Comparison of three different phantoms and methods of MR image geometric distortion measurement for three MR scanners

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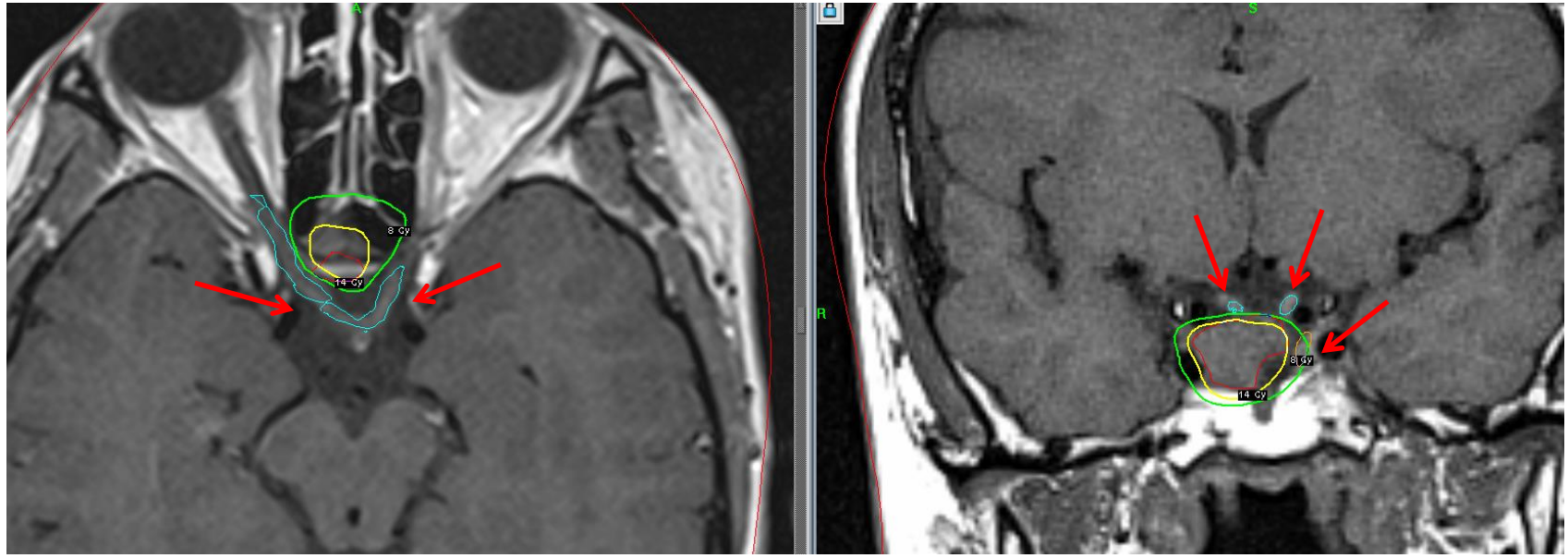
Stereotactic imaging

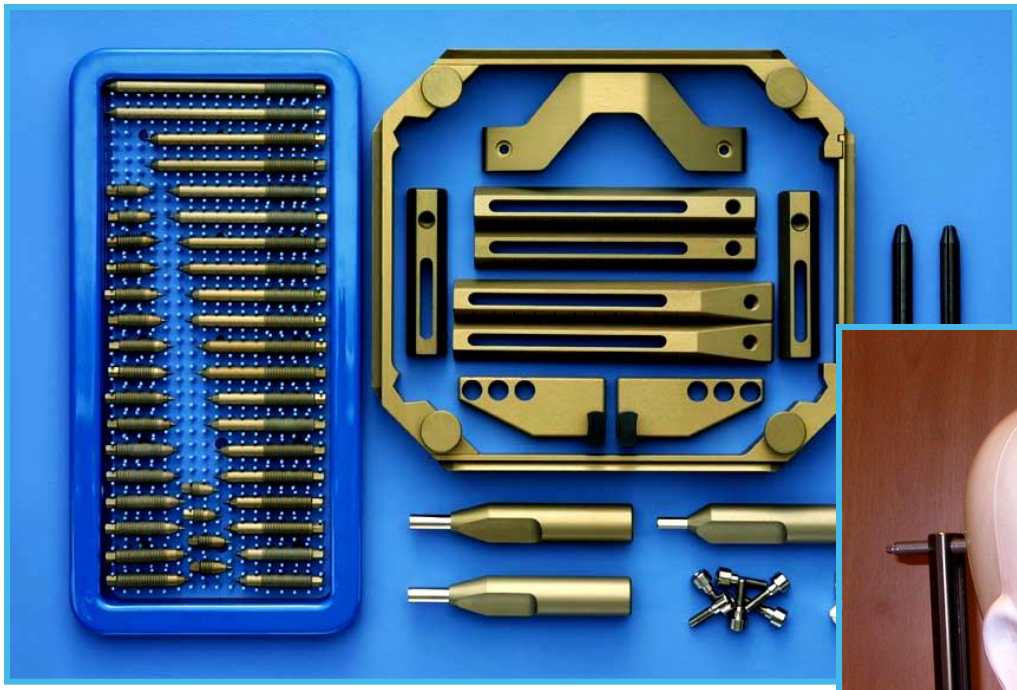
- Provides basic anatomical information to define target, critical structures and etc.

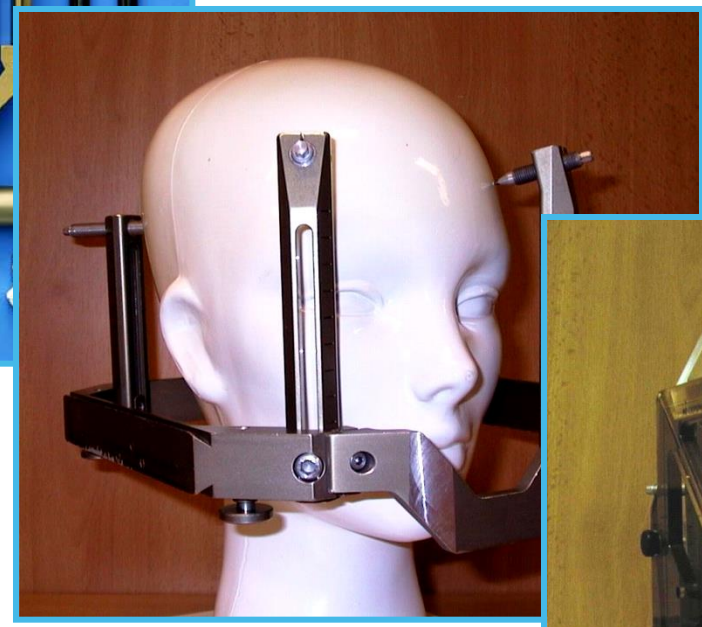
- Provides geometrical information to define spatial location



