cost MRI Distortion Phantom Made from PaintBalls and Pourable Foam

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ABSTRACT

Title: Low Cost MRI Distortion Phantom Made from Paintballs and Pourable Foam
Purpose: To describe a low-cost method for construction of an MR phantom for geometric distortion measurements. MRI has become an essential part of multi-modality imaging/treatment planning/target definition for radiation oncology and many small centers do not have access to specialized MR phantoms for verifying the performance of their systems. The standard ACR MR QA phantom is too large to fit in many head coils.
Methods: An MRI distortion phantom was constructed out of 0.68 caliber paintballs (gelatin shell /polyethylene glycol-based paint) imbedded in polyurethane foam (2-part liquid resin mix). Phantom exterior consisted of a plastic food canister. Foaming chemicals were mixed in the canister and then paintballs were added during the foaming/curing process to provide reproducible and stable structure. MR and CT scans performed with the phantom in approximately the same orientation and image registration between the images was used to visualize distortion of the MRI. For the purposes of this work, the CT images were assumed to be ground truth.
Results: Constructed phantom provided high quality MR images and foam substrate provided significant enough density differential between individual paintballs that they were also discernable on CT. MRI distortion relative to CT for the head-sized phantom were less than approximately 1-2 mm in each of the cardinal directions depending on imaging protocols, type of coil, and phantom position. For initial experiments, the phantom was imaged using CT before and after MRI experiment to ensure there were minimal changes in physical structure.
Conclusions: The simple, low-cost phantom described in this work successfully provided a method for verification of geometric distortion in an MR imaging system. The mechanical stability of the phantom over time may be of concern and will be monitored via CT imaging.

INTRODUCTION

Image registrations between MRI and treatment planning CT scans are commonplace in modern radiation therapy, especially for intracranial SRS and spine SBRT. In both clinical applications, the MRI portion of the imaging workup is often the sole provider of the necessary anatomical information for radiation therapy treatment planning (i.e. brain lesion in intracranial SRS, or true spinal cord in spine SBRT). Since MRI is well known to be susceptible to geometric distortions, especially at large distances from the center of the bore, it is critical that the spatial integrity of the MRI datasets be examined and kept within clinical tolerances. This work provides a method for creation of a low-cost MRI distortion phantom that can be used for verification of geometric integrity and as a learning tool to help clinicians visualize potential uncertainties with MRI. Construction methods are simple and accessible to virtually anyone. The materials are also readily available.

One of the challenges of creating MRI compatible phantoms is signal generation. Many of the readily available and accurately machinable solid materials such as plastics and resins often do not provide any usable MR signal. It is possible to machine cavities in solid materials that can then be filled with liquids capable of producing MRI signal such $CuSO_4$, mineral oil, or water, but this manufacturing process is expensive and not readily accessible to the average clinical physicist. There are purchasable phantoms that can perform geometric distortion measurements, but they are expensive and often out of reach for small radiation oncology departments.

Price et al.[2] utilized rigid polyurethane foam plates, precisely machined to create a large phantom (approaching size of the MRI bore) which included individual machined inserts for placement of MRI-visible markers (paintballs). Paintballs are small spheres used as projectiles in recreational combat games and generally consist of a gelatin-based shell filled with a polyethylene glycol-based paint. Polyethylene glycol (PEG) has been studied as an MRI contrast agent[1] and is known to produce signal required for MR image formation. The phantom of Price et al provided quantitative information regarding geometric distortion over a large image volume and required specialized software for analysis and image processing. The scope of their project is beyond what a typical clinical physicist could perform, but a simplified extension of their concept is able to provide the clinical physicist with useful information and an interesting learning experience.

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METHODS

Construction Materials:
0.68 Caliber Paintballs (~500 count)
(available at many retailers, including online sellers)
2-part mix (polyurethane foam)
(available at many retailers, including online sellers)
Plastic container, preferably with a secure, screw top lid.
Verify that it fits properly in head coil or whatever imaging coil is to be used for testing.

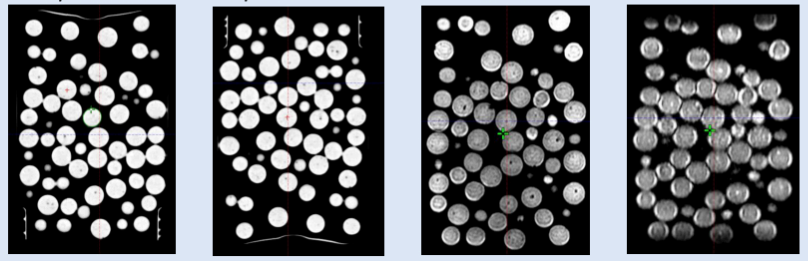
Based on the experience gleaned during this work, it is recommended that a test phantom in open container be constructed in order to gain experience about the expansion ratio of the foam. Caution should be taken to prevent excessive pressure buildup in a sealed container, which could explode or rupture. Protective clothing and equipment (glasses/goggles/chemical respirator/gloves, etc) is also recommended. Also, the curing foam does give off chemical odor, so perform tasks in a well-ventilated area or fume hood. Read and follow the manuals and material safety datasheets provided by the manufacturers.

