Lucy Phantom MR Grid Evaluation

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I. Introduction:

The MR distortion grid, used as an insert with Lucy 3D QA phantom, is designed to assess spatial distortion in MR images. Spatial distortions appear as geometric warping of scanned objects in MR images and may be caused by either the scanner (for example, magnetic field in-homogeneities, susceptibility effects, gradient field nonlinearities, signal to noise ratio, SNR, etc.) or the patient (chemical shift, blood-flow). Spatial distortions introduce contouring errors and therefore misrepresentation of target volume and organs at risk (OARs) resulting in erroneous treatment plans. It is important to evaluate the magnitude of spatial distortions in MR image scans.

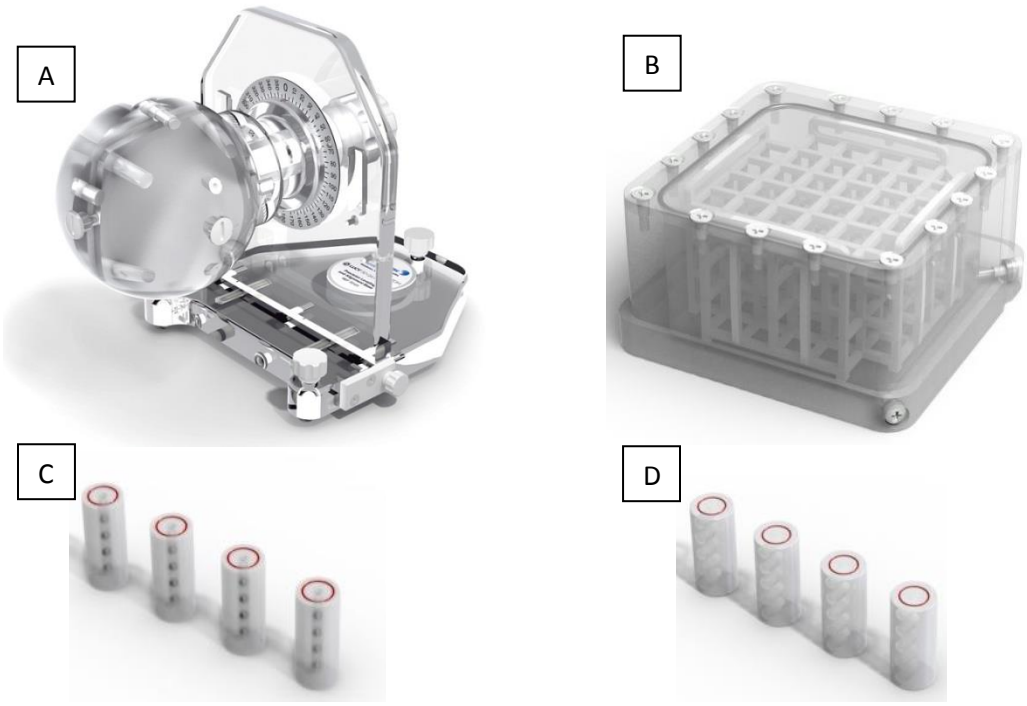

Figure 1. Lucy phantom and accessories used in MR distortion correction grid evaluation and testing. (A) Lucy 3D QA phantom; (B) MR grid insert; (C) CT marker cylinders; and (D) MRI marker cylinders.

II. Methods and Materials:

The QA phantom and accessories required to perform distortion correction testing are:

Lucy 3D QA phantom, MR distortion grid and CT/MR marker cylinders (figure 1).