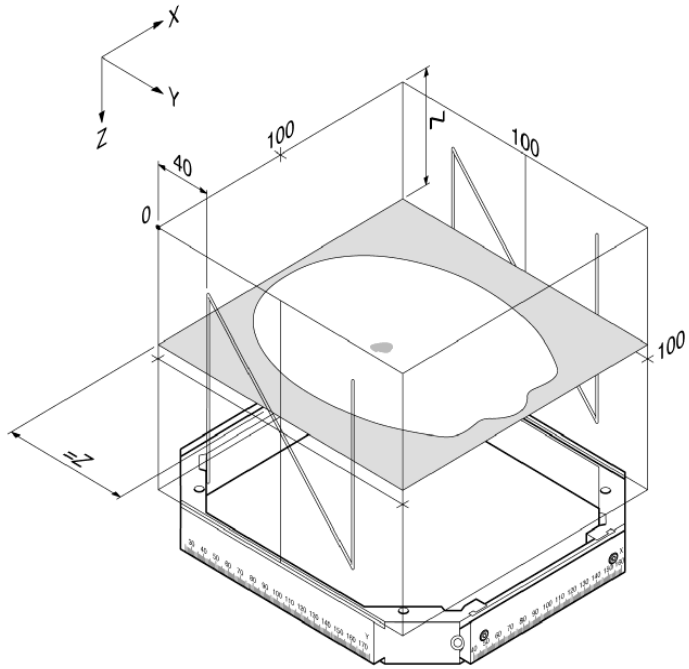
Treatment will be as accurate as our images are…!

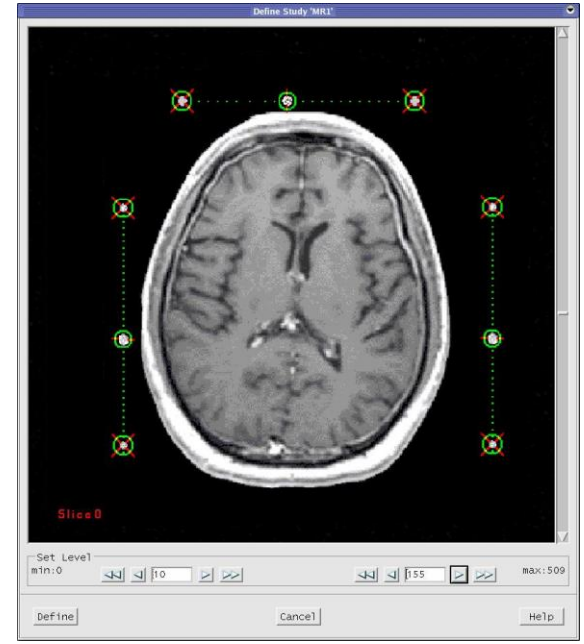
Stereotactic target localization in Leksell system

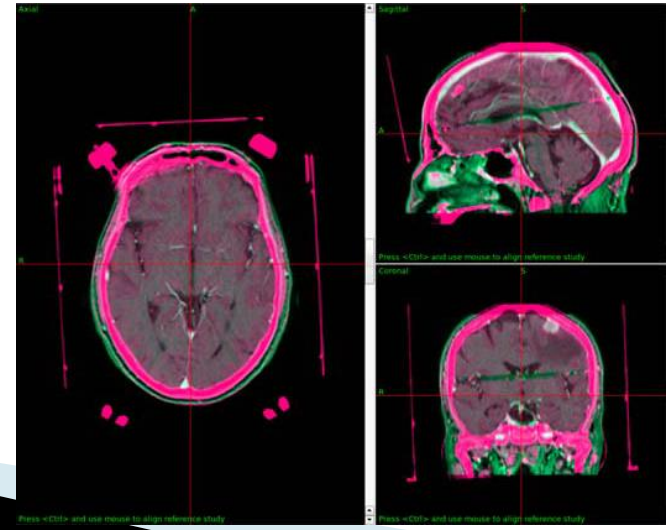




Principles of target coordinate determination (CT and MR)

