Impact of a 3D convolution neural network method on Liver segmentation: an accuracy and time-savings evaluation

NM Cole[1], H Wan[1], J Niedbala[2], YK Dewaraja[3], A Kruzer[1], D Pittock[1], C Halley[1], AS Nelson[1]

1. MIM Software Inc., Cleveland, OH
2. Michigan Medicine, Ann Arbor, MI
3. University of Michigan, Ann Arbor, MI

Purpose

The growing practice of treating primary and metastatic liver cancer with yttrium-90 microsphere selective internal radiation therapy (SIRT) and liver dominant neuroendocrine tumors with ^{177}Lu-DOTATATE molecular radiotherapy has increased the need for fast, accurate, automated liver segmentation. Personalized dosimetry-based treatment planning requires accurate liver contours, however manual segmentation is time consuming. Previously, atlas-based segmentation was shown to greatly reduce the time burden, nonetheless, we sought to further decrease this time burden with a neural network approach. This study evaluates the accuracy and time-savings of a 3D Convolutional Neural Network (CNN) auto-segmentation method.

Materials and Methods

The CNN architecture is based on RefineNet[1] and includes additional 3D convolution blocks to leverage contextual information in all directions. The CNN model takes the entire CT volume as input then outputs a contour for the liver and was trained with 108 contoured data sets. In this study, the trained CNN model was used to automatically segment the livers on 37 patient CTs from SPECT/CT and PET/CT scans. These contours were compared to the manually edited contours using the dice similarity coefficient (DSC), mean Hausdorff distance (HD), and the 95% max Hausdorff distance (95-HD).

Results

The main results are summarized in Figure 1. For 37 patient scans, the average time to edit the liver contour was 2.6 ± 2.4 minutes with 9 subjects requiring no edits. The maximum time to edit was 8 minutes.

The overall average DSC was 0.97 ± 0.05 and lower DSCs correlated with longer adjustments times and low CT quality as shown in Figures 2 and 3. However, the CNN performed well with very low dose (≤15 mAs) CTs with an average DSC of 0.94 ± 0.06 and editing time of 4.3 ± 2.4 minutes across 13/37 scans.

Averaged mean HD was 2.1 ± 3.7mm and averaged 95-HD was 12.2 ± 22mm with a median of 0mm. Time to edit the liver contour for each scan averaged 2.6 ± 2.4 minutes. Figures 3 and 4 also show the correlation between 95-HD and adjustment time and CT quality. As with DSC, high CNN performance (low 95-HD) correlated with low adjustment times and higher quality CT.