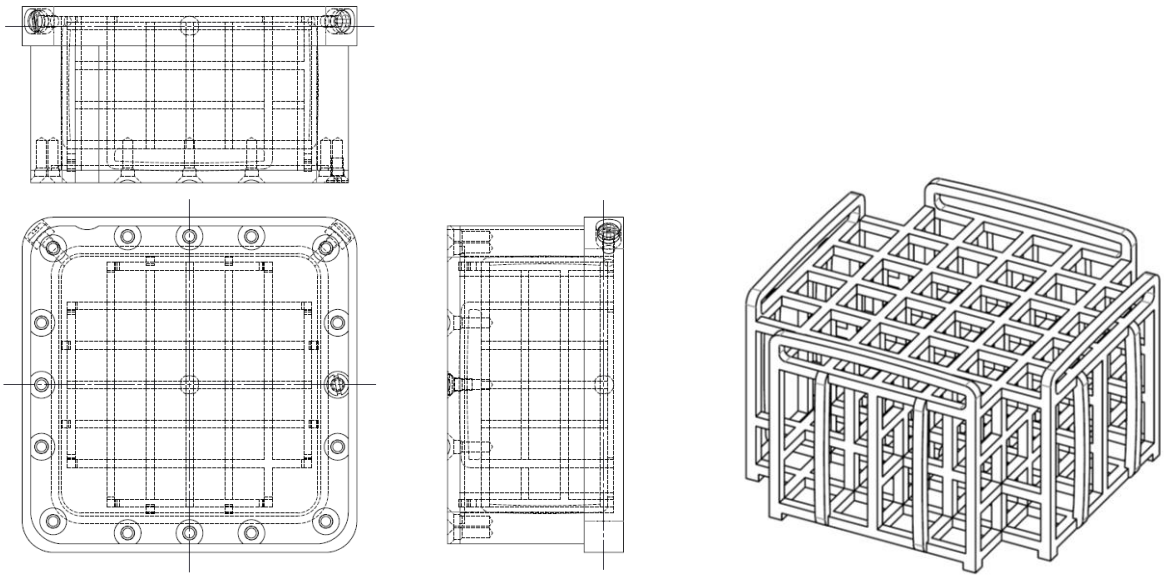

Figure 2. MR distortion grid insert in planar (left) and 3D (right) views.

Lucy phantom (Figure 1A) is a spherical (140mm diameter) Lucite phantom designed to perform "End-to-End" QA (or process QA) for stereotactic radiosurgery treatments. In addition, the phantom can also be used to evaluate performance of individual components of the SRS program: imaging, planning and treatment. Several inserts are available with the Lucy phantom for this purpose.

The MR distortion grid (Figure 1B) consists of 60 x 60 x 30 mm array of orthogonal wires (in 10 x 10 mm grid spacing) embedded in an acrylic box (85 x 85 x 45 mm outer dimensions). The acrylic box is filled with MR contrast enhancing manganese chloride solution (0.1mM $MnCl_2$). The 2mm thick wires are composed of glass reinforced polyamide. As per design specifications, the grid is accurate to within 0.1 mm in the XY directions and 0.2 mm in the Z direction.

A set of four marker cylinders for CT and MRI (Figure 1C, 1D) are provided with the Lucy phantom to evaluate positional and fusion accuracy. Each CT marker cylinder contains five 2mm diameter aluminum spheres spaced 5mm center to center. The MR marker cylinders are identical to CT markers except that the aluminum spheres are replaced by mineral oil.

A. CT scan:

First, the phantom was first CT scanned to obtain grid baseline dimensions that could be used as template against which to compare MR images. This also ensured that the phantom had been constructed to the relevant specifications. The MR grid was placed in the center of the Lucy phantom with CT markers in place. The phantom was positioned on the CT scanner couch and aligned with lasers (or physical axes of the scanner). CT scans of the grid were acquired on a multi-slice CT scanner (Phillips Brilliance Big Bore 16-slice). Scan parameters were: axial (non-helix), slice width = 0.75mm, 120 kV, 455 mAs, image matrix 512x512, FOV = 350 mm.

CT images were imported in a treatment planning system (TPS) and grid separation measured with the measuring tool. Grid spacing was measured along the long dimensions and diagonal in both central and peripheral parts of the phantom. Grid spacing was verified to be within +/- 0.1 mm. In addition, CT marker spacing was also checked.