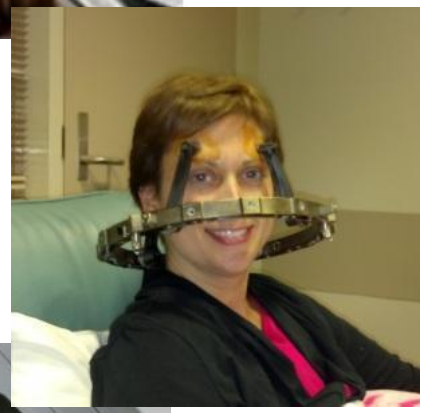






Invasive and non invasive head immobilisation

INVASIVE FIXATION

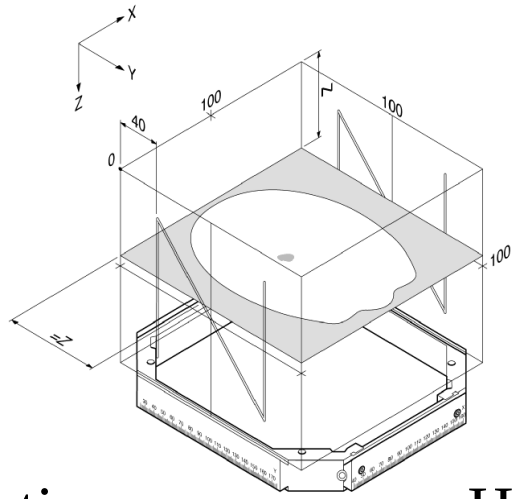


NOINVASIVE FIXATION

Stereotactic imaging for Leksell Gamma Knife

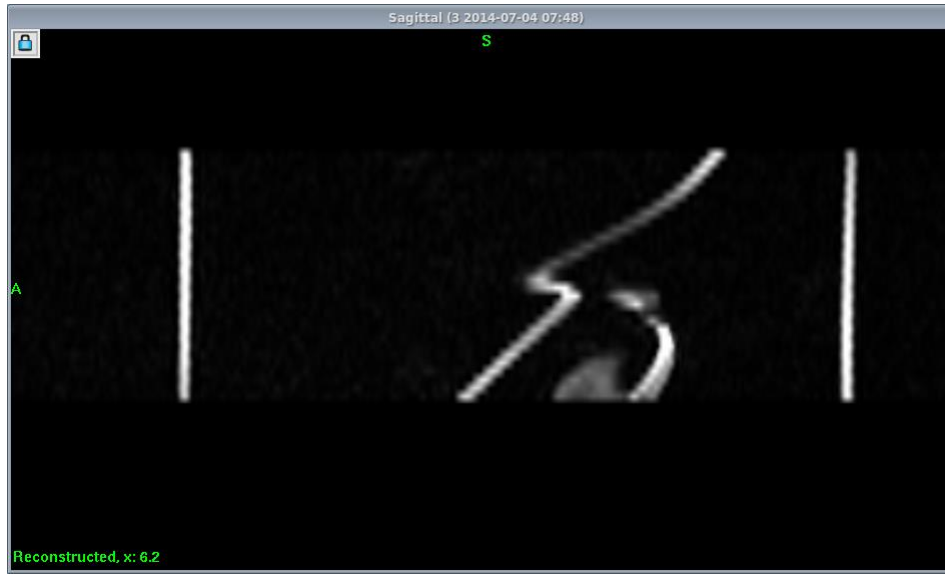
- MRI (Most of the time only imaging!)
- CT not required
- Angiography (DSA) in the case of AVM
- PET
- MEG

MR geometric distortion



Negligible geometric distortion

Huge geometric distortion



Main reasons for geometrical MR image distortion

- **Gradient field nonlinearities (imperfection in linear gradients)**
  - barrel aberration, potato chip, and bow tie effect

- **Resonance offsets**
  - chemical shift
  - static B_0 magnetic field inhomogeneity induced by MR unit itself

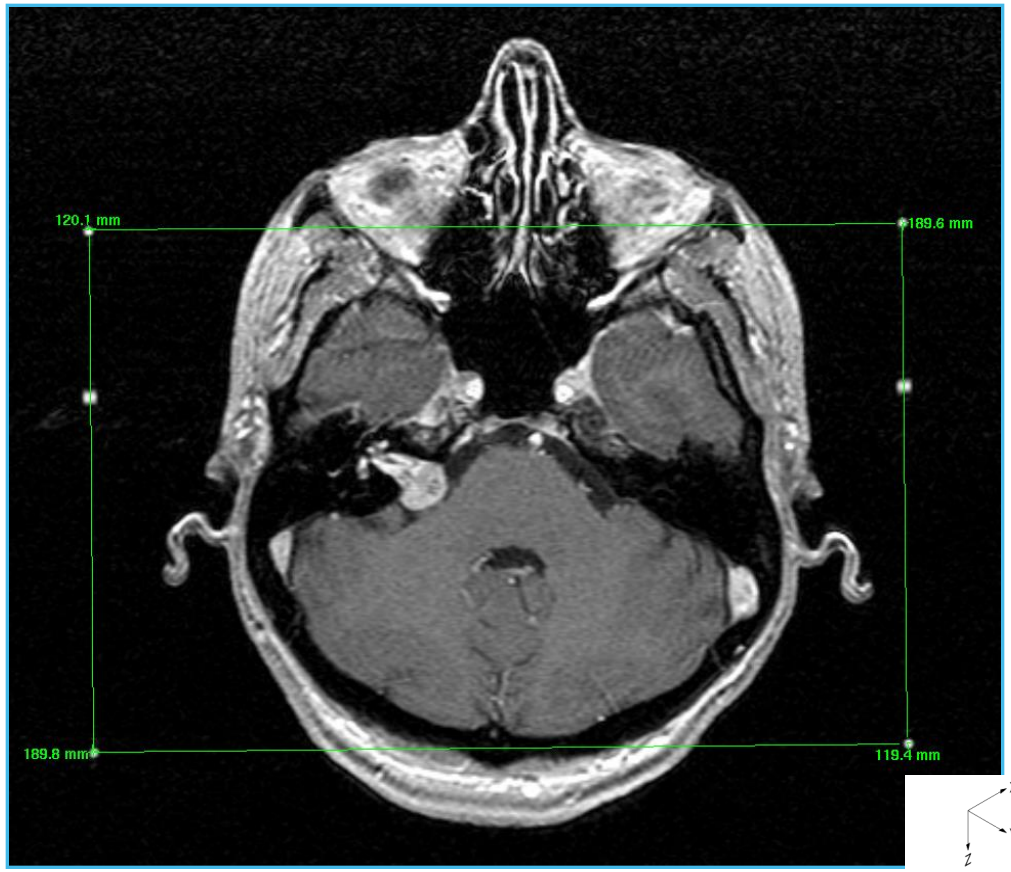
  or by the imaged object (both material and shape are important)

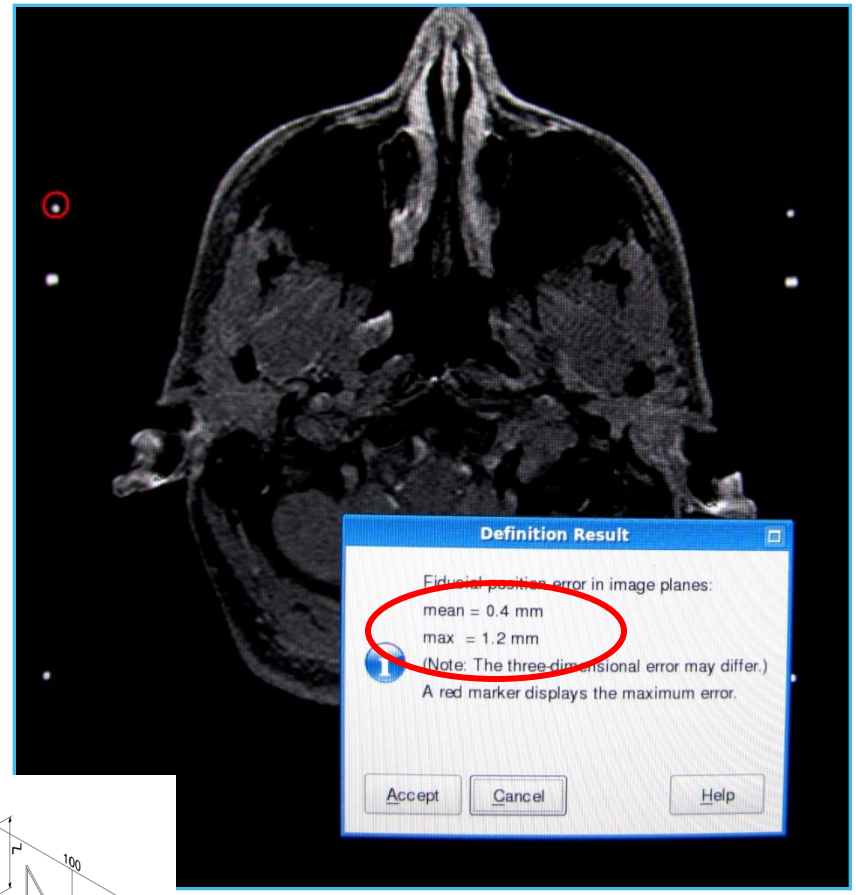
Three ways to check MR geometric distortion

