Feasibility of MRI-only simulation for CyberKnife Skull Tracking

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2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Introduction

External beam radiotherapy relies on the use of high-definition 3D images of the patients for accurate treatment plan dose calculations and image registration procedures. In CyberKnife (CK) radiosurgery, patient alignment and target tracking is based on the registration between two orthogonal x-ray images (Camera A and Camera B) and corresponding Digitally Reconstructed Radiographs (DRRs). The latter are 2D projections created from the 3D reference data, usually CT images.

In recent years, MR simulation has emerged as an alternative to CT simulation with the advantages of providing better soft tissue contrast and lower dose to patient due to the lack of ionizing radiation. MR images, however, can't be used directly for radiotherapy dose calculation and DRR generation, and need to be converted into Synthetic CT images (sCT) to achieve these tasks.

In our previous work, we have validated the accuracy of sCT-based dose calculation [1] and fiducial tracking [2] for prostate patients.

In this work, we conducted an initial proof of concept study to determine if sCT-based DRR images can be used for CK skull tracking treatments.

Methods

The study included 10 anonymized brain patients treated on CK who underwent both CT simulation and MRI simulation. T1 Dixon MRI (in-phase, out-of-phase, water, and fat images) were acquired on a 3T scanner. sCT images were created using a commercially available 2D deep learning-based prediction model (Syngo; via, Siemens Healthineers). For each patient, 34 DRR image pairs were generated, for a total of 680 images. These images were compared against their sCT equivalent images using the following quantities:

- Mean Squared Error (MSE)
- Root Mean Squared Error (RMSE)
- Mean Absolute Error (MAE)
- Normalized Root Mean Squared Error (NRMSE)
- Pearson Correlation (PC)
- Mutual Information (MI)
- Normalized MI (NMI)
- Structural Similarity (SS)

Image sharpness was also calculated using the gradient strength map. The goal is to show that despite differences between the two image modalities, CT-based and sCT-based DRR provide similar differentiation of the bony anatomy edge, thus supporting the suitability of sCT-based DRR for skull tracking.

Figure 1: Skull Tracking treatment sample delivered on the UCSF CyberKnife.

Results

Table 1: CT and sCT similarity metrics results. The table shows the mean and standard deviation of each metric used on this work for each Camera (point of view) independently.

Quantity	Camera A	Camera B
MSE	0.015 ± 0.003	0.015 ± 0.003
RMSE	0.123 ± 0.013	0.122 ± 0.013
MAE	0.043 ± 0.006	0.044 ± 0.006
NRMSE	0.123 ± 0.013	0.122 ± 0.013
PC	0.585 ± 0.064	0.599 ± 0.057
MI	0.612 ± 0.027	0.610 ± 0.027
NMI	1.234 ± 0.014	1.231 ± 0.014
SS	0.594 ± 0.063	0.608 ± 0.056
CT sharpness	0.106 ± 0.025	0.102 ± 0.023
sCT sharpness	0.116 ± 0.020	0.121 ± 0.019

