Fiducial-free real-time image-guided robotic radiosurgery for tumors of the spine

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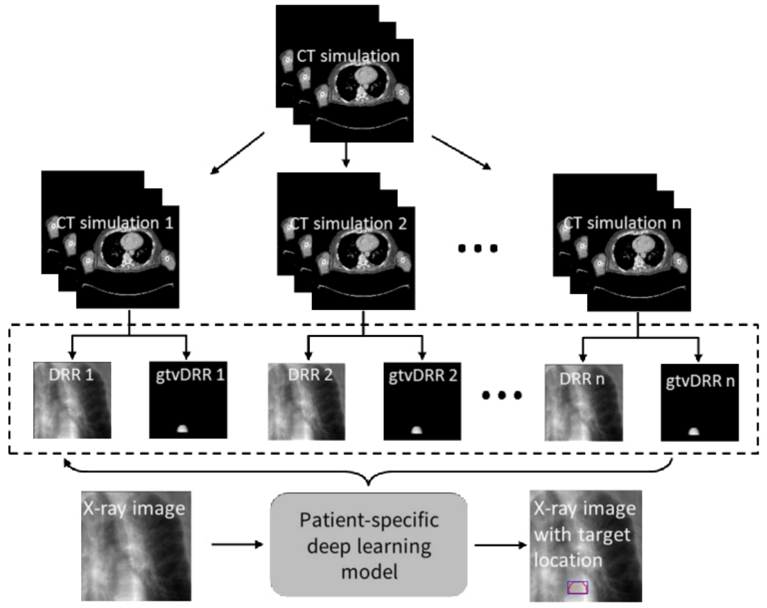
INTRODUCTION

Image-guided radiosurgery (IGRS) is a safe and attractive treatment option for many sites, such as brain, spine and lung, and especially for lesions that are surgically inaccessible. Current IGRS is mostly fiducial-free and often relies on the use of image registration for patient setup and intra-fractional tracking. In our current clinical practice, the intensity-based image registration method is inadequate in a few cases, especially when the target involves multiple vertebral bodies.

AIM

Accordingly, we aim to develop a novel fiducial-free targeting strategy using deep learning approach to interpret routine live kV X-ray images for spinal radiosurgery. Due to the limited access to the training data, we are also developing a realistic training data generation scheme for the deep learning model.

METHOD



The above (*Figure 1*) shows the workflow of the proposed deep learning-based IGRS method. The first step is to incorporate the motion model to the planning computed tomography (CT) images. Second, the deformed and translated CT simulations were projected in the geometry of the live imaging system to generate digitally reconstructed radiographs (DRRs). Finally, the DRRs together with their corresponding gross target volume annotations were used to train a patient-specific model to localize target position on the real-time live images.