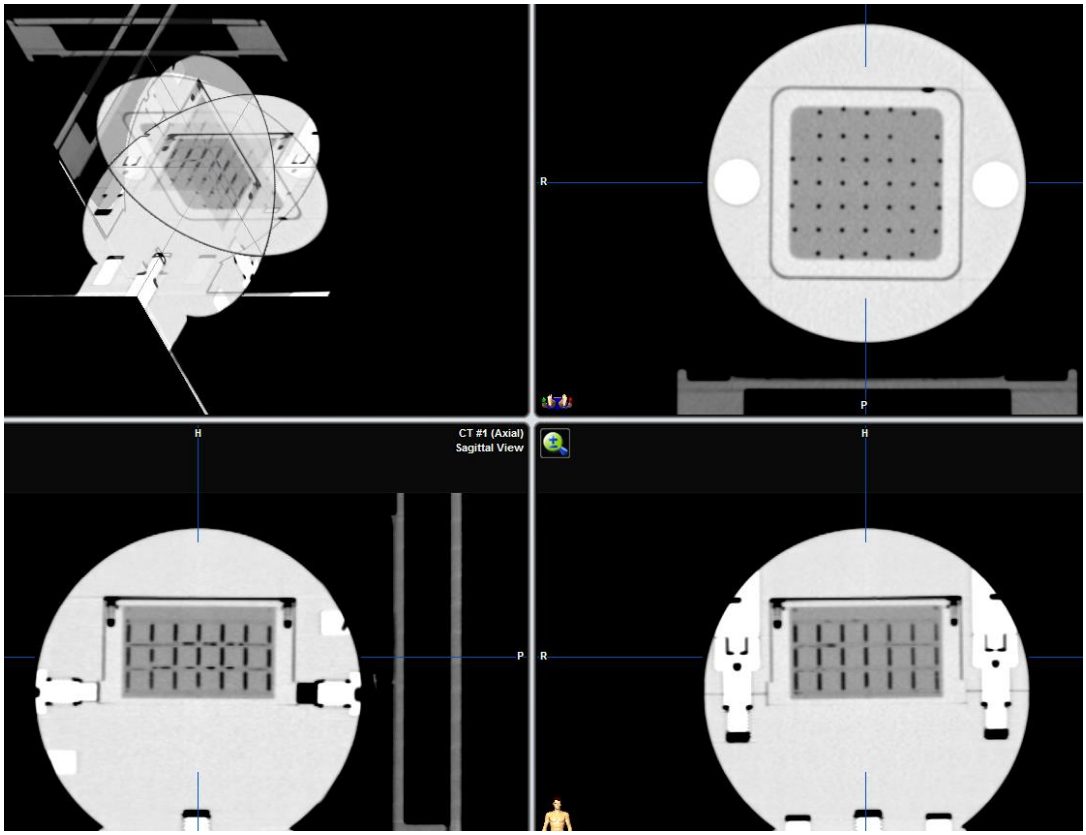

Figure 3. CT scan of grid insert imported into the treatment planning system. Shown are (clockwise from top left): 3D, axial, coronal and sagittal views.

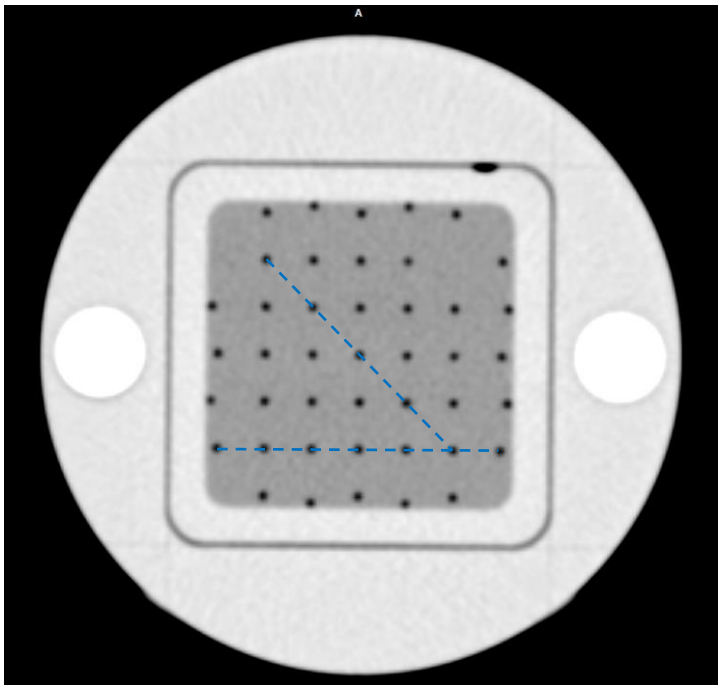

Figure 4. Axial CT scan of grid insert. Grid dimensions were measured along the long dimensions (60 mm) and diagonal (shown as dashed lines) in the central and peripheral sections of the grid.