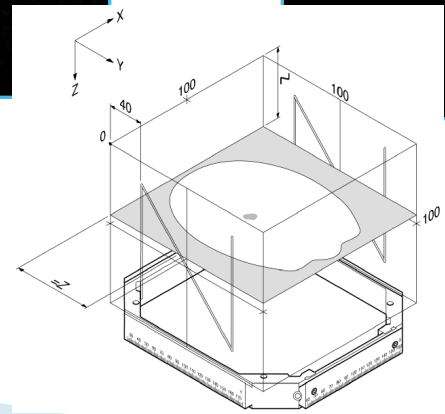
- Measurement of fiducials geometry (individual for each patient)
- Comparison of clinical patient data (images) from CT and MR or MR and MR
- Phantom measurements (most accurate)

Best is to use all methods!

Quality control of imaging – fiducial markers measurement







Studies performed in our center

Journal of Radiosurgery, Vol. 1, No. 2, 1998

Assessment of the Accuracy of Stereotactic Target Localization Using Magnetic Resonance Imaging: A Phantom Study

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Magnetic resonance imaging is a valuable technique for brain target visualization and localization for stereotactically guided open surgery, stereotactic biopsy, or stereotactic radiosurgery. However, questions remain regarding the extent of image distortion (caused mainly by inhomogeneity of the constant magnetic field induced by the imaged object and nonlinearities in the gradient fields) and its effect on the accuracy of stereotactic localization. A phantom study has been carried out to assess the accuracy of stereotactic localization using spin echo T1-weighted, T2-weighted, proton density, and gradient echo three-dimensional magnetic resonance imaging. A special cubical perspex phantom with the insert of an array of 81 solid perspex rods (2 mm in diameter and spaced 15 mm) was constructed and attached to the base of a Leksell sterotactic frame. The deviations between sterotactic coordinates based on magnetic resonance imaging determined in the treatment planning system and real geometrical position given by the construction of an array of perspex rods within the phantom were evaluated in a series of axial and coronal images for the above-mentioned four sequences. No dependence of the extent of deviations on the investigation sequences was observed. The image orientation and spatial position of measured points in the volume of cubical phantom were also not significantly influenced. The maximal deviation was observed for T1-weighted coronal study, 1.8 mm in the *Z* coordinate. However, average deviations in all of the eight performed studies were less than or equal to 0.6 mm. Phantom measurements proved minimal distortion effects for all i
applied for stereotactic localizatio

KEY WORDS: Magnetic resonance; in MRI.

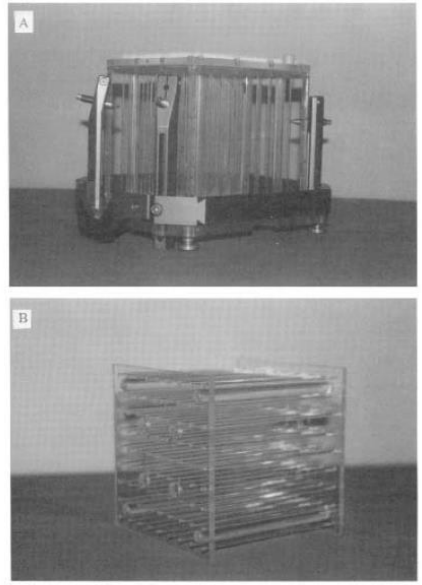

Fig. 1. The cubical perspex phantom secured to the base of the Leksell stereotactic frame (A), and the insert to this phantom consisting of an array of 81 solid perspex rods (B).

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Does new magnetic resonance imaging technology provide better geometrical accuracy during stereotactic imaging?

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Object. The authors sought to compare the accuracy of stereotactic target imaging using the Siemens 1T EXPERT and 1.5T SYMPHONY magnetic resonance (MR) units.

Methods. A water-filled cylindrical Perspex phantom with axial and coronal inserts containing grids of glass rods was fixed in the Leksell stereotactic frame and subjected to MR imaging in Siemens 1T EXPERT and Siemens 1.5T SYMPHONY units. Identical sequences were used for each unit. The images were transferred to the GammaPlan treatment planning system. Deviations between stereotactic coordinates based on MR images and estimated real geometrical positions given by the construction of the phantom insert were evaluated for each study. The deviations were further investigated as a function of the MR unit used, MR sequence, the image orientation, and the spatial position of measured points in the investigated volume.

Conclusions. Larger distortions were observed when using the SYMPHONY 1.5T unit than those with the EXPERT 1T unit. Typical average distortion in EXPERT 1T was not more than 0.6 mm and 0.9 mm for axial and coronal images, respectively. Typical mean distortion for SYMPHONY 1.5T was not more than 1 mm and 1.3 mm for axial and coronal images, respectively. The image sequence affected the distortions in both units. Coronal T_2-weighted spin-echo images performed in subthalamic imaging produced the largest distortions of 2.6 mm and 3 mm in the EXPERT 1T and SYMPHONY 1.5T, respectively. Larger distortions were observed in coronal slices than in axial slices in both units, and this effect was more pronounced i Image distortion in Expert and Symphony units
tom were associated wi

**KEY WORDS • ma
phantom measurem**

FIG. 1. The inhouse made cylindrical Perspex phantom secured to the base of the Leksell stereotactic frame was used for measurements made in this study.