RESULTS

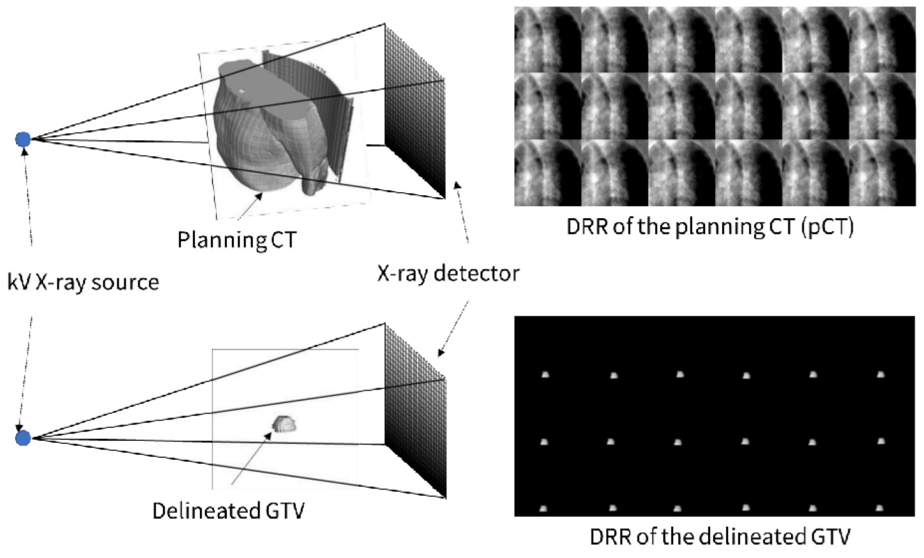


Figure 2. Generation of the simulated kV live images using motion incorporated planning CT images with geometry consistent with the in-room orthogonal bi-plane X-ray imaging system. For this purpose, we placed patient planning CT images in the live image geometry, and then introduced a series of changes (translations/rotations/deformations) in planning CT images to mimic different clinical scenarios. For each of the changes, we generated two DRRs which are consistent with the live images acquired using the bi-plane imager. Meanwhile, the DRRs of the delineated GTV were also generated for each of the changes.

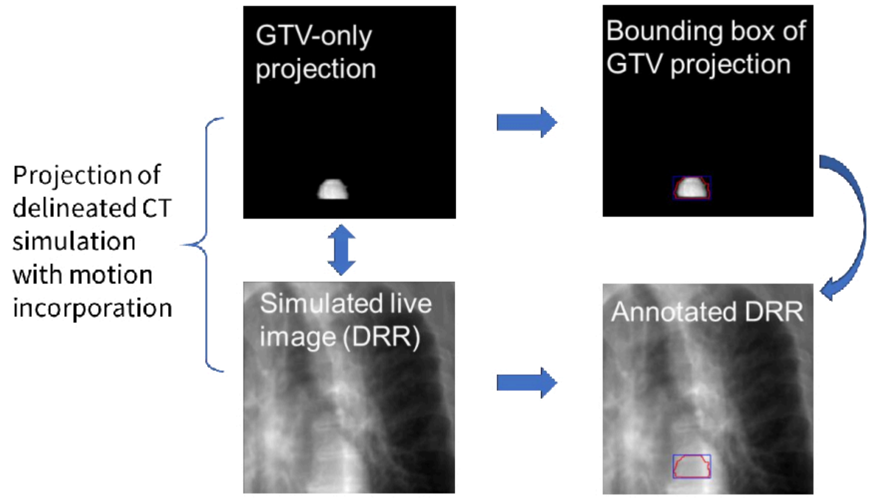


Figure 3. Generation of the annotated DRRs for model training. For each of the simulated live image and its corresponding GTV-only DRR, we first find the contour and bounding box of the target in the GTV-only DRR and then attach them to the simulated live image to obtain an annotated sample.

Figure 4. Examples of the predicted positions on the simulated DRRs and real live images. The model predicted target position are highly consistent with the corresponding ground truth positions that were derived from the CT simulations for both detector A (a) and detector B (b). For the real live images acquired using detector A of the bi-plane image system, the predicted target (yellow boxes) positions match well with the positions derived from the CT simulations and the spine anatomy for both fractions (c-d).

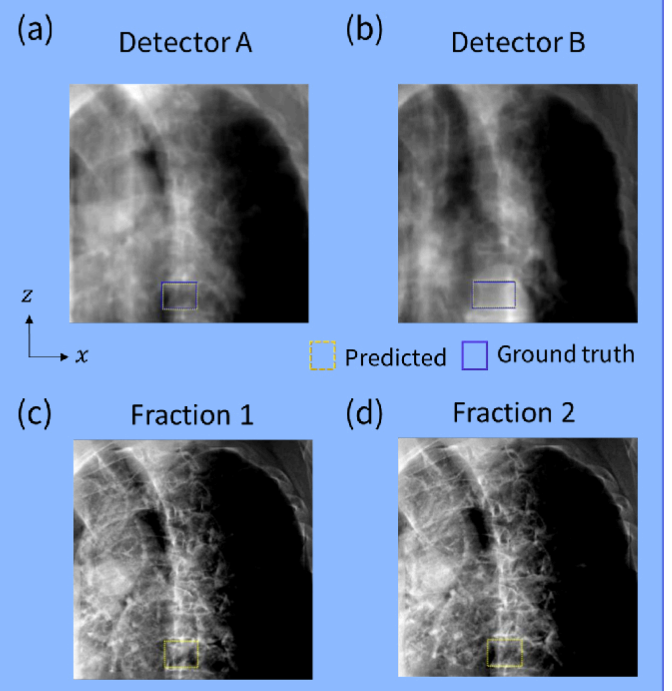


Table 1. Quantitative evaluation of the predicted results on simulated live images.