B. MR scans:

With the MR marker cylinders in place, the phantom was aligned with the MR scanner lasers (scanner axes) and images acquired as per our SRS scan protocol (see table 2) used for all patient studies. T1 and T2 MR Image sets were obtained in axial and coronal planes on a 1.5 T MR scanner using 1mm and 2mm slice separation.

All images were imported into our SRS treatment planning system. For each image modality, appropriate window/level setting was selected to achieve the best image contrast. The grid wires appear as dark pixels and the fiducial markers as bright spots on CT and MR image sets. Center of each marker was identified and the measurement tool available in the TPS was used to check grid separation in the central and peripheral parts of the grid image (axial plane). Measurements were performed in central and peripheral axial planes. MR T1 coronal image set was reconstructed in to axial images prior to measurement. In addition, the separation between fiducial markers in the marker cylinders was measured. Each measurement was repeated three times to minimize random errors. To obtain distortion data, a one-to-one correspondence was established between grid point locations in MR and CT data sets.

III. Results:

MR image scan results are shown in Figures 5 and 6. Window level settings for optimum image contrast are shown in Table 1.

Overall MR Axial T1 images with 1mm slice separation provide the best image quality. In general, T1 images are superior compared to other MR images and 1mm slice separation is better than 2mm.

When grid dimensions were compared to the baseline values, MR Axial T1 image (1mm) set provided the best agreement with the smallest variance (standard deviation). Marker spacing in T1 Axial image set also agreed better with the baseline CT data.

As shown in table 1, a comparison of peripheral vs. central grid spacing can provide an estimate of distortion in MR images. In general, MR image grid measurements were slightly less than those measured in CT image set. A slight "bowing-in" was noted in the central part of all MR images as evidenced by the MR central grid separation measurements being slightly smaller than those in the peripheral regions. Our results indicate a distortion correction of 0.3% – 0.6% over the grid dimensions for MR Axial T1 images acquired at 1mm slice separation.

In contrast, MR T2 images at 2mm slice separation resulted in relatively larger distortion correction, with other sequences showing intermediate results. Similarly, caution should be exercised when Coronal T1 images that have been reconstructed into axial plane are used in drawing targets. These reconstructed images tend to show greater variation caused by spatial distortion than their native axial images counterparts.

IV. Summary:

An estimate of MR distortion corrections is necessary to help improve target delineation in SRS planning. These results should also be helpful in estimating dose calculation errors when MRI images are solely used for treatment planning. The MR distortion grid when used with the Lucy phantom can provide distortion correction data for MR image sets. Furthermore, low distortion MR sequences may be investigated to minimize potential errors in radiotherapy planning.