field. Hydrogen nuclei bound to fat and water molecules show a difference in Larmor frequency.[8,9,23] This variation may cause different objects in images to shift relative to each other in the so-called frequency encoding direction and perhaps appear in identical pixels. This situation, which can happen for instance in cases of fatty tumors,[8] is of negligible importance for a clinical neuroradiologist but can be critical for a stereotactic neurosurgeon. Magnetic field inhomogeneities on the other hand may be induced by the MR unit itself or by the imaged object. Main magnetic field B_0 is designed to be highly constant within the unit's FOV. With recent improvements in magnets and shimming methods, unit-induced inhomogeneities have no significant influence on image distortion effects.[7,23] More important is the geometrical distortion caused by inhomogeneity induced by the imaged object. The distortion in this case depends on both the material (patient's head with the stereotactic frame)

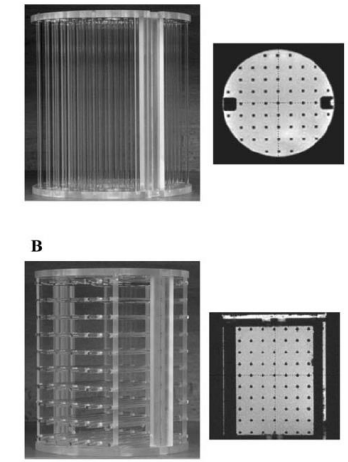
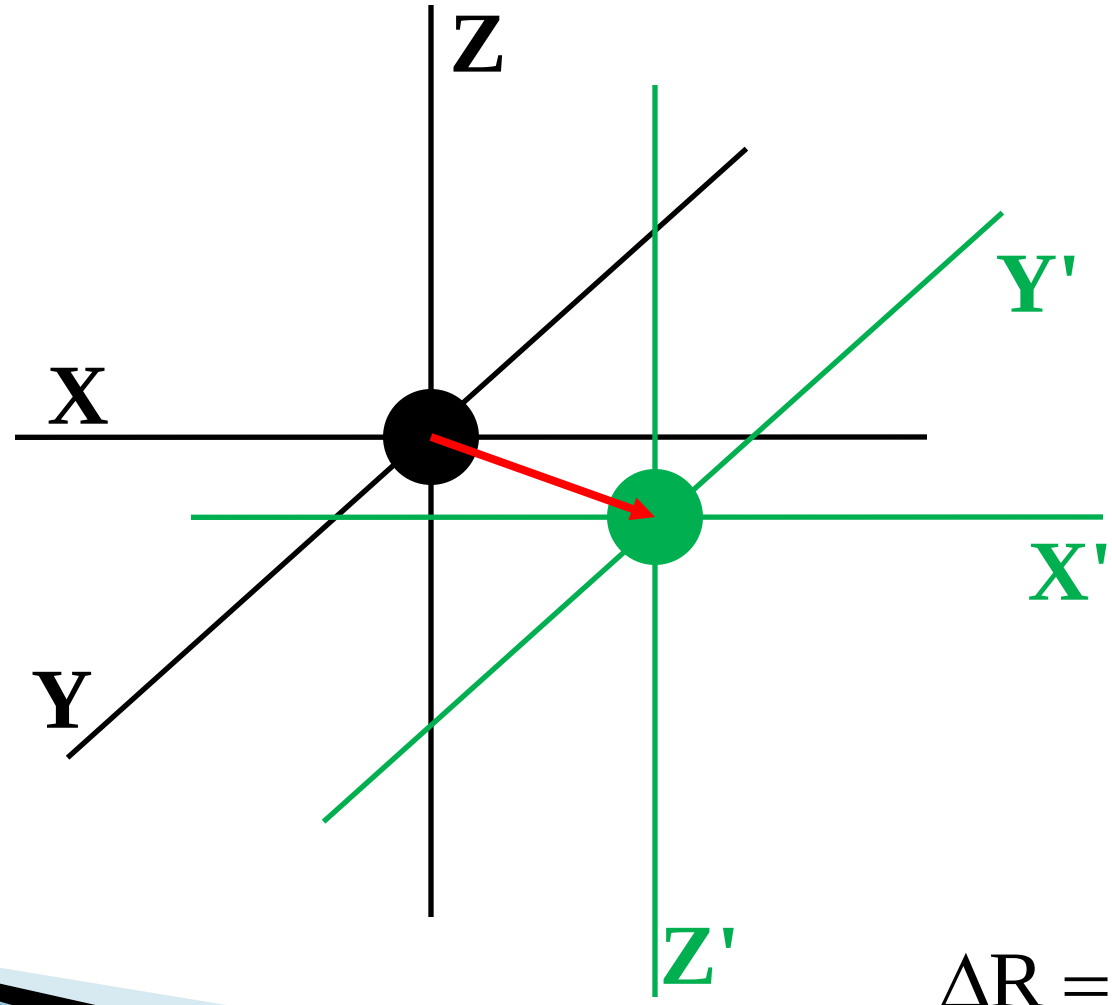


FIG. 2. Two inserts consisting of solid glass rods (3 mm in diameter and spaced 15 mm apart) were used to assess the accuracy of axial and coronal MR images. There were 59 and 63 glass rods in the case of axial (A) and coronal inserts (B), respectively. An MR image in one slice of both inserts is shown.

Objectives of this study

- Evaluate image distortion for three different Siemens MR scanners.
- Test and compare three different phantoms and methodology of measurement.
- Evaluate image co-registration uncertainty.

MR distortion measurement



$$\Delta x = x' - x$$

$$\Delta y = y' - y$$

$$\Delta z = z' - z,$$

$$\Delta R = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}$$

MR scanners and scanning parameters in this study

- Identical scanning conditions as for a patient (same frame, posts, fixation screws, MR adaptor)
- Identical stereotactic image definition conditions as for a patient (Leksell GammaPlan)
- T1-weighted 3D imaging, whisper gradients, distortion correction applied when available

