

# The Importance of MRI Distortion Routine QA Check for Stereotactic Radiosurgery

- the experience from distortion measurements on more than 20 MRI scanners over 10 consecutive years

## The James

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## Background

### 1. What is MRI image distortion?

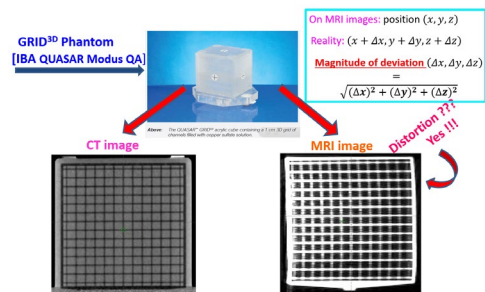


Fig. 1: Schematic view showing MRI distortion.

### 2. Why is MRI distortion concerning?

Modern radiation therapy is based on 3-D spatial coordinates of targets and organs at risk (OARs) which are defined by images:

- 1) Tumors/targets and OARs are delineated and contoured based on MRI images owing to the feature of soft-tissue tumor contrast enhancement, and doses to them are prescribed, calculated, and evaluated.
- 2) Dose distribution in 3-D space and dose volume histograms (DVHs) of targets and OARs depend on images and contours, which are used to evaluate the dose to targets and OARs.
- 3) In MRI-guided radiation therapy, MRI images are used to set up and guide treatments.
- 4) Distortion in MRI images will cause inaccurate targeting and dose deviation.

5) ACR-based protocol Radiology MRI QA (ACR - American College of Radiology) is more focused on the diagnosis aspect; the tolerance of geometric distortion may not meet the requirement for radiation therapy, especially radiosurgery or SRS/SBRT.

6) For small targets in SRS/SBRT/Gamma Knife treatments (such as trigeminal neuralgia, small lesions, essential tremor, and OCD), the impact on treatment efficacy & risk to OARs is significant!

7) Tolerance of geometric distortion for Gamma Knife Radiosurgery & SRS/SBRT: 1 mm.

**Examples:** MRI distortion could cause significant problems

- 1) Gamma Knife radiosurgery for right trigeminal facial pain
- 2) Gamma Knife radiosurgery for two small metastatic brain lesions in parietal lobe and spinal cord.

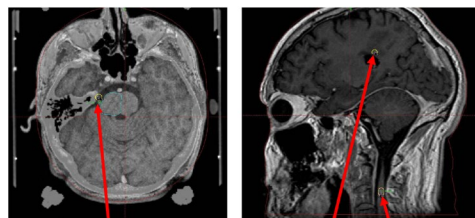


Fig. 2: Example of how MRI distortion could impact the outcome of radiosurgery

## Method & Materials

**Phantoms:** GRID<sup>3D</sup> & MRID<sup>3D</sup> [IBA ModusQA]

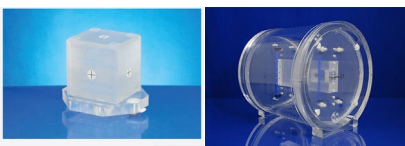


Fig. 3: (1) GRID<sup>3D</sup> (left) (2) MRID<sup>3D</sup> (right)

**Step 1:** Scan a phantom containing thousands of reference/control points with known physical coordinates (x, y, z) to acquire MRI images on the MRI scanner under investigation. Scan protocols:

- 3D volumetric sequences that are used to scan patients for Gamma Knife and Linac-based SBRT/SRS, GE: 3DSPGR; Siemens: FL3D or T1VIBE. Slice thickness: 1 mm.

**Step 2:** Compare the associated reference points' coordinates shown on the MRI images to find out the difference – the deviation from their physical positions.

**Step 3:** Review the distortion/deviation on the MRI images for every spatial point within the 3-D space of the phantom: (1) The magnitude of distortion; (2) The direction of distortion; and (3) The position of distortion.

## Results

1. Result of distortion QA measurements for all 24 Scanners across our medical center (including all inpatient and outpatient centers) during the 2025-2026 QA cycle that are available for RT, SRS/SBRT, and Gamma Knife: 22 Siemens & 2 GE; 12 are 3T & 12 are 1.5T (Fig.3).

Comparison of the magnitude of distortion for 6 of 24 scanners that are used for frame-based Gamma Knife radiosurgery. Distortion < 1 mm.

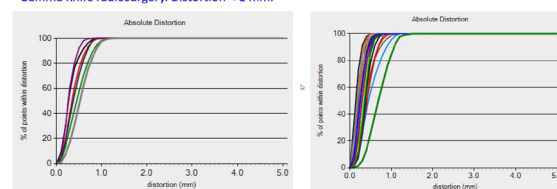


Fig. 4: Comparison of the distortion magnitude for 6 of 24 scanners that are used for frame-based Gamma Knife (left) and all 24 scanners for frameless Gamma Knife and other SBRT/SRS (right). Distortion < 1 mm.

2. Large distortion occurred for some scanners due to many factors (Fig. 5a, b, c):

- (1) A scanner was so old that its hardware/software could not reduce distortion (Fig. 5a).
- (2) Distortion Correction was turned off for a scanner (Fig. 5b).
- (3) A scanner underwent a major upgrade (Fig. 5c). MRI distortion became much larger compared with previous several years (2019, 2020, 2021) after a major software upgrade (2022/5/22). After the problem was identified and corrected the image distortion became normal (2022/6/17).