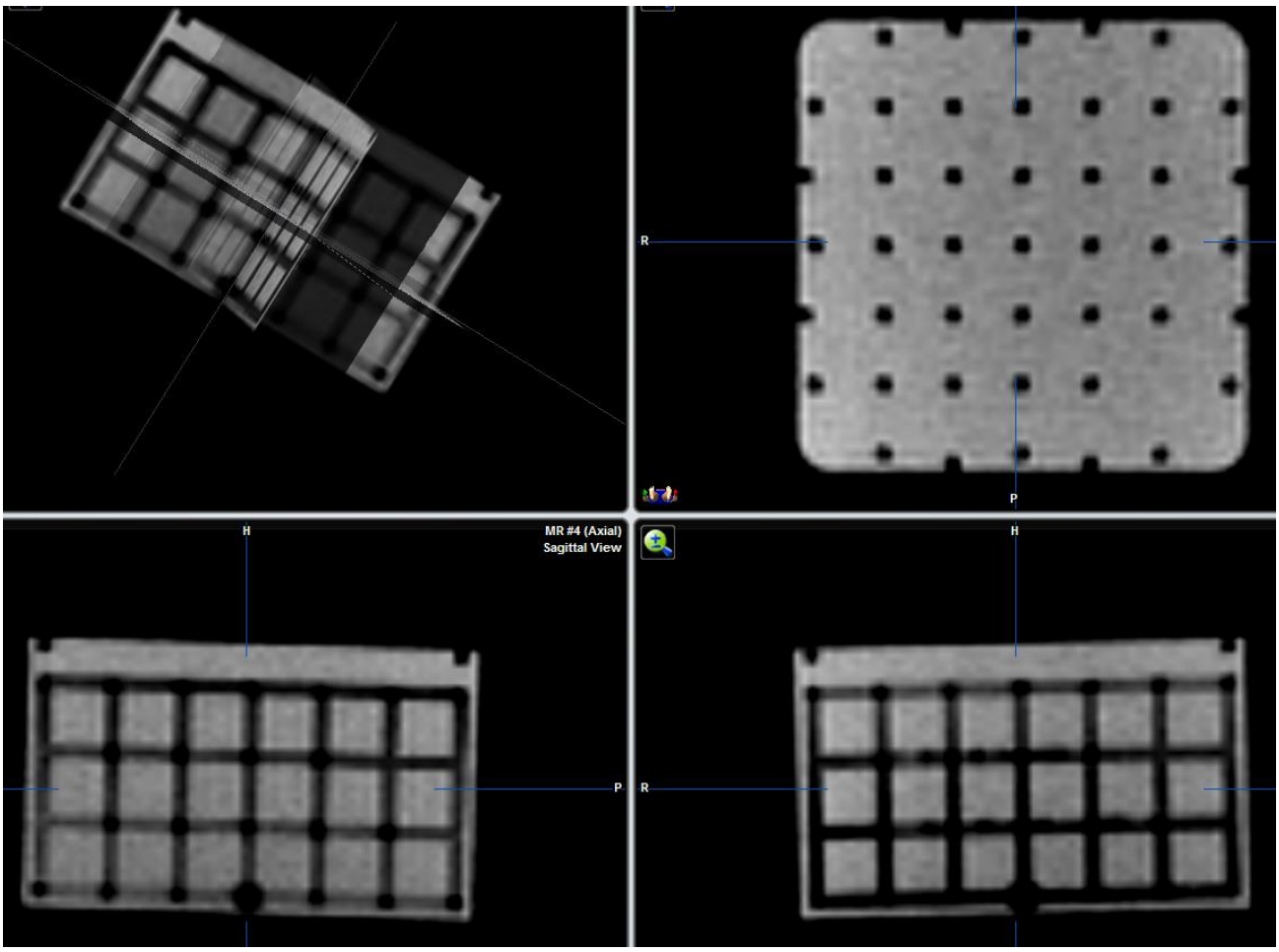

Figure 5. MRI scan (Axial T1, 1mm spacing) of distortion grid. Shown are clockwise from top left: 3D, axial, coronal and sagittal views.