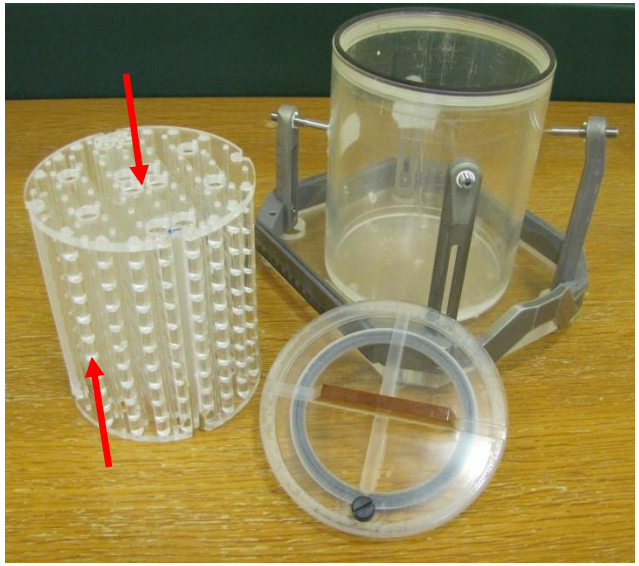
- Siemens Symphony 1.5T

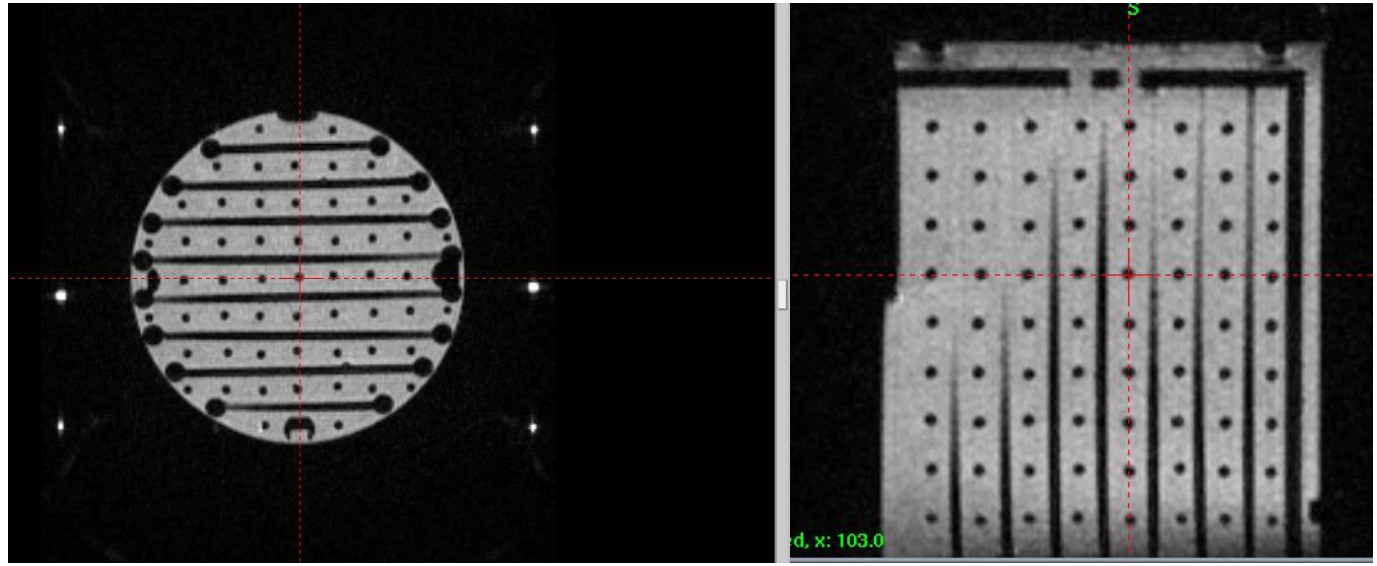
- Siemens Avanto 1.5T

- Siemens Skyra 3T

In-house made phantom

Na Homolce Hospital, Prague, Czech Republic

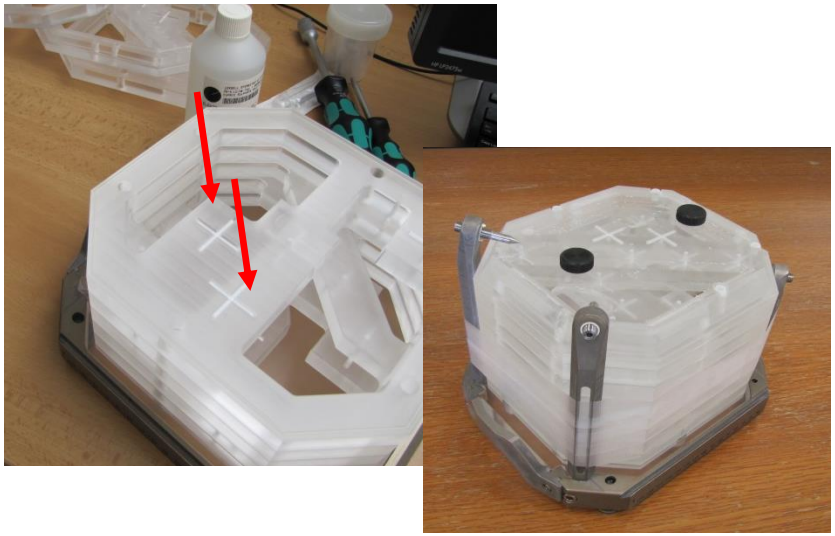


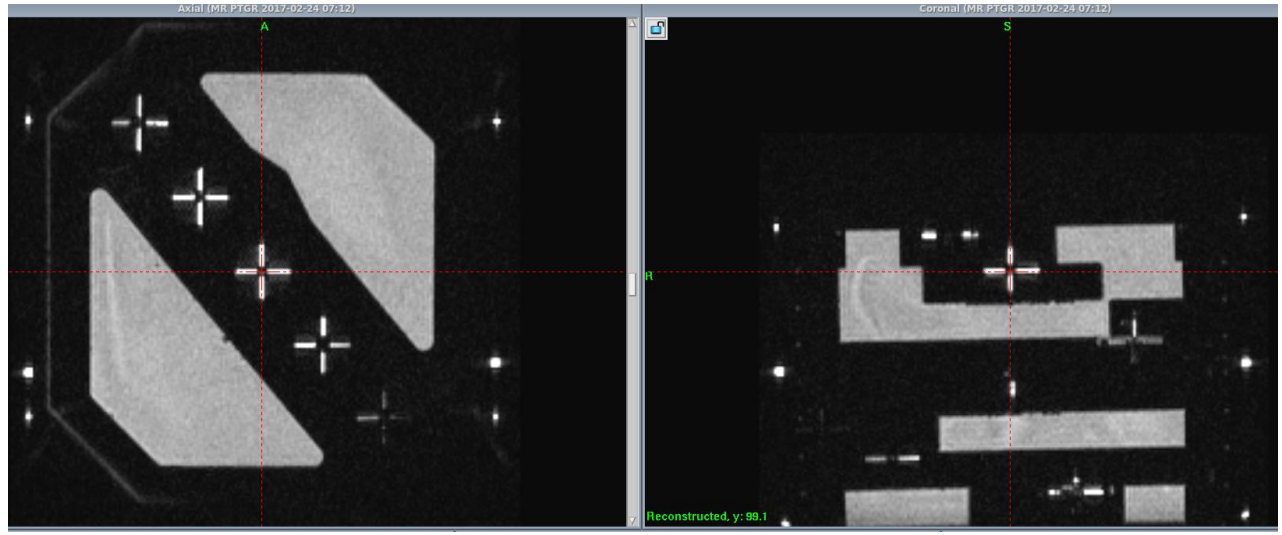


- 55 axial and 72 coronal grid equidistant points 15 mm apart
- reference imaging is needed (MR compared to CT)