Phantom Construction:
1. Pour appropriate amount of 2-part mix into bottom of plastic container and stir. Note the small volume used as the expansion ratio is significant and the paintballs take up most of the container volume.
2. Add paintballs and monitor foaming process: leave cover off at this point

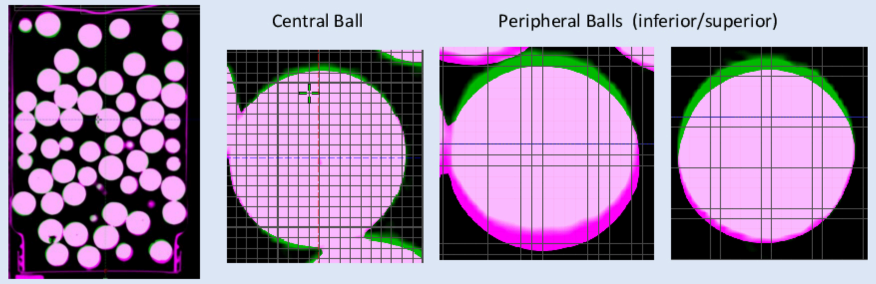
3. Add additional 2-part mix if necessary--for our case it was necessary to finish filling the container. Once reaction has slowed, place the cap on the top of the phantom. The foam will continue to slowly build up pressure in the final stages of it's curing process, which can be released by drilling holes in the outer shell. Note that the container did become mildly pressurized during this, late-stage, curing process after being capped—bowing the walls slightly. Capping the phantom too soon could result in hazardous pressure buildup. Also note that foam material will extrude from any vent holes created, so you will need to wipe it up with a paper towel and monitor during curing process

DATA COLLECTION / ANALYSIS

For this work, CT imaging was taken as ground truth. CT is known to have very low image distortion, which was confirmed by in-house measurements as well as routine quality assurance from consulting diagnostic medical physicists. A 16 slice Toshiba Aquillion LB CT scanner was used to image the phantom with a small FOV, 0.5 mm slices, and tightest pitch available. In order to assess the mechanical stability of the phantom over time, CT imaging was iteratively performed over a series of months. CT images from the first two months, showed that the phantom did not appreciably degrade or change. Using two GE Artist 1.5T MR scanners, the phantom was imaged using clinical protocols for treatment planning: Intracranial SRS in head coil and Spine SBRT with spine coil. T1 (SPGR) and T2 (Cube) weighted images were acquired with 0.7 mm slice reconstruction.

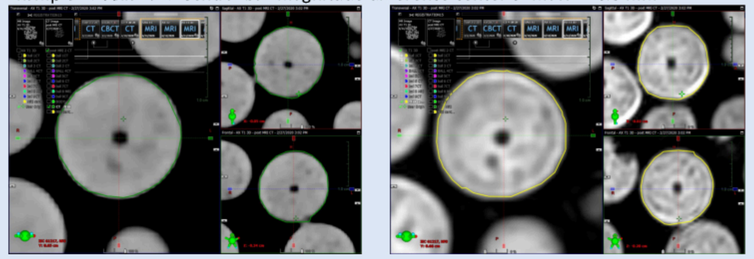


These images were then registered to the reference CT dataset. A qualitative summary of the geometric distortion can be viewed via image registration. Image registration was based on a region of interest (ROI) that encompassed the central section of the phantom. Based on this type of registration it is easy to visualize geometric distortion the further you move away from the registration ROI. See magenta/green color blend visuals below.

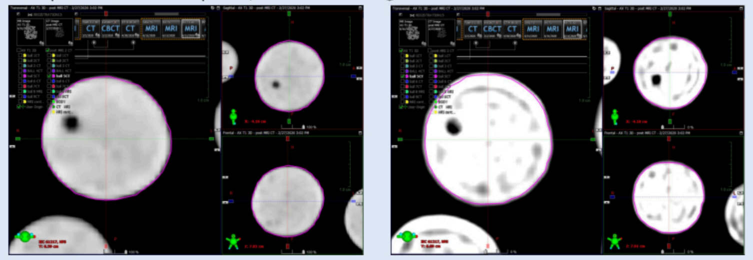


In order to make a more quantitative analysis of image distortion, representative balls were contoured on both the MRI and CT and the center of mass coordinates of those contours were compared to determine an offset value.