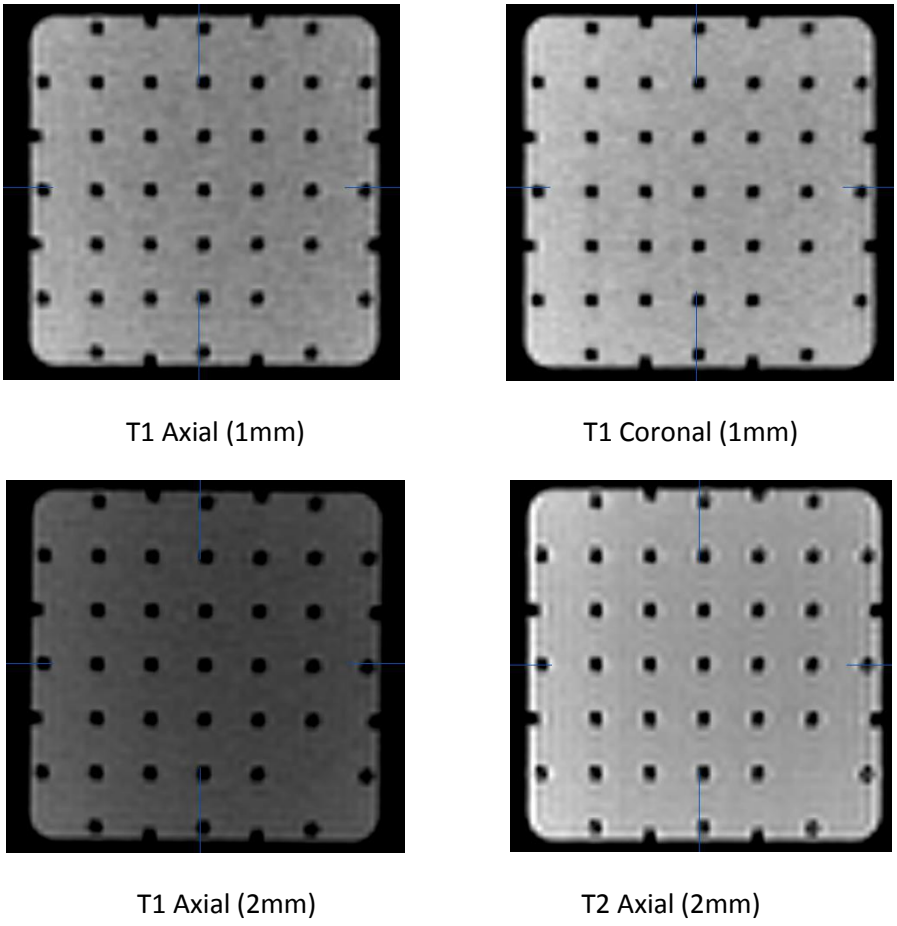

Figure 6. MR scans of grid insert.

Table 1. Window/Level settings, grid-dimensions and marker spacing for scan types used in this study.

Scan Type	Window/Level		Grid Dimension (mm)				Markers Spacing
			Long		Diagonal		
			Peripheral	Central	Peripheral	Central	
CT	**-252 - 167**		**60**	**60**	**56.57**	**56.57**	**20**
MRI Ax T1 (1mm)	**0 - 425**	**Ave**	59.80	59.62	56.55	56.20	19.97
		S.D.	*0.17*	*0.10*	*0.07*	*0.00*	*0.06*
MRI Cor T1 (1mm)	**0 - 700**	**Ave**	59.82	59.85	56.45	56.50	19.87
		S.D.	*0.11*	*0.14*	*0.21*	*0.00*	*0.15*
MRI Ax T1 (2mm)	**0 - 270**	**Ave**	59.80	59.75	56.35	56.30	20.10
		S.D.	*0.15*	*0.08*	*0.07*	*0.00*	*0.17*
MRI Ax T2 (2mm)	**0 - 383**	**Ave**	59.70	59.67	56.40	56.30	19.87
		S.D.	*0.15*	*0.12*	*0.14*	*0*	*0.15*

Table 2. MR Scan parameters used in this study.

	Scan Type				
Parameters	**Localizer**	**Sagittal T1**	**Axial T2**	**Axial T1**	**Coronal T1**
Contrast	Pre	Pre	Pre	Post	Post
TE		9	102	9	9
TR		600	2884	600	600
FOV	28	28	28	28	22.4
Slice thickness	5	3	2	1 or 2	1 or 2
Slice Separation	0	0	0	0	0
Image Parameters					
Plane	3 plane	Sagittal	Axial	Axial	Coronal
Mode	2D	2D	2D	2D	2D
Pulse Sequence	Gradient Echo	Spin Echo	FSE-XL	Spin Echo	Spin Echo
Image Option	Seq, Fast	none	FC Fast	none	none
Frequency		256	256	256	256
Phase		256	256	256	256
NEX		1	1	1	1
Phase FOV		1	0.75	0.75	1
Shim		Auto	Auto	Auto	Auto