PTGR known target phantom

Physikalisch-Technische Gesellschaft für Radiologie – mbH, Tübingen, Germany

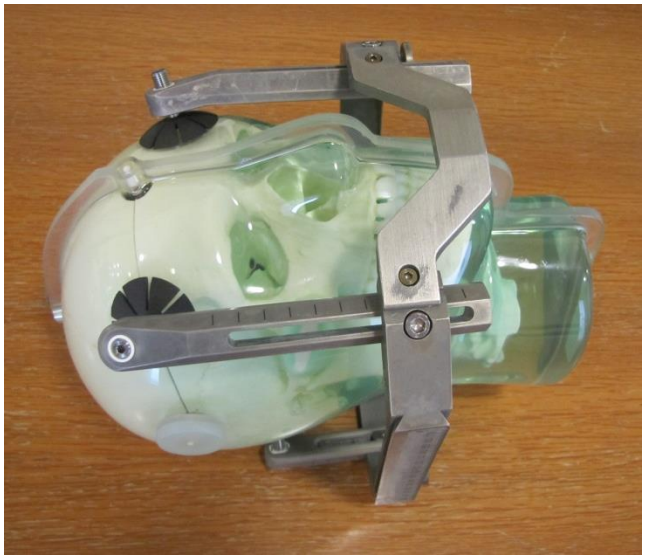


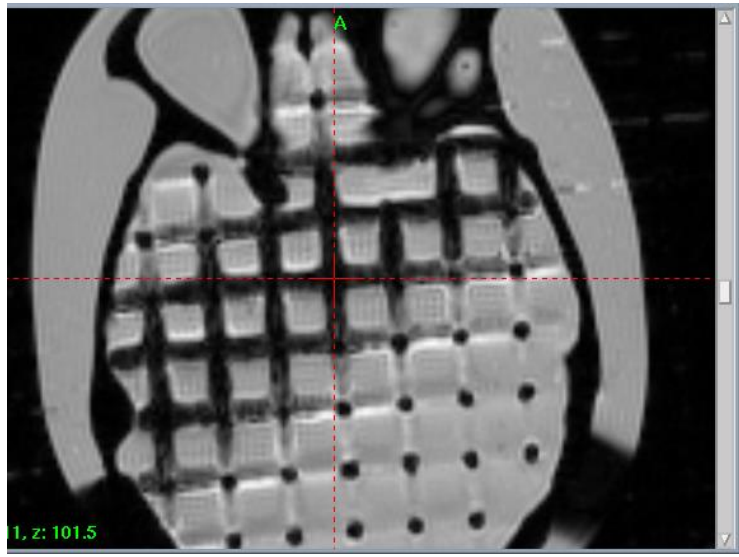


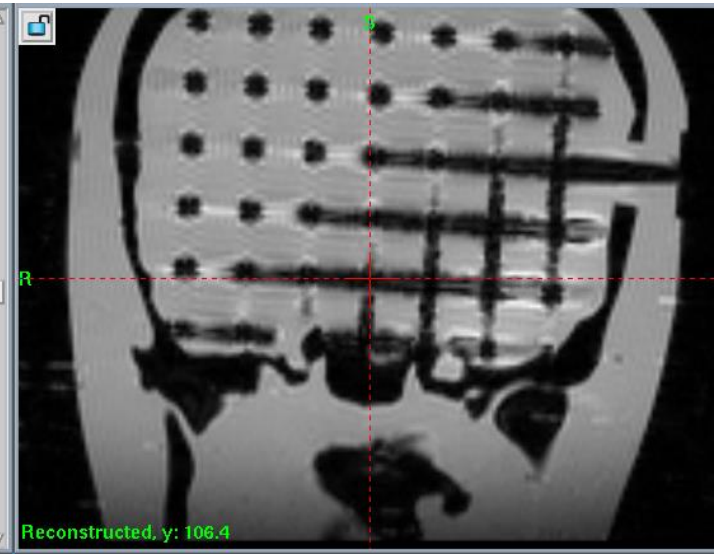
- 21 three dimensional cross hairs filled with contrast medium
- positioned at known Leksell coordinates covering the whole stereotactic space

CIRS 3D Anthropomorphic Skull Phantom

CIRS, Computerized Imaging Reference Systems, Inc., Norfolk, VA, USA

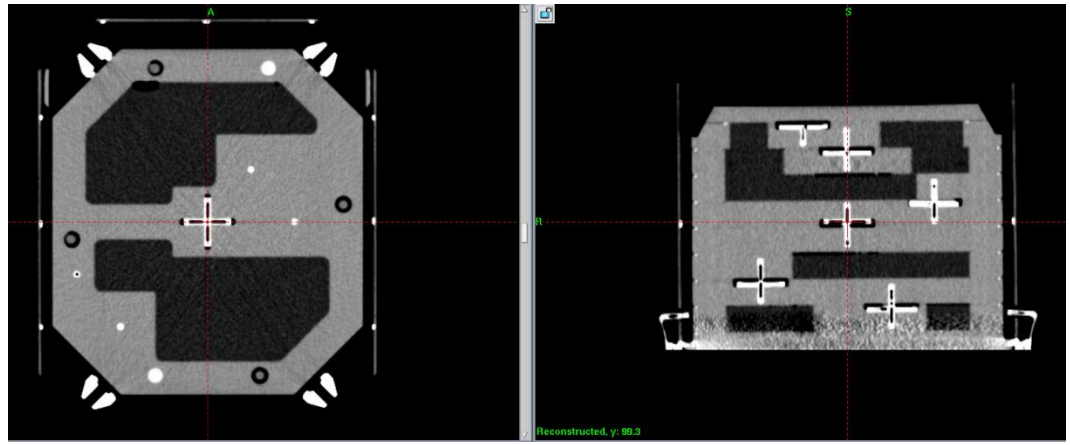






- entire skull volume is filled with a 3D matrix of 3 mm diameter rods spaced 15 mm apart
- reference imaging is needed (MR compared to CT)
- used also for image co-registration accuracy assessment in this study, MR Skyra - MR Avanto, MR Skyra - MR Symphony, MR Skyra – CT co-registrations tested and compared with fiducial based image definition

