Geometric Distortion Quantification and Reduction in MR

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SCAN PARAMETERS

Vendor	GE	Siemens	Siemens	Siemens
Scanner	Premier	Sola	Skyra	Terra.X
Field Strength (T)	3.0	1.5	3.0	7.0
Orientation	Sagittal	Sagittal	Sagittal	Sagittal
Sequence	MP-RAGE	MP-RAGE	MP-RAGE	MP-RAGE
TR	3749.26	2520	2520	2510
TE	3.44	3.37	3.3	3.19
TI	1152	1500	1500	1500
Matrix	256x256	256x256	256x256	256x256
FOV (mm)	256	256	256	256
Slice Thickness (mm)	1	1	1	1
Voxel Size (mm^3)	1x1x1	1x1x1	1x1x1	1x1x1
Pixel Bandwidth (Hz)	97.66	199	199	199
Scan Duration	12:45	11:50	10:44	10:42
Coil	48Ch Head	Head Neck 20	Head Neck 20	Nova 8Tx32Rx Head

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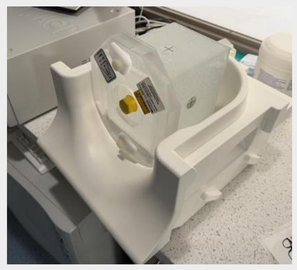
INTRODUCTION

In clinical applications such as radiation oncology and DBS placement, geometric accuracy is critical for accurate target delineation and treatment planning. This study aimed to quantify the magnitude of geometric distortion and evaluate the performance of vendor-provided distortion correction across four Siemens and GE MRI scanners operating at 1.5 T, 3 T, and 7 T.

METHODS AND MATERIALS

A grid distortion measurement phantom (Modus Medical Devices) was scanned on a Siemens Sola 1.5T, Siemens Skyra 3T, GE Signa Premier 3T, and Siemens Terra.X 7T. The base imaging protocol consisted of a sagittal 3D T1 MPRAGE sequence (scan parameters are listed in the table in the left column). Three image sets were acquired on each scanner: without distortion correction, with 2D distortion correction, and with 3D distortion correction (where available). In addition, images were acquired using different receiver bandwidths to evaluate the effect of bandwidth on geometric distortion. Distortion measurements were performed using QUASAR GRID3D software specifically developed for automated analysis of the grid phantom. The distortion analysis methodology is described in detail in the following section.

a



b

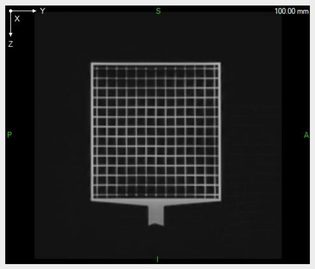


Figure 1. Grid3d phantom used for study. **a.)** Example of phantom positioning in Siemens Head Neck 20 coil. **b.)** Sagittal slice view of phantom as scanned, illustrating Right-Anterior-Superior (RAS) coordinate system used in the analysis.

DISTORTION MEASUREMENTS

The Grid3D software provides automated analysis of distortion across the matrix of grid points in the phantom. In the absence of the Leksell head frame, the software reports distortion vectors for each point relative to the detected phantom isocenter in DICOM space. After finding phantom isocenter, the software calculates the expected location of each point in the grid and then finds the difference between the expected location and the detected location. Four distortion values are reported, with x,y, and z being the distortion vectors along those planes in the RAS coordinate system, and r (absolute distortion) being the magnitude of those vectors for each point

