Human-Level Comparable Control Volumes Mapping with An Unsupervised-Learning Model for CT-Guided Radiotherapy

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PURPOSE

To develop an unsupervised deep learning model with auto-mapped control volume (CV) from daily patient positioning CT (dCT) to planning computed tomography (pCT) for highly accurate and efficient patient positioning.

METHOD

An unsupervised learning framework is proposed to automatically generate the couch shifts (translations and rotations) for mapping CV from dCT to pCT shown in Figure 1. Inputs to the network are the dCT, the pCT, and the CVs' locations within the pCT. The outputs are the transformational parameters of the dCT for head-and-neck (HN) patient positioning. We train the network to maximize image similarity between the CV in the pCT and dCT using normalized cross-correlation. Network training was performed with 470 CT scans from 146 patients. Each patient has several CT scans at different time points. The trained network was tested with 72 dCTs from 12 patients. For each test case, couch shifts are obtained by averaging translational and rotational parameters derived with different CVs. These means are then compared to ground-truth reference shifts obtained by the alignment of bony landmarks identified by an experienced radiation oncologist.

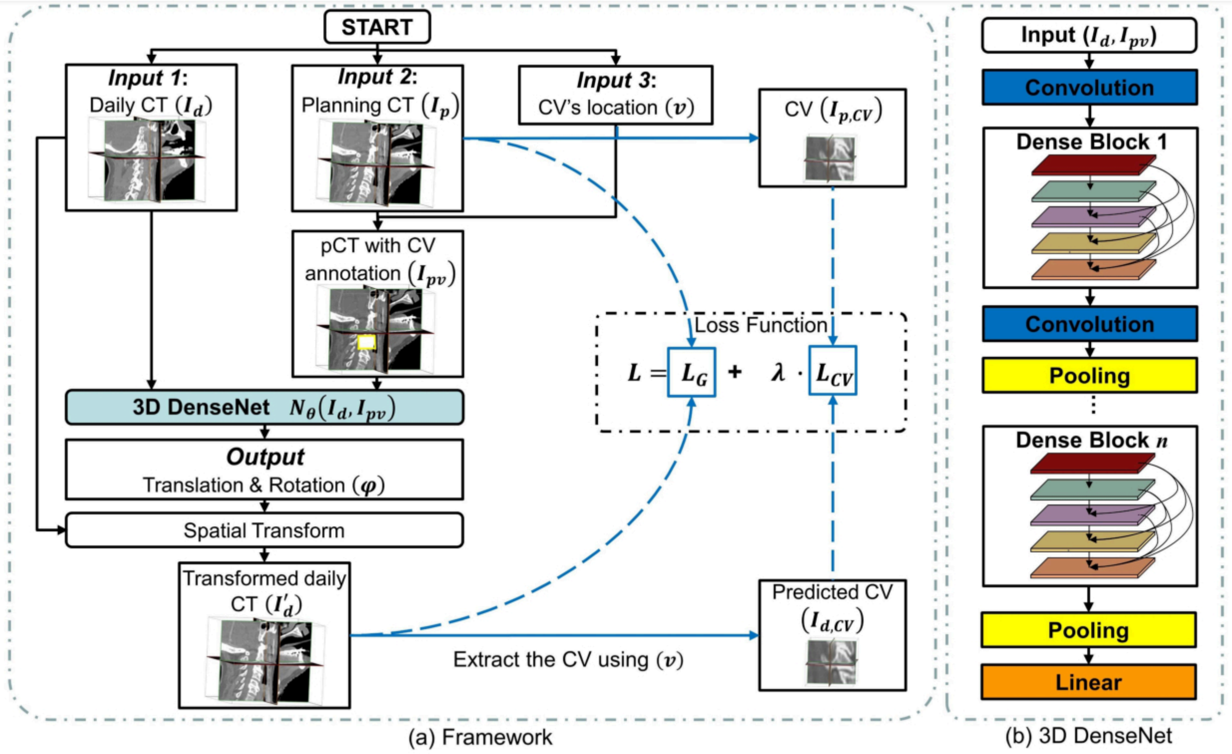

Figure 1. Proposed unsupervised learning framework for CV mapping. (a) Schematic of the methodology and (b) architecture of the underlying 3D-DenseNet machine learning model. Abbreviation: pCT = planning computed tomography, CV = control volume, L_G = the global image similarity loss, L_{CV} = and the CV image similarity loss.

RESULTS

Systematic/random positioning errors between the model prediction and the reference are smaller than 0.49/1.17 mm and 0.13/0.28° in translations and rotations, respectively. Pearson's correlation coefficient between model predictions and reference values exceeded 0.99. In comparison to standard registrations, the proposed method increased the proportion of cases registered within clinically accepted tolerance from 63.9% to 86.1%.

