Rapid Prototyping of a 3D Grid Phantom for MR Image Guided Therapy Quality Assurance

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Introduction: Three dimensional grid phantoms offer a number of advantages for measuring imaging related spatial inaccuracies in MR imaging[1,2]. We have used rapid prototyping technology to directly fabricate a 3D grid phantom from CAD drawings. The phantom was then used to measure spatial inaccuracies in 3D images acquired in a 12 channel receive only head coil in a 3T MR scanner. The ultimate purpose is to characterize MR imaging related spatial inaccuracies for image guided surgery and radiotherapy.

Materials and Methods: Grid Phantom:We have tested three different solid freeform fabrication processes/materials for build accuracy and stability after immersion and determined that Selective Laser Sintering (SLS)/polyamide to have the best accuracy and stability. We then fabricated a full size grid designed to fit within a water tight chamber assembly that can be fixed to a stereotactic frame (Leksell) using an adapter plate (Fig. 1). The basic design with 13 grid disks forming the 3D structure contains 221 grid intersections and 2873 isotropically distributed control points. The grid intersections are formed from intersecting 2 x 2 mm rectangular posts and struts, and the control points are designed as a Cartesian array with each node separated by 8 mm. Build accuracy was determined by comparing control points identified in CT space to CAD specifications after aligning the coordinate spaces. This was done by convolving the image volume with a 3D mask reflecting the structure of the grid intersection and using interpolation to refine the coordinate estimates from the filtered image volume. MR Imaging: The grid assembly was then imaged in a 12 channel head coil on a 3T MR scanner (Trio/Tim, Siemens Medical Solutions, Erlangen, Germany) using a 3D T1W MPRAGE (0.4x0.4x0.8 mm pixel size) sequence with and without 2D distortion correction (supplied with manufacturer software) and the Leksell frame. MR spatial distortion within the head phantom space was determined at each of 2873 control points formed by a high density 3D grid array immersed in a solution of 3.60g NaCl and 1.955g $CuSO_4*5H_2O$ per liter dH2O. Registration of the MR and CT localized grid arrays was performed in two steps (rotational alignment using a transformation matrix derived from single value decomposition, followed by translational registration using a least square error minimization criteria. After registration, the distances between the MR (no distortion correction) and corresponding CT localized control points in the x, y, and z direction as well as the Euclidean distance/direction were determined and averaged over the entire 3D volume. For assessing spatial distortion in the region of localizer panels of a Leksell stereotactic frame, the grid phantom was fixed to the halo of the frame, and the phantom imaged by MR (with and without distortion correction) and CT with the localizer panels attached to the halo. MR and CT image spaces were registered as described above using only the grid phantom so as to project the CT-localized fiducials into MR image space, and the Euclidean distance between observed MR and projected CT fiducial points was determined for each axial image slice, then averaged over the entire fiducial span.

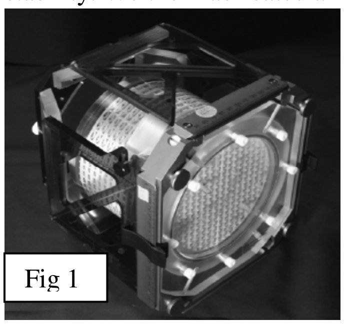

Fig 1

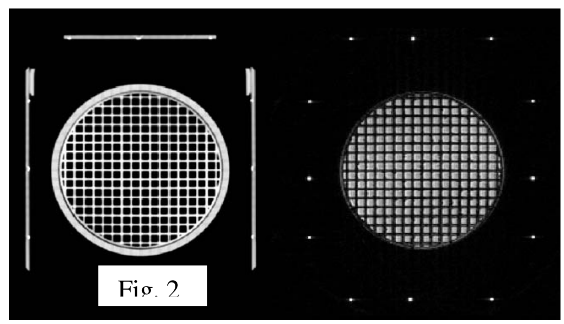

Fig. 2

Results: Axial images through one of the grid disks of the phantom after fixation to the Leksell frame (Fig 2.) The mean ± standard deviation and 97.5% quantile for the distances between the MR and CT localized Leksell fiducials and head phantom control points formed by the intersection of 2mm x 2mm posts and struts of the imaging grid are summarized in Table I.

	Mean Absolute Error (microns)* (± Standard Deviation)				Maximum Error (microns) (97.5% Quantile)			
	X	Y	Z	Rho	X	Y	Z	Rho
Within Head Phantom Volume N = 2973	250±290	410±470	170±200	560±180	450	770	370	890
Localizer Panel Fiducials (No Distortion Correction) N = 1188	ND	ND	ND	800±460	ND	ND	ND	1790
Localizer Panel Fiducials (Distortion Correction) N = 1179	ND	ND	ND	520±310	ND	ND	ND	1200

*Absolute error of MRI compared to CT localized coordinates in the x, y, and z directions and the associated Euclidean distance (Rho). Maximum error determined at the 97.5% quantile to eliminate errors due to entrapped bubbles lodged at the grid intersections and within the fiducial channels. ND = Not Determined.

Discussion: As expected, maximum error was less when measured only from control points within the phantom (positoned in the center of the head coil) and increased when measured at the periphery of the coil where fiducials are located. Distortion correction decreased the maximum error on the periphery.

Conclusion: Phantoms such as described are useful to evaluate MR imaging inaccuracies under various clinical situations.

References: 1) Wang D, et al. Magn. Reson. Imaging. 2004 Nov;22(9):1223-32. 2) Baldwin LN, et al. Med. Phys. 2007 Feb;34(2):388-99.