$$r = \sqrt{x_distortion^2 + y_distortion^2 + z_distortion^2}$$

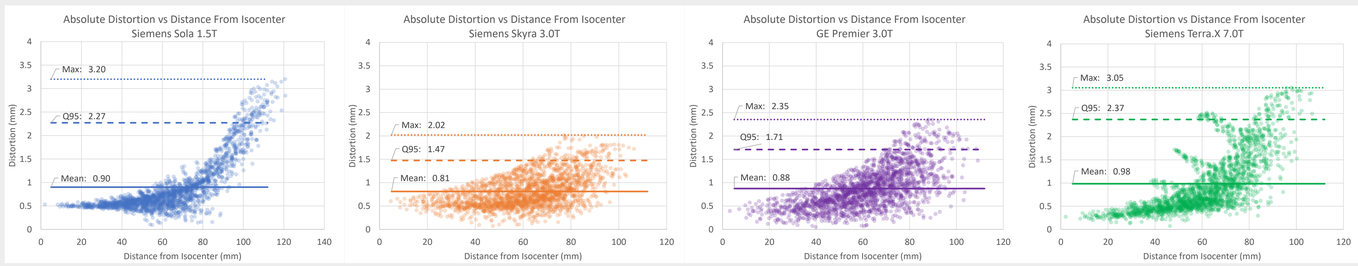
For most results in this study, r is used unless otherwise noted.

DISTORTION CORRECTION

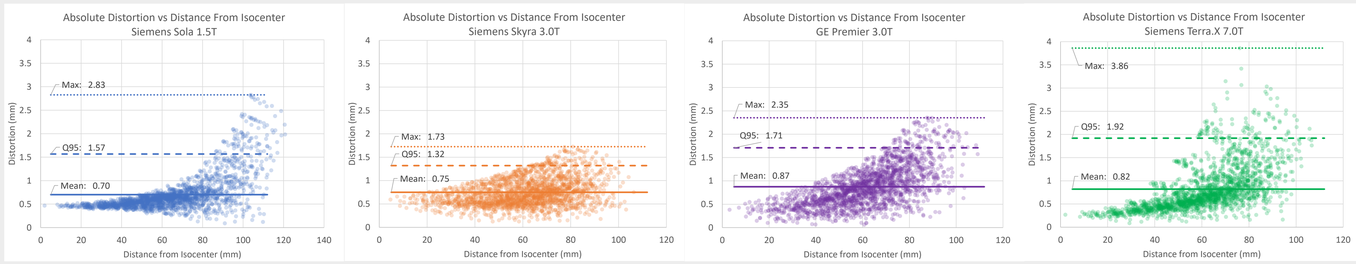
GE and Siemens MRI systems implement different approaches for geometric distortion correction of 3D T1-weighted anatomical images. GE provides vendor-specific geometry correction to compensate primarily for gradient nonlinearity, whereas Siemens offers both 2D and 3D distortion correction options. The 3D correction provides more comprehensive whole-volume geometric correction and may improve the spatial accuracy of anatomical images used for ROI generation and subsequent image registration.

RESULTS

a. No Distortion Correction



b. 2D Distortion Correction



c. 3D Distortion Correction

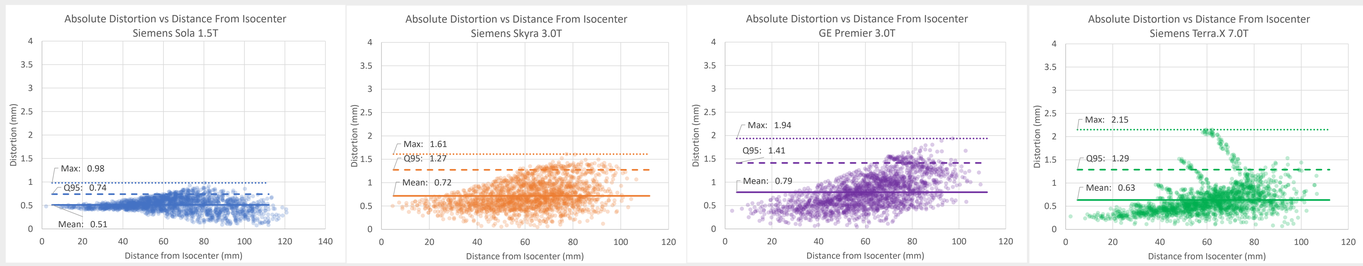


Figure 2. Absolute distortion vs distance of measured point from isocenter for four scanners. Distortion increases as distance from isocenter increases. **a.)** Results without any distortion correction selected in the sequence parameters. **b.)** Results with 3D correction type applied.

