Stereotactic radiosurgery for multiple brain metastases: Does MR/CT co-registration improve target localization accuracy compared to the MR-only approach?

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This research is co-financed by Greece and the European Union (European Social Fund-ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning 2014-2020» in the context of the project "Assessment of spatial uncertainties in target determination related to MRI and their impact on stereotactic radiotherapy treatment planning in multiple brain metastases cases" (MIS 5047965)

European Union
European Social Fund

Operational Programme
Human Resources Development, Education and Lifelong Learning
Co-financed by Greece and the European Union

ΕΣΠΑ 2014-2020
ανάπτυξη - εργασία - αλληλεγγύη

Introduction - Scope

Two clinical workflows for frame-based Gamma Knife radiosurgery of multiple brain metastases:

✓ **MR-only workflow**

- Cranial MR images of the patient with the stereotactic headframe are spatially co-registered to the Leksell stereotactic space by identifying the N-shaped fiducials of the MR-compatible localization box.
- Target localization accuracy is affected by (i) MR distortion at the lesion locations, (ii) MR distortion at the locations of the N-shaped fiducials, affecting the MR – Leksell space co-registration accuracy

✓ **MR/CT workflow**

- A CT scan of the patient is performed including the stereotactic headframe and the CT-compatible localization box. MR images are spatially co-registered to the CT image volume based on patient anatomy. Moreover, CT images are registered to the Leksell stereotactic space by identifying the N-shaped fiducials
- Target localization accuracy is affected by (i) MR distortion at the lesion locations, (ii) MR distortion at the surrounding anatomical regions affecting MR/CT co-registration accuracy, (iii) inherent MR/CT registration uncertainty relevant to the image quality and performance of the algorithm employed

MR distortions are also patient-induced and thus might not be relevant in a phantom study. This work aims at comparing target localization accuracy for both workflows employing patient images used in Gamma Knife treatment planning.

Materials and Methods

Patients, images and planning

- ✓ 15 patients totaling **81 metastases**
- ✓ Stereotactic headframe pinned to each patient's head during all scans
- ✓ CT imaged at 120kVp with no contrast agent
- ✓ Contrast enhanced T1w MR images acquired at 1.5T
- ✓ Treatment planning performed by following the **MR-only and the MR/CT workflows**, independently
- ✓ Delineation of targets relied on the MR images using **automatic threshold-based contouring** in the GammaPlan TPS
- ✓ For the MR/CT co-registration, a **global image registration approach** was followed.

Reference lesion locations

- ✓ The **mean image distortion correction** technique was used to minimize sequence dependent MR distortion. The method is described in Ref 1
- ✓ An additional MR pulse sequence was added to the standard clinical MR imaging protocol
- ✓ The extra sequence is identical to the clinical T1w one, except for a **reversal of the polarity of the frequency encoding axis**.
- ✓ Frequency encoding was reversed from Anterior-Posterior to Posterior-Anterior
- ✓ By averaging the pixel intensities in the forward and reversed polarity images, **MR-corrected images** were obtained.
- ✓ This method undistorts the entire image volume, including the N-shaped fiducials
- ✓ MR-corrected images were imported to the TPS for treatment planning, without using CT images

Analysis & comparison

- ✓ Three workflows were followed for treatment planning, independently; (i) **MR-only**, (ii) **MR/CT** and (iii) **MR-corrected**
- ✓ For each workflow, created structures were exported in DICOM-RT format with corresponding vertices registered to the MR image coordinate system
- ✓ All **rigid transformations calculated by the TPS** (either MR/CT, MR/Leksell space or CT/Leksell space were exported in xml file format
- ✓ Using in-house routines, **the centroids of all structures** corresponding to the 81 lesions were calculated in the **Leksell stereotactic space**, applying all rigid transformations involved
- ✓ **MR-corrected centroids served as reference** for the evaluation of the MR-only and MR/CT workflows

Results (I)