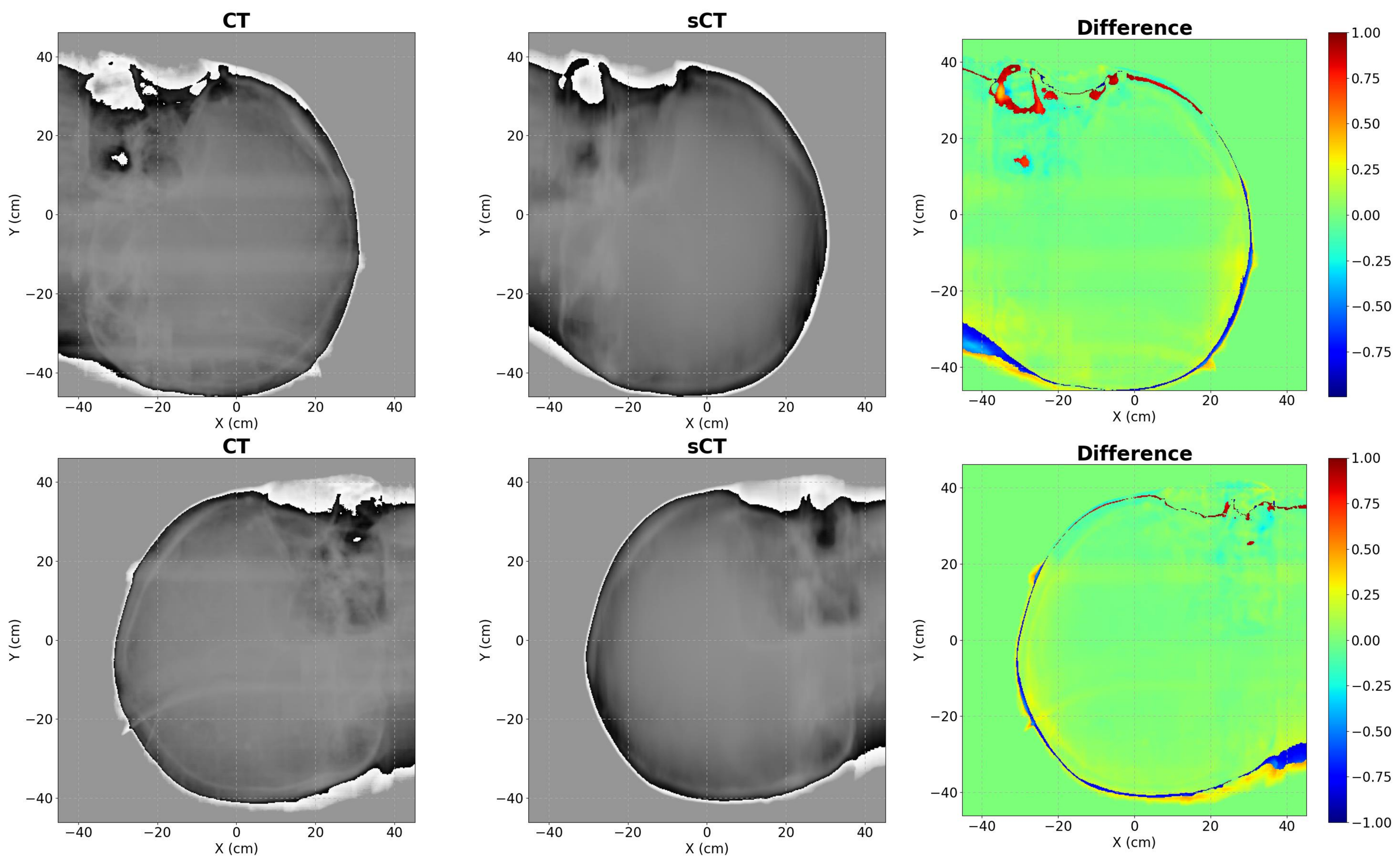

Figure 2: Visual image analysis sample. The top row show the results for Camera A and the bottom row correspond to Camera B. The rightmost column shows a simple difference plot between CT-based and sCT-based DRR images.

Discussion

The results show that all metrics used to compare the similarities between CT-based and sCT-based DRR images were within statistical uncertainties for Camera A and Camera B.

Results for MSE, RMSE, MAE and NRMSE indicated mixed results between good (MSE=0.015 and MAE=0.04) and medium (RMSE=0.12 and NRMSE=0.12) agreement. For these tests, the closer to 0 is the result the better the agreement. PC results also indicate medium agreement (PC=0.59), as on this test a value close to 1 (usually between 0.9-1.0) indicate a good agreement. The same trend of medium agreement was found in the results for MI and NMI, in which the higher values indicate better correlated images. The fact that those values are far from 0 for MI and 1 for NMI indicate that although the images are clearly different, they are still correlated. The same logic is followed by the SS value, in which a value closer to 1 indicate a good result.

Sharpness results for CT-based and sCT-based DRR are promising, with a result of around 0.110. Image sharpness does not depend on the other image but on how well defined is the anatomy edge from the background. The average calculated value was indistinguishable within statistical uncertainties between the two sets.

Conclusion

All similarity metrics demonstrate medium to good agreement between CT and sCT-based DRR. This suggests that there are clear differences between the CT and sCT images, mostly found in the nasal cavity and back of the neck region (Figure 2). Differences near the nasal cavity are due to the presence of soft cartilage tissue. Disagreement in the posterior neck might be due to head rest differences between the CT sim and MR sim protocols at our institution. Further work is necessary to isolate the cause of this discrepancy.

However, skull tracking methods rely heavily on the image sharpness alone. Hence the similarity between CT and sCT images is not the main factor to determine if MRI-only simulation would be feasible for CK skull tracking. Since the sharpness results between CT and sCT were undistinguishable, results strongly suggest that it is possible.

Future work will be performed at our institution to validate this claim by using anatomical phantoms.

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References

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