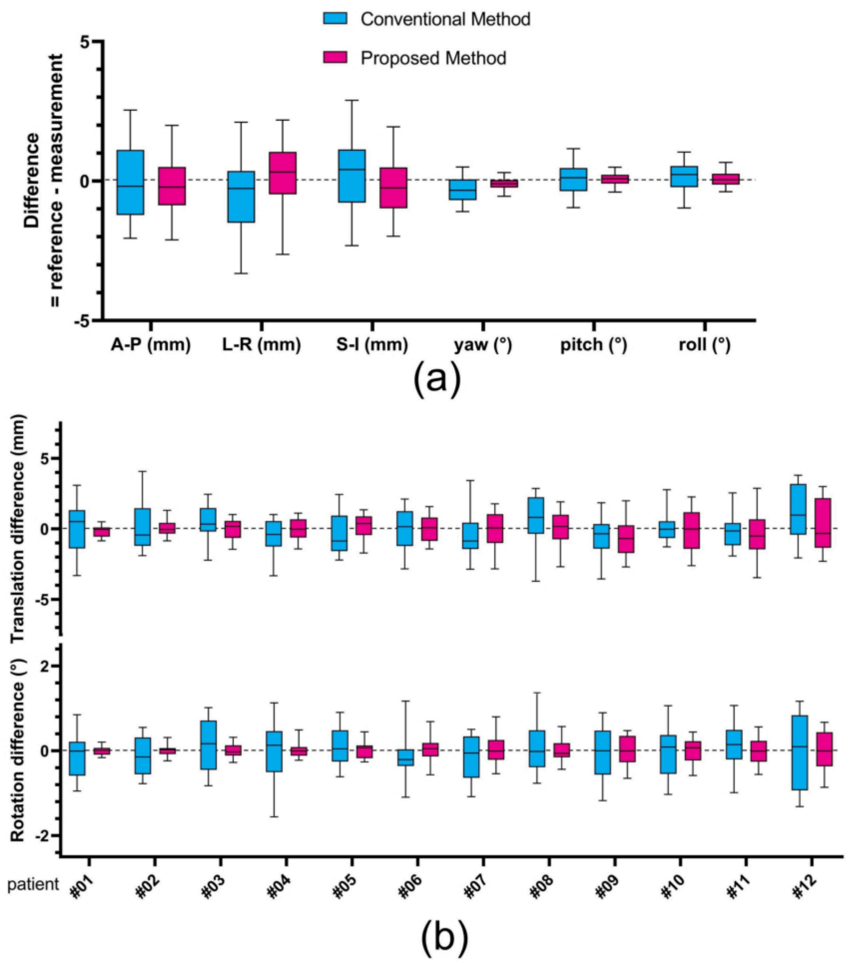

Figure 3. The 5% and 95% Box-and-whisker plots for the differences in couch shifts between the measurement and reference. The blue and red boxes indicate the measurement using the conventional and the proposed method, respectively. (a) the difference for all the fractions in the six dimensions. (b) the difference for each patient in translational and the rotational dimensions. Abbreviation: A-P = anterior-posterior, L-R = left-right, S-I = superior-inferior.

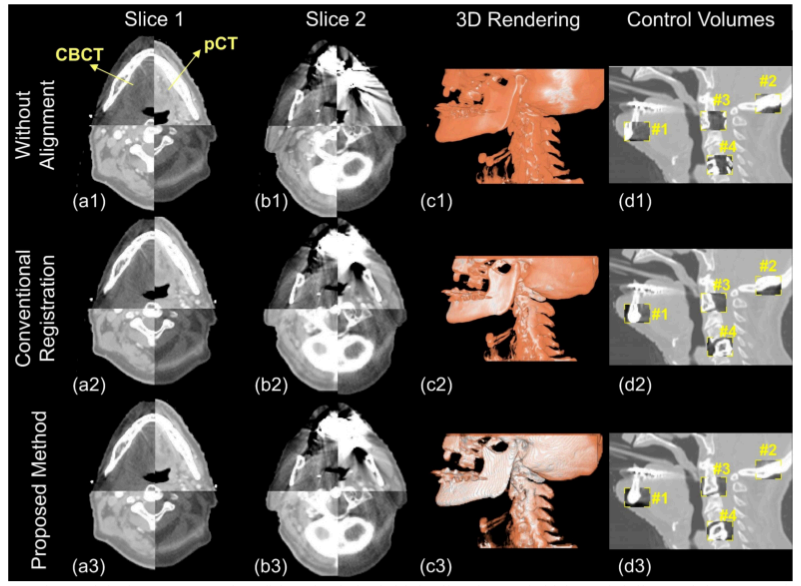

Figure 2. Examples of CV mapping results on the CBCT image of an HNC patient. Rows (1), (2) and (3) show results without alignment, with conventional global alignment, and with the proposed method, respectively. Columns (a) and (b) show checkerboard displays of two axial slices. Column (c) shows superposition of 3D renderings (image differences are highlighted in orange). Column (d) shows the selected yellow rectangular CVs, #1 to #4, as overlays on the background pCT image, with the image in each corresponding to a volume of interest cropped from the transformed CBCT image.

CONCLUSIONS

A novel unsupervised learning technique was established to map CVs from dCT to pCT for HN patient positioning. Our results show that fast and highly accurate HN patient positioning is achievable by leveraging state-of-the-art deep learning strategies.

ACKNOWLEDGEMENTS

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