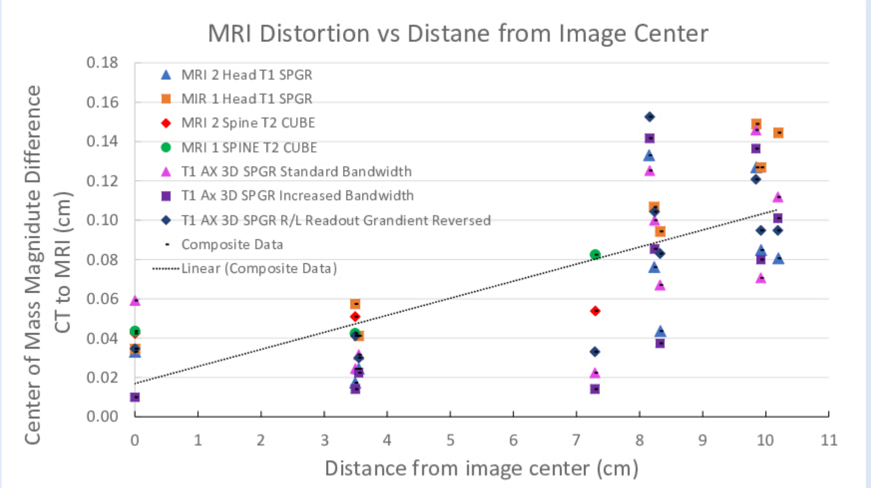
Example 1: Axial T1: Central ball magnitude difference center of mass = 0.3 mm



Example 2: Axial T1: Superior/anterior ball magnitude difference center of mass = 1.1 mm



The scatter plot below summarizes data acquired from runs of SRS head and SBRT Spine imaging protocols. Datapoints are based on contouring representative balls on each image set and comparing center of mass coordinates. Additional datasets with variations in pulse sequence parameters are also included.

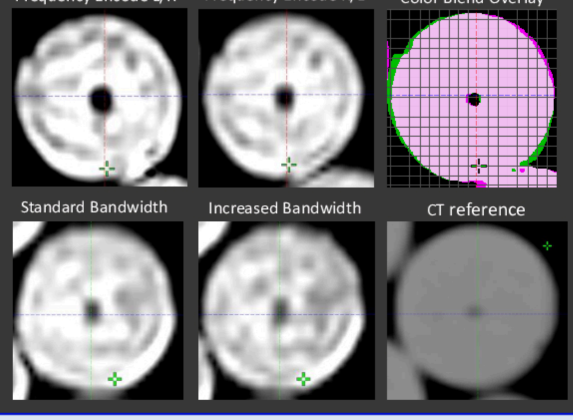


DISCUSSION

In other works[2,3,4] the effects of other sources of distortion (isolating gradient non-linearity) were minimized by performing two scans with the frequency encoding gradient reversed between them and using both datasets in the analysis. This was not done in our initial datasets. Additionally, chemical shift artifacts created by gelatin shells and polyethylene glycol likely causes the center of mass of the paintball contour to be systematically biased. In a continuation of the initial study, a set of images was acquired with the frequency encoding gradient reversed and another scan was performed with increased bandwidth. A summary of these test are shown below. It may not be obvious from static pictures, but a blended view in image registration software demonstrates noticeable pulse-sequence dependencies. Further work is needed to study the potential effects of material choices and pulse sequences.

Top Row: Frequency encoding gradient reversed between acquisitions. Notice changes in appearance of paintballs suggesting chemical shift is of potential concern.

Bottom Row: Bandwidth increased between acquisitions—notice that 2nd image shows more spherical paintball and better agreement with what is seen on CT. Increasing bandwidth is known to reduce chemical shift artifacts[5].



CONCLUSIONS

The phantom constructed in this work was able to produce adequate CT/MRI image quality and was able to demonstrate and quantify geometric distortion in MRI images. Image distortion was measured to be up to approximately 1.5 mm between the center of the phantom and periphery when considering the CT images as ground truth and image registration focused on center of phantom. The phantom was shown to be mechanically stable over several months and will be further evaluated over time. The results of these tests were reviewed by other members of the radiation oncology team who found it insightful to be able to visualize geometric distortion firsthand. In our clinical practice, care is being taken to reduce error induced by potential geometric distortion, including use of multiple local registrations if regions of interest are separated by large distances within the same image dataset. The potential to further refine pulse sequences for radiation therapy treatment planning are also being investigated. Further validation of the phantom would be required to better understand its overall performance characteristics.