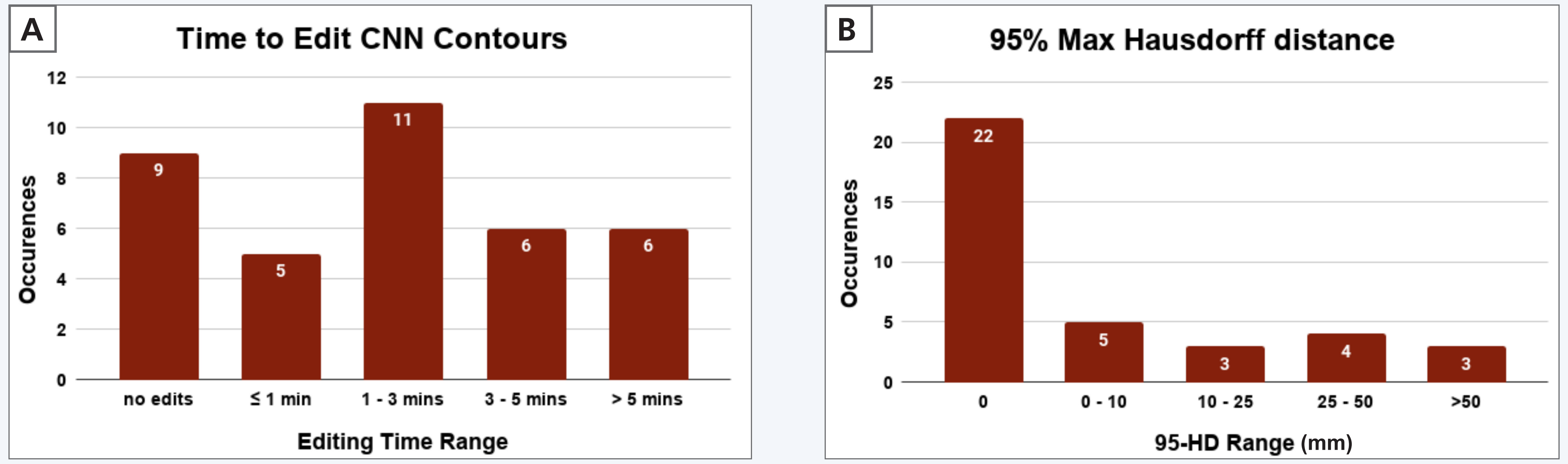

Figure 1. Results histograms for manual editing time (A) and 95% max Hausdorff distance (B) between CNN contours and manually edited contours.

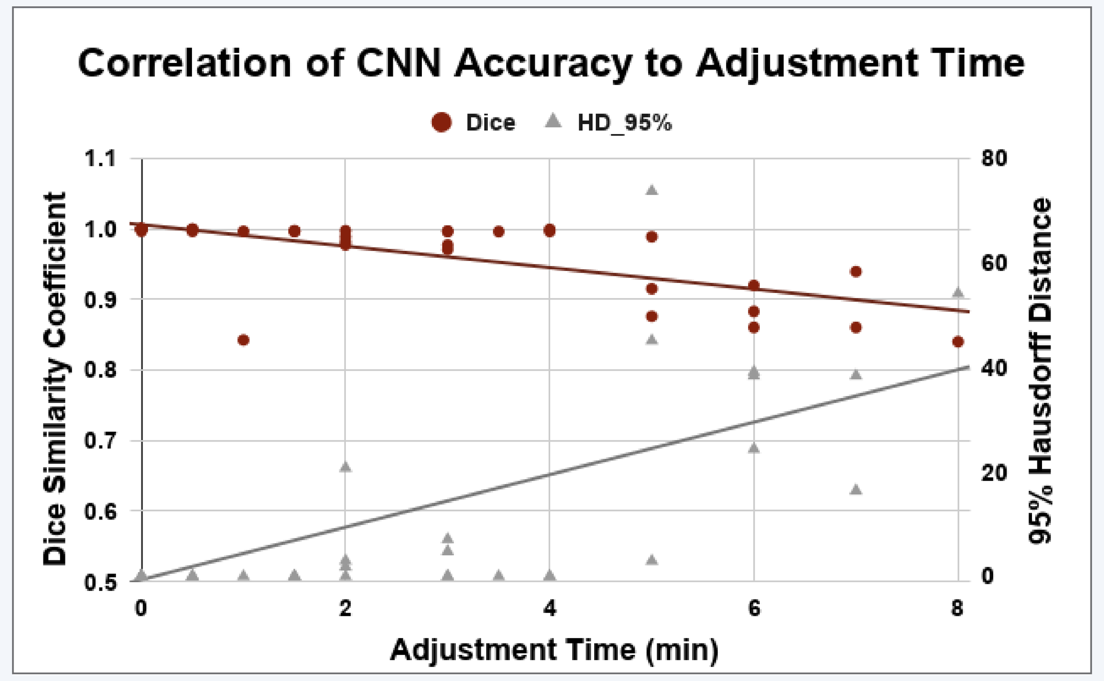

Figure 2. Correlation of adjustment time to CNN output performance. (**Left Axis**) Dice similarity coefficient between the CNN output contours and the manually edited contours (● and **trendline**). (**Right Axis**) 95% Hausdorff distance (▲ and trendline).