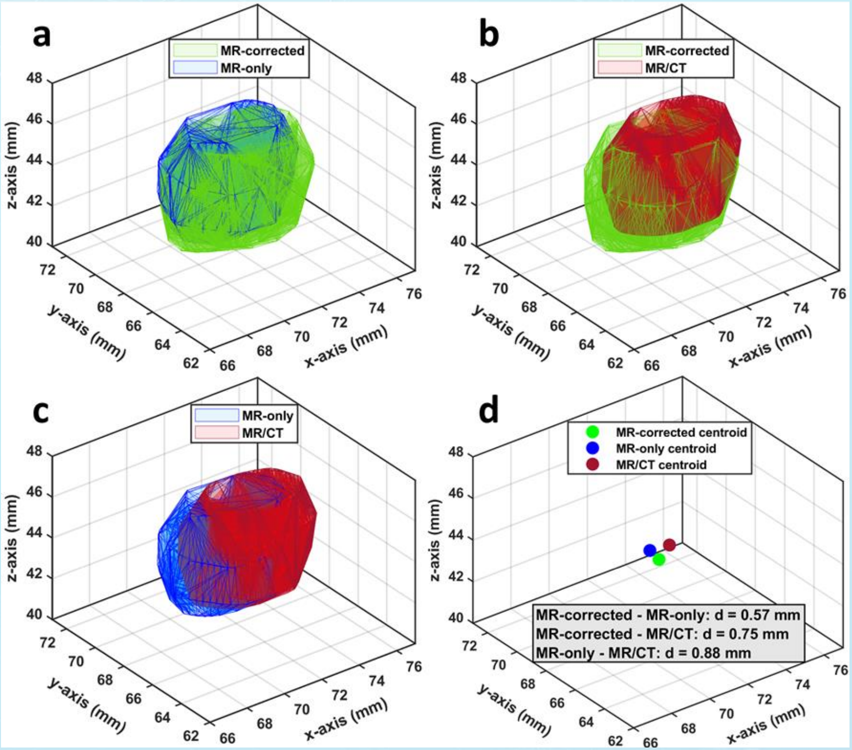

Figure 1. (a,b,c) An indicative brain lesion, contoured on the contrast-enhanced T1w MR images and localized in the Leksell Stereotactic Space (LSS), following the three frame-based workflows. Transformed structures are shown in 3D, in pairs of two for visibility and comparison purposes. (d) The position of the centroid corresponding to each workflow, localized in the LSS coordinate system and corresponding radial distances. x, y, z axes correspond to the normal axes of the LSS.

For an indicative lesion, target locations in the Leksell stereotactic space obtained following the two clinical and the reference workflow are shown in Figure 1.

Results related to all 81 lesions are summarized in Figure 2. For the MR-only approach, a median geometric offset of 0.6 mm was estimated. Targets lying at the superior side of the brain demonstrated the greatest (up to 1.1 mm) spatial offsets, potentially due to compromised B_0 uniformity. Regarding the MR/CT workflow, estimated spatial offsets were comparable than the corresponding MR-only uncertainties, resulting in median and maximum values of 0.7 mm and 1.4 mm, respectively (Figure 2).

Results (II)

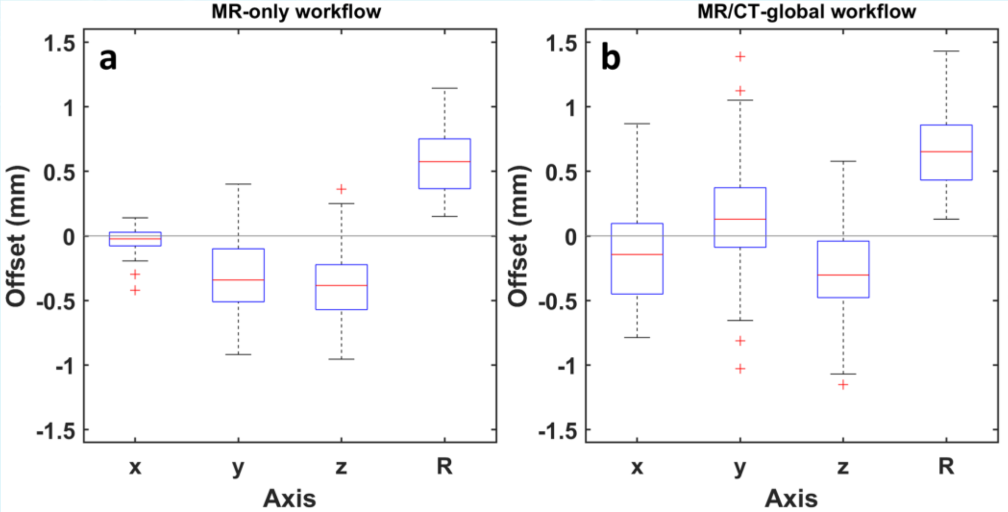

Figure 2. Box-whisker plots, implementing the (a) MR-only and (b) MR/CT workflows. Red lines indicate median detected offsets on each axis, whereas blue boxes range from the 1st to 3rd quartile. Whiskers depict the remaining data or extend up to 1.5 times the interquartile range in either direction. In each dataset, remaining outliers (if any) are shown by the red marks.

Conclusion

MR/CT co-registration does not seem to improve target localization accuracy, compared to the distortion-corrected MR-only approach, due to the additional uncertainty associated with the extra co-registration step. Regarding the clinical MR-only implementation, attention should be paid to distortions affecting target and fiducial locations.

References

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Acknowledgement

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