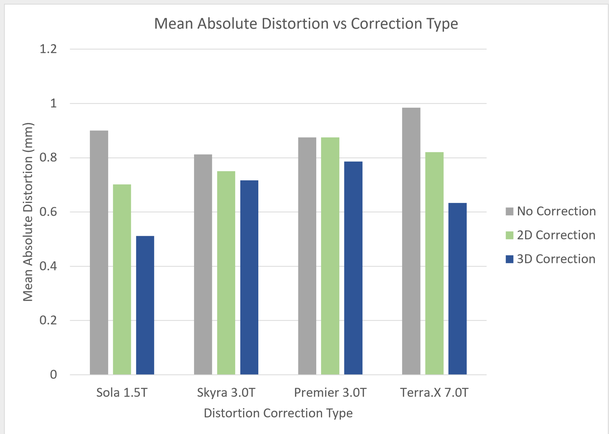


Figure 3. Mean absolute distortion vs type of distortion correction. 3D corrections generally provided the most significant reduction in distortion. The reduction was most pronounced at 1.5T, followed by 7.0T and then 3.0T.

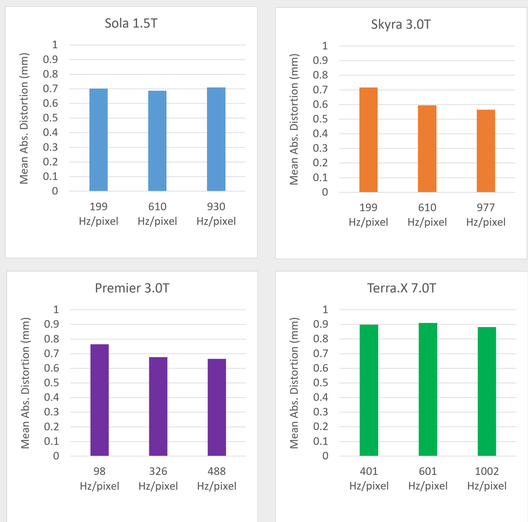


Figure 4. Mean absolute distortion vs pixel bandwidth for each scanner. A minimum, intermediate, and maximum value were selected for the protocol on each scanner.

DISCUSSION

This study evaluated the effects of no distortion correction, 2D distortion correction, and 3D distortion correction. In routine clinical imaging, 3D distortion correction generally reduced geometric distortion. As shown in Figs. 2 and 3, the mean/maximum distortion decreased from 0.90/3.20 to 0.51/0.98 mm (Sola 1.5T), 0.81/2.02 to 0.72/1.61 mm (Skyra 3.0T), 0.88/2.35 to 0.79/1.94 mm (Premier 3.0T), and 0.98/3.05 to 0.63/2.15 mm (Terra.X 7.0T).
The effect of receiver bandwidth on geometric distortion was also evaluated. Increasing the bandwidth reduced image distortion in some cases. As shown in Fig. 4, distortion remained relatively constant across bandwidths for the Sola and Terra.X scanners, whereas increasing the bandwidth produced a modest reduction in absolute distortion for both 3.0T scanners.

CONCLUSIONS

As expected, overall phantom distortion increased with magnetic field strength. Among the scanners evaluated, 3D distortion correction provided the greatest reduction in geometric distortion. Optimizing the receiver bandwidth also enabled further distortion reduction in some cases.
Future work will build upon the findings of this study. Additional analyses will be performed using axial and coronal acquisitions, and three-dimensional maps of distortion across the scanner bore will be generated. These data may then be used to characterize and correct geometric distortion in clinical MRI images.

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