Results – assessment of CT scanner accuracy



	Mean deviations [mm]			
	PTGR phantom			
	ΔX	ΔY	ΔZ	ΔR
CT scanner	0.10	0.30	0.30	0.47±0.19

- **CT scanner:** Siemens SOMATOM Definition Flash
- **PTGR phantom:** evaluated all 21 points positioned through the entire stereotactic space

Results – estimated total uncertainty of measurement

	Estimated uncertainty of measurement [mm]		
Uncertainty	In-house	PTGR	CIRS
Mechanical accuracy of phantom manufacturing	N.A. (0.10)	0.10	N.A. (0.10)
Accuracy of CT reference image	0.30	N.A.	0.30
Precision of point measurement in Leksell GammaPlan	0.10	0.10	0.10
TOTAL UNCERTAINTY	**0.32**	**0.14**	**0.32**

Results – 3 phantoms, 3 MR scanners

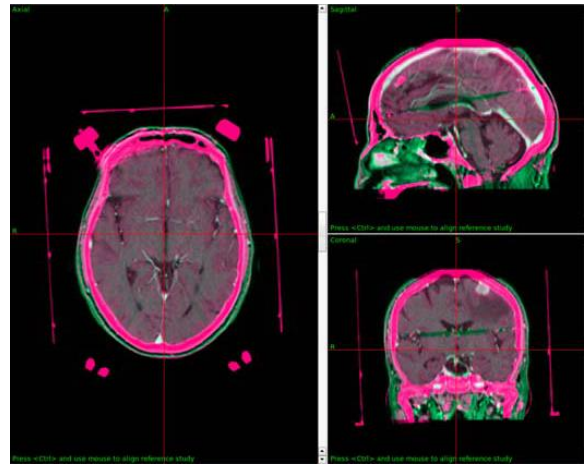
	Different phantoms mean deviations [mm]											
	In-house				PTGR				CIRS			
MR scanner	ΔX	ΔY	ΔZ	ΔR	ΔX	ΔY	ΔZ	ΔR	ΔX	ΔY	ΔZ	ΔR
Symphony 1.5T	0.25	0.63	0.45	0.90±0.31	0.19	0.34	0.60	0.78±0.47	0.22	0.54	0.76	1.08±0.49
Avanto 1.5T	0.26	0.40	0.30	0.63±0.23	0.28	0.67	0.38	0.92±0.39	0.20	0.42	0.97	1.15±0.48
Skyra 3T	0.27	0.48	0.42	0.78±0.37	0.25	0.75	0.65	1.20±0.53	0.27	0.68	1.03	1.35±0.49

- **In-house phantom:** evaluated in total 48 selected points in three different slices (superior, middle, inferior)
- **PTGR phantom:** evaluated all 21 points positioned through the entire stereotactic space
- **CIRS phantom:** evaluated 30 selected points through the entire stereotactic space

Results – image co-registration

	Mean deviations for image co-registration [mm]			
	CIRS			
Co-registration	ΔX	ΔY	ΔZ	ΔR
MR Skyra - MR Avanto	0.25	0.44	0.97	1.17±0.52
MR Skyra – MR Symphony	0.26	0.57	0.73	1.02±0.44
MR Skyra – CT	0.21	0.37	0.64	0.83±0.37
MR Skyra fiducial based image definition	**0.27**	**0.68**	**1.03**	**1.35±0.49**

- CIRS anthropomorphic phantom used
- CT taken as a reference imaging modality



Conclusions – this study specific

- CT scanner which was tested in this study and used as a reference imaging modality demonstrated minimal geometric distortions: 0.10; 0.30; 0.30 mm for X, Y, Z coordinates, respectively.

- Total estimated uncertainty in distortion measurement in one coordinate was in our study determined to be 0.32 mm and 0.14 mm for methods using and not using reference CT imaging, respectively.

- All three methods and phantoms presented in this study showed capability to reliably measure MR image geometric distortion.

- Results from all three phantoms and methods were comparable within the level of estimated uncertainty except CIRS phantom where larger distortion was observed in Z coordinate.

Conclusions – this study specific

- Better results were observed for Siemens 1.5T Avanto and 1.5T Symphony than Siemens 3T Skyra. Total radial distortion R was typically lower than 0.9 mm.

- Accuracy of image co-registration was tested with CIRS anthropomorphic phantom for 3T Skyra images which were co-registered to 1.5T Avanto, 1.5T Symphony and CT. All three co-registered images showed better accuracy than fiducial based image definition (CT image was taken as a reference). Best result was obtained for co-registration with CT providing total radial distortion R 0.83 mm compared to fiducial based definition where R was 1.35 mm.

Conclusions - general

- The geometric MR distortion usually affects the fiducial markers from the MR indicator box rather than the image itself.

- For the accurate assessment of the image geometric distortion direct measurement of stereotactic X, Y, Z coordinates of given points is needed instead of only distance measurement between these points.

- Newer MR technology does not automatically imply better MR image geometric accuracy.

- Geometric distortions depend on: MR model, unit itself, slice orientation, scanning parameters of the scanning protocol, scanning position from the center of the MR head coil, disturbing materials related to patient (surgical clips, dental materials and etc.).

Conclusions - general

- Geometric distortions vary between scanning protocols even on the same MR scanner.

- Typically larger geometric distortions are observed for coronal slice orientation than axial orientation.

- Higher distortions are typically observed for non-centrally located slice positions in the investigated volume (further inferior or further superior).

- Changes in scanning protocol parameters that may help:

  - whisper gradients mode

  - adjust optimal bandwidth

  - nonselective excitation

  - image distortion correction (if available)

Conclusions - general

- When in doubt regarding geometrical accuracy of MR images always investigate the reason and perform independent imaging (different MR or CT).

- Image co-registration is an efficient software tool to help in some difficult clinical situation to improve inaccuracy of distorted images.

Thank you!