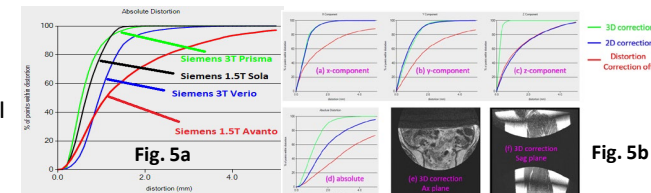


Fig. 5: Large distortion occurred for some scanners attributed to various causes.

### 3. Comparison of distortion between 1.5T and 3T scanner:

Diagnosis Incenter (DOB)	MRI Scanners				MRI Scanners - 2000 mm			
	Mean (mm)	STD (mm)	95th (mm)	% Above 2.50 mm	Mean (mm)	STD (mm)	95th (mm)	% Above 2.50 mm
GE 1.5T Avanti	0.320	0.400	2.124	0.000	0.320	0.400	2.124	0.000
Siemens 1.5T Solta	0.064	0.317	1.933	1.270	0.000	0.000	0.000	0.000
Siemens 1.5T Aera	0.061	0.320	1.910	1.307	0.000	0.000	0.000	0.000
Siemens 1.5T Aera2	0.062	0.304	1.928	1.302	0.000	0.000	0.000	0.000
Average of 4 of 4 1.5T MRI Scanners	0.062	0.321	1.922	1.305	0.000	0.000	0.000	0.000
MRI Scanners	Mean (mm)	STD (mm)	95th (mm)	% Above 2.50 mm	Mean (mm)	STD (mm)	95th (mm)	% Above 2.50 mm
Siemens 3T Prisma	0.526	0.360	2.338	1.318	0.000	0.000	0.000	0.000
Siemens 3T Verio	1.054	0.400	2.008	1.312	0.000	0.000	0.000	0.000
Siemens 3T Verio2	0.010	0.000	4.780	1.199	0.000	0.000	0.000	0.000
Siemens 3T Verio3	0.003	0.000	4.230	1.800	0.000	0.000	0.000	0.000
Siemens 3T Aera2	1.143	0.536	4.261	1.215	1.850	0.000	0.000	0.000
Siemens 3T Aera3	0.880	0.507	4.116	1.262	1.874	0.000	0.000	0.000
Average of 6 of 6 3T MRI Scanners	0.531	0.313	3.632	1.321	1.874	0.000	0.000	0.000
MRI Scanners	Mean (mm)	STD (mm)	95th (mm)	% Above 2.50 mm	Mean (mm)	STD (mm)	95th (mm)	% Above 2.50 mm
GE 1.5T Avanti	0.320	0.130	0.680	0.000	0.320	0.000	0.000	0.000
Siemens 1.5T Solta	0.066	0.130	0.500	0.000	0.066	0.000	0.000	0.000
Siemens 1.5T Aera	0.061	0.128	0.613	0.000	0.061	0.000	0.000	0.000
Siemens 1.5T Aera2	0.062	0.128	0.613	0.000	0.062	0.000	0.000	0.000
Siemens 1.5T Solta	0.061	0.116	0.728	0.000	0.061	0.000	0.000	0.000
Average of 5 of 5 1.5T MRI Scanners	0.062	0.127	0.613	0.000	0.062	0.000	0.000	0.000
MRI Scanners	Mean (mm)	STD (mm)	95th (mm)	% Above 2.50 mm	Mean (mm)	STD (mm)	95th (mm)	% Above 2.50 mm
Siemens 3T Prisma	0.649	0.222	1.307	0.000	0.649	0.000	0.000	0.000
Siemens 3T Verio	0.479	0.484	1.441	0.000	0.479	0.000	0.000	0.000
Siemens 3T Verio2	0.146	0.193	1.210	0.000	0.146	0.000	0.000	0.000
Siemens 3T Verio3	0.005	0.010	1.028	0.000	0.005	0.000	0.000	0.000
Siemens 3T Aera2	0.818	0.330	1.228	0.000	0.818	0.000	0.000	0.000
Siemens 3T Aera3	0.372	0.156	1.147	0.000	0.372	0.000	0.000	0.000
Average of 6 of 6 3T MRI Scanners	0.372	0.156	1.147	0.000	0.372	0.000	0.000	0.000

Fig. 6: Comparison of the magnitude of the image distortion between 1.5T and 3T scanners: (a) ROI with a radius of 200 mm and (b) ROI with a radius of 100 mm.

## Summary

- MRI distortion routine QA checks dedicated to radiation therapy aside from the ACR MRI QA are essential, especially for Gamma Knife radiosurgery and SBRT/SRS.
- Large MRI distortion may occur in the routine clinical MRI scans for some scanners, which indicates the importance of routine MRI distortion QA checks.
- Measures/policy/protocol should be created and applied to prevent the large distortion images from being used for radiosurgery treatment planning.

## References

1. QUASAR™ MRID3D Geometric Distortion Analysis System User's Guide - 01132016.
2. L. Lu, et al., Assessment of MRI image distortion based on 6 consecutive years of annual QAs and measurements on 14 MRI scanners used for radiation therapy. J Appl Clin Med Phys. doi: 10.1002/acm2.13843. Epub 2022 Nov 16. PMID: 36385457; PMCID: PMC9859981.