	Plane A		Plane B	
	Δx (mm)	Δz (mm)	Δx (mm)	Δz (mm)
Case 1	0.35	0.36	0.30	0.58
Case 2	0.53	0.40	0.48	1.17
Case 3	0.73	0.58	0.51	0.31
Case 4	0.77	0.74	0.38	0.58
Case 5	0.50	0.40	0.51	0.66
Case 6	1.38	1.21	1.08	1.47
Mean$\pm$std	0.71$\pm$0.36	0.61$\pm$0.32	0.54$\pm$0.27	0.79$\pm$0.43

CONCLUSIONS

The deep learning model required approximately one hour of training for each view angle of the two orthogonally mounted X-ray systems. Following training, the model identified the spinal tumor on the testing DRR or a live image within 200 ms. The deviations between the target position obtained by deep learning model and the testing DRRs range from -2.25 mm to 1.48 mm and from -1.10 mm to 1.23 mm for the two X-ray systems. The overall mean absolute targeting error for the two X-ray systems are 0.66 mm. Target positioning provided by the trained deep learning model for tracking periodic live images is consistent with the derived positions from the couch correction.

This study demonstrated that fiducial-free spinal tumor targeting for radiosurgery is achievable with high accuracy by using a deep learning approach. The proposed method may be useful for pre-treatment patient setup and real-time target tracking during treatment delivery. It provides a clinically valuable solution for routine spinal radiosurgery and could be adapted to other challenging treatment sites.

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REFERENCES

1. Chuang C, Sahgal A, Lee L, Larson D, Huang K, Petti P, Verhey L, Ma L. Effects of residual target motion for image-tracked spine radiosurgery. Medical physics. 2007 Nov;34(11):4484-90.
2. Murphy MJ, Chang SD, Gibbs IC, Le QT, Hai J, Kim D, Martin DP, Adler Jr JR. Patterns of patient movement during frameless image-guided radiosurgery. International Journal of Radiation Oncology* Biology* Physics. 2003 Apr 1;55(5):1400-8.
3. Adler Jr JR, Chang SD, Murphy MJ, Doty J, Geis P, Hancock SL. The Cyberknife: a frameless robotic system for radiosurgery. Stereotactic and functional neurosurgery. 1997;69(1-4):124-8.
4. Zhao W, Han B, Yang Y, Buyyounouski M, Hancock SL, Bagshaw H, Xing L. Incorporating imaging information from deep neural network layers into image guided radiation therapy (IGRT). Radiotherapy and Oncology. 2019 Nov 1;140:167-74.
5. Zhao W, Shen L, Han B, Yang Y, Cheng K, Toesca DA, Koong AC, Chang DT, Xing L. Markerless pancreatic tumor target localization enabled by deep learning. International Journal of Radiation Oncology* Biology* Physics. 2019 Oct 1;105(2):432-9.
6. Pan J, Ho AL, D'Astous M, Sussman ES, Thompson PA, Tayag AT, Pangilinan L, Soltys SG, Gibbs IC, Chang SD. Image-guided stereotactic radiosurgery for treatment of spinal hemangioblastoma. Neurosurgical focus. 2017 Jan 1;42(1):E12.
7. Kilby W, Dooley JR, Kuduvalli G, Sayeh S, Maurer Jr CR. The CyberKnife® robotic radiosurgery system in 2010. Technology in cancer research & treatment. 2010 Oct;9(5):433-52.

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