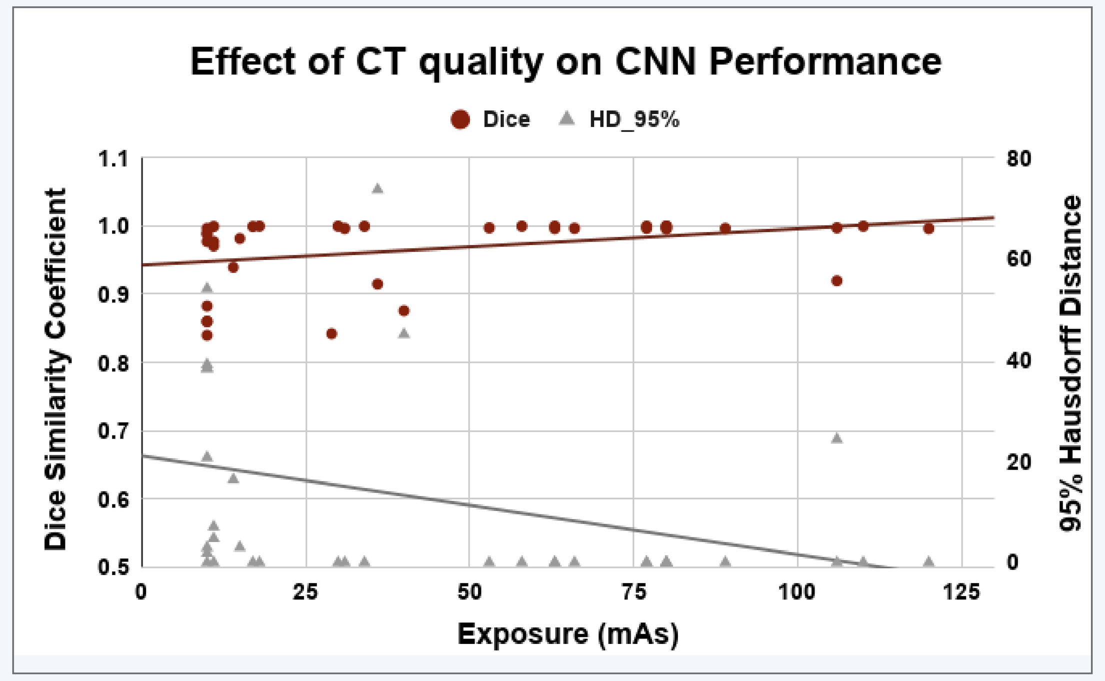

Figure 3. Effect of CT quality on CNN performance. (**Left Axis**) Dice similarity coefficient between the CNN output contours and the manually edited contours (● and **trendline**). (**Right Axis**) 95% Hausdorff distance (▲ and trendline).

