Accuracy of Tissue Heterogeneity Corrected MRI-based Treatment Planning in Brain Radiation Therapy

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Purpose: MRI is necessary for tumor delineation in radiation therapy planning for most cases because it allows for superior visualization of soft tissue differences compared to CT. However, the current radiation therapy process relies on CT data for dose calculation, because CT image intensities (unlike MR image intensities) show a clear relationship with tissue electron densities. Currently, most radiation oncology facilities acquire both MRI (for anatomical delineation) and CT (for dose calculation) and employ MR-CT image co-registration during treatment planning. However, MR-CT co-registration can generate errors of > 5 mm, depending on the type of co-registration algorithm and treatment site of interest. This degree of co-registration error becomes clinically significant with the use of sophisticated technologies such as IMRT, VMAT, and robotic SBRT, which produce highly conformal dose distributions with steep dose gradients. Such uncertainties may contribute to locally recurrent disease, due to geographical miss, or unintentionally overdose critical structures. We propose the use of a treatment planning process based entirely on MRI, which uses pseudo CT (pCT) data generated from MRI images for dose calculation. Such a process would preserve the accuracy in target delineation achieved via MRI. The work proposed here will 1) quantify the accuracy of dose calculations on pseudo CTs (pCT) generated from input MRIs using an automated method; and 2) evaluate the influence of MRI acquisition sequence on pCT quality.

Methods: MRIs from 15 brain cancer patients who had prior Intensity Modulated Radiation Therapy (IMRT) were retrospectively chosen for this study. For each case, MRIs from 3 pulse sequences (Axial Fast Spoiled Gradient Echo, T1 Spin Echo, T2 Flair) used for target delineation, and a CT used for dose calculation were available. A pCT was generated for each MRI using a prototype version of Advantage Sim MD™ (GE Healthcare), which performs a body and bone segmentation on the MRI to generate a pCT with contrast similar to an offline CT bone atlas. The pCTs and the corresponding MRIs were co-registered with the reference CT (rCT) for each case and sent to Pinnacle™ where the IMRT plan was copied and the dose calculated. The entire head was considered water equivalent for dose calculation on the MRI (figure 1). The three dose distributions were compared using (1) gamma analysis, and (2) average dose volume histograms (DVHs) for the target volume and the 'entire head' tissue contour.

Results: The pCT visually co-registered well with the rCT for 10 cases generated using T1 SE or FSPGR images. Higher gamma pass rates were seen for the FSPGR based pCTs compared to their corresponding homogeneous MRIs (hMRIs – figure 2a). On average, gamma pass rates were above 90% for FSPGR based pCTs for gamma criteria ranging from 2%/2 mm to 3%/3mm. For T1 SE based pCTs the average gamma pass rates were either comparable or lower than those for the corresponding hMRIs. Comparing the average tissue contour DVHs (figure 2b), the volume difference between the T1 SE based pCTs and the rCT was larger (2 to 4 times more) compared to the differences seen for FSPGR based pCTs, in low dose points ranging from 5 to 30 Gy (~1/2 the prescription dose). For pCTs and hMRIs from both MRI sequences, the average target volume DVH showed higher dose heterogeneity within the tumor compared to that of the rCT. The maximum dose within the target volume was the highest for the hMRIs. T2 Flair images resulted in poor quality pCTs and were eliminated from this dose comparison.

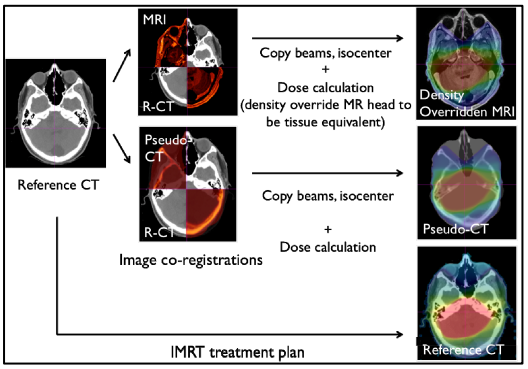

Figure 1: Overall process for producing dose distributions on the pCT and hMRI for comparison with the rCT dose distribution.

Discussion: The observed dose differences are most likely due to a combination of the following: differences in (1) the external contour of the head (due to differences in the scan extent of the MRI and CT), (2) the skull contour due to weaknesses in the auto segmentation of the skull on the input MRI and, (3) in tissue heterogeneities between the pCT, rCT and hMRI. A better agreement was seen between the FSPGR based pCT and rCT dose distributions compared to the T1 SE based pCT. FSPGR MRIs provided better quality pCTs for the particular automated pCT generation method utilized in this study.

Conclusion: Our results indicate that the pCT quality is influenced by the acquisition sequence of the input MRI. Using MRI sequences specifically optimized for pCT generation should improve the accuracy of pCT based dose calculations for radiation therapy treatment planning. Our preliminary study shows the potential for using MRI for both target delineation and dose calculation for brain treatments with the clinical integration of an automated pCT generation method, and the use of appropriate MRI sequences.

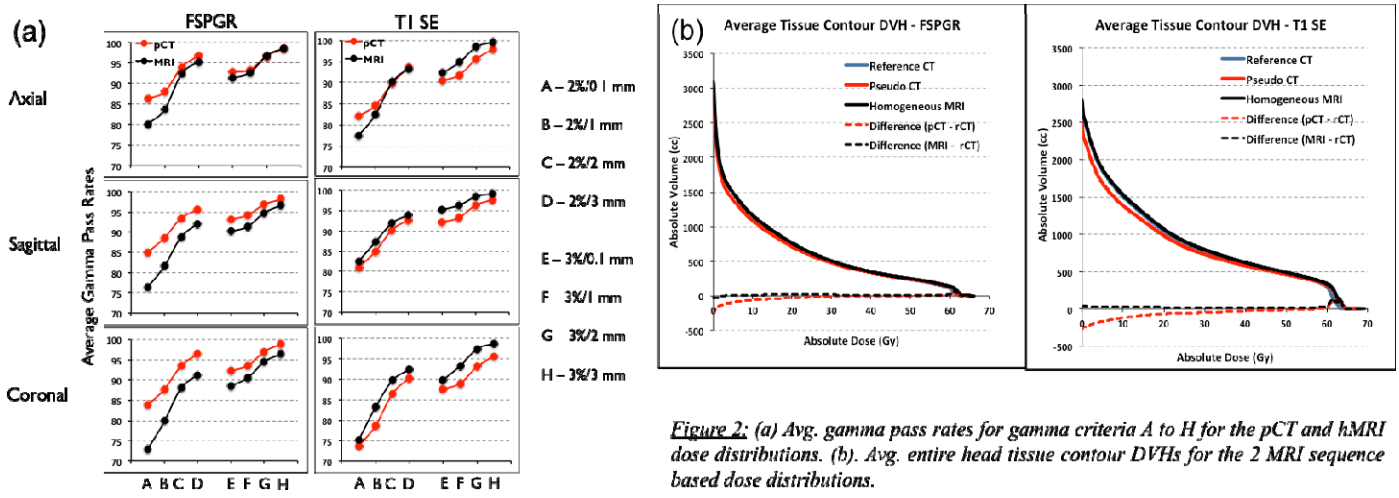

Figure 2: (a) Avg. gamma pass rates for gamma criteria A to H for the pCT and hMRI dose distributions. (b). Avg. entire head tissue contour DVHs for the 2 MRI sequence based dose distributions.