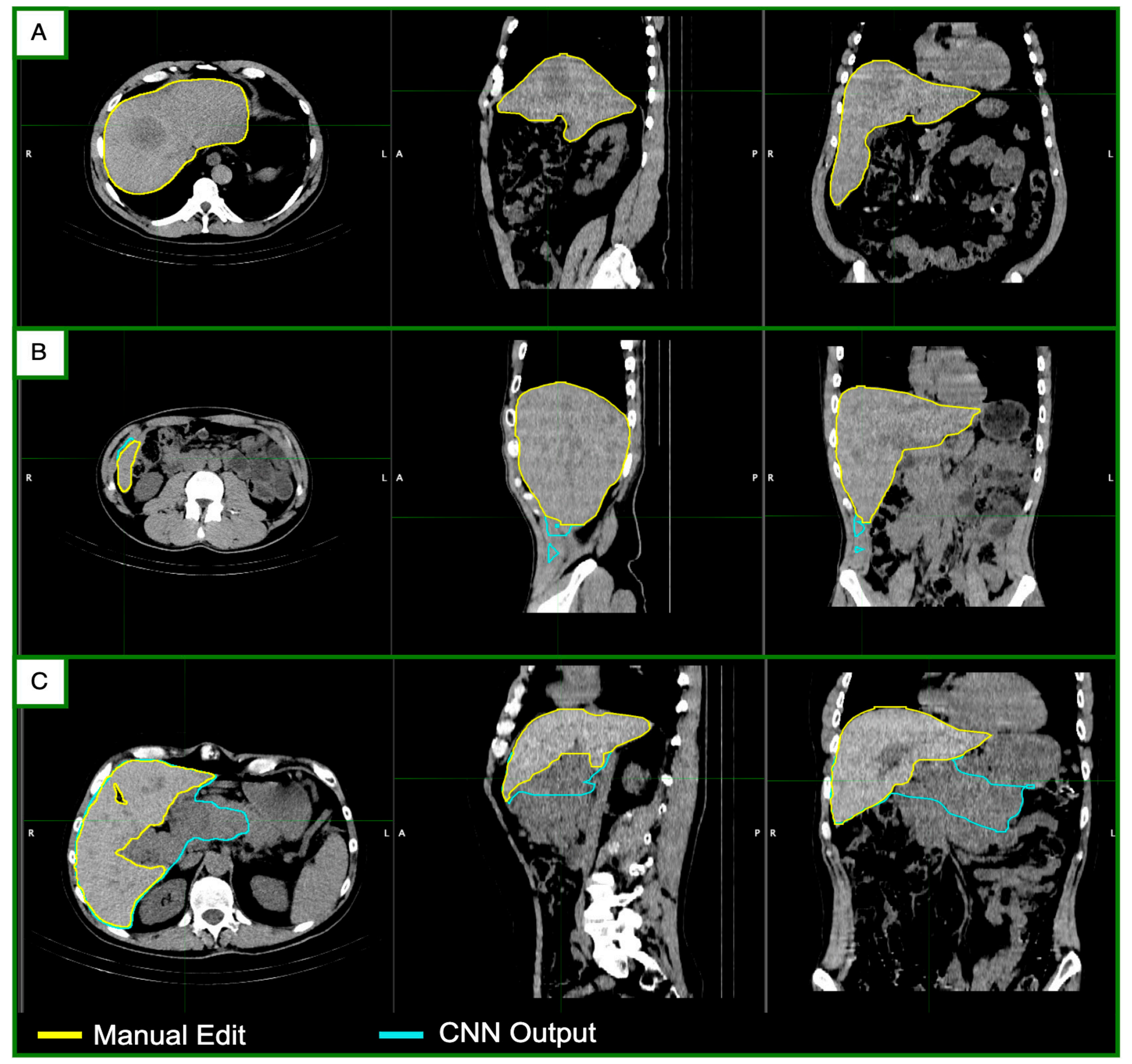

Figure 4. Example CNN contour output compared to manually edited contours. (**A**) No editing was required for this scan; the true contour and output contour are the same. (**B**) Less than 30 seconds of editing were required for this scan. (**C**) About 3 minutes of editing were required for this scan.

Innovation and Impact

This study evaluated the efficacy of a neural network-based auto-segmentation approach. The purpose of this auto-segmentation approach is to reduce the time-burden of manually contouring the liver for cancer treatment planning and dosimetry. With the growing use of selective internal radiation therapy for primary and metastatic liver cancers, there is an increased need for personalized dosimetry. Accurate segmentation is essential for yttrium-90 microsphere treatment planning and subsequent dosimetry. Molecular radiotherapy with ^{177}Lu-DOTATATE is currently used for the treatment of liver-dominant neuroendocrine tumors therefore the liver is at a higher risk for toxicity and dosimetry is used to mitigate this risk.

Previously[2], atlas-based segmentation was used to estimate the liver volume, drastically reducing the time required to generate an accurate contour: 10.8 ± 4 minutes of adjustments compared to total manual segmentation time of 34.8 ± 8 minutes. In this study, the NN approach provided higher levels of accuracy and greater time savings compared to the previously reported atlas results.

These results show that the 3D Convolutional Neural Network can accurately auto-segment the liver, requiring little to no manual adjustment, leading to a significant decrease in processing time for dosimetry-based treatment planning in SIRT and molecular radiotherapy.

References

1. G. Lin, A. Milan, C. Shen, and I. Reid "RefineNet: Multi-path refinement networks for high-resolution semantic segmentation," Proc, - 30th IEEE Conf. Comput. Vis. Pattern Recognition, CVPR 2017, vol. 2017-Jan, pp. 5168-5177

2. M. Hovart, A. Nelson, and S. Pirozzi. "Time savings of a multi-atlas approach for liver segmentation" J Nucl Med May 2014 vol. 55 no. supplement 1 1523