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Automated Multi-Chamber Segmentation and Imaging Plane Re-slicing of Cardiac CT Images via Deep Learning

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Introduction: Cardiac function assessment requires accurate segmentation of chamber volumes, and multiple long-axis (LAX) planes and the short-axis (SAX) stack are the standard for visualization of cardiac anatomy. However, cardiac CT currently requires manual segmentation and re-slicing of planes after acquisition. We developed a deep learning (DL) system to simultaneously segment multiple chambers and identify cardiac imaging planes to enable routine evaluation.

Methods: Segmentation of the left ventricle (LV) and left atrium (LA) and expert-defined three LAX (two-, three- and four-chamber plane) and one SAX (mitral valve plane) planes were obtained for CT acquisitions in 94 patients. The DL approach utilized a modified U-Net convolutional neural network to predict chamber segmentation and three "plane-specific" vectors (translation vector $\vec{t}$ and x- and y-direction vectors for plane orientation) using 5-fold cross-validation. Segmentations were evaluated via Dice similarity and accuracy in prediction of LV ejection fraction (EF); planes were assessed using Euclidean distance between the center of the predicted plane and the expert-defined plane, angular difference between normal vectors, and expert visual assessment to ensure the clinical use.

Results: The predicted segmentations had Dice measures as 0.88 ± 0.11 for the LV and 0.86 ± 0.15 for the LA (Figure A). The EF derived from predicted LV segmentation EF_{DL} had correlation with ground truth EF_{gt} ($EF_{DL} = 0.93 * EF_{gt} + 6.71$, Pearson's $r = 0.95$, Figure B). The predicted LAX and SAX planes had a center displacement error of 4.8 ± 2.3mm and angular orientation error of 9.4 ± 5.6 degrees. For all planes, ~95% of cases were scored as adequate by the expert reader as shown in the Table and Figure.

Conclusions: A deep learning-based approach can be used to obtain segmentation of multiple heart chambers and cardiac imaging planes, with high segmentation accuracy, low displacement and orientation error of the predicted cardiac planes, and a high proportion of cases approved by an expert reader.

Table: Expert visual assessment result

	Adequate Visualization No. of cases (%)
2CH	91 (96.8%)
3CH	91 (96.8%)
4CH	94 (100%)
mitral valve	85 (90.4%)

Figure:

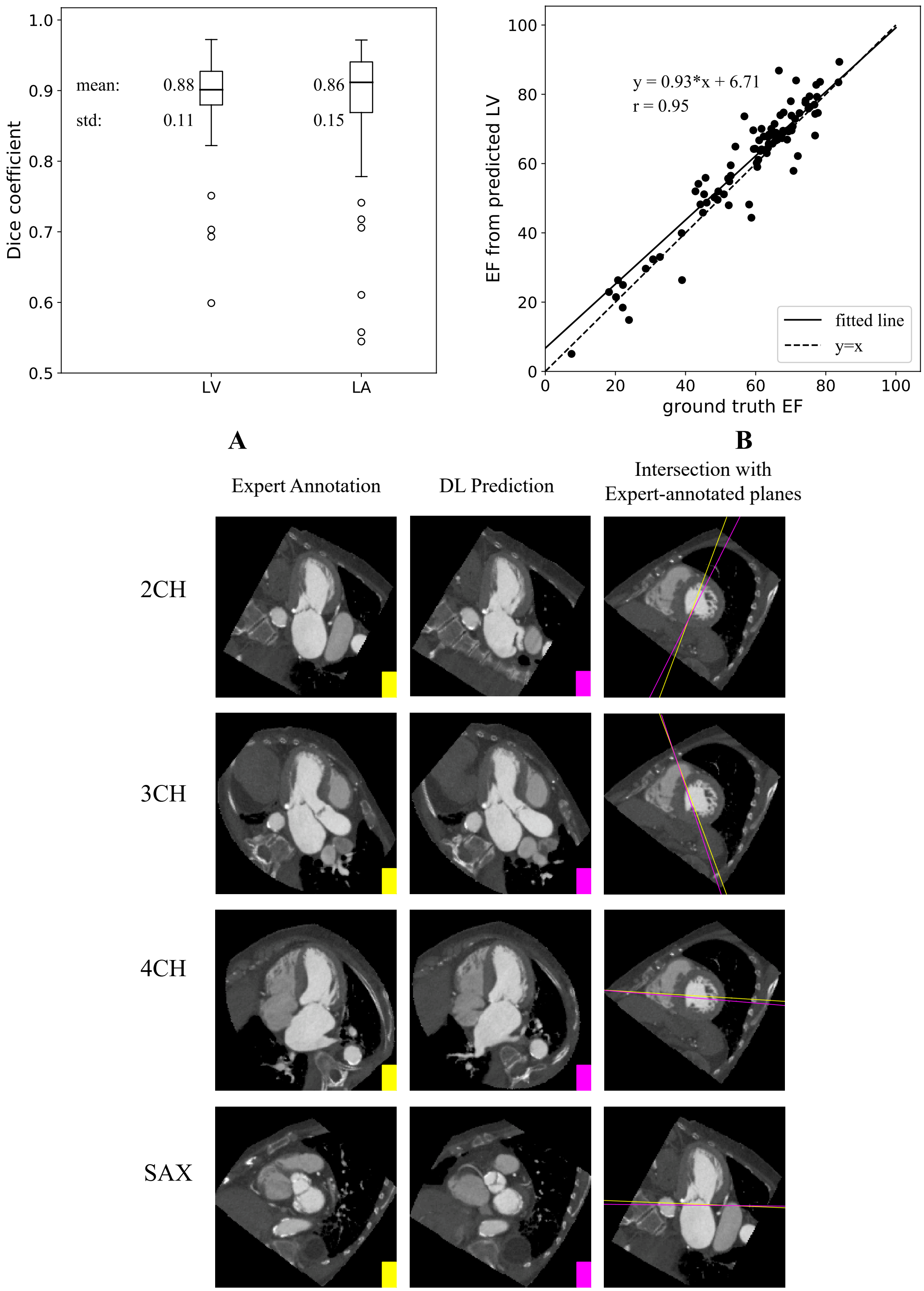

Figure: (**A**) Dice measures for LV and LA. (**B**) Linear plot of EF_{DL} vs. EF_{gt}. (**C**) One example image of agreement between expert-annotated (yellow) and predicted (magenta) planes. The first three rows show the LAX planes as solid lines on an expert-defined mid-ventricular slice, and the last row shows the mitral valve plane on an expert-defined 2CH plane. Note: window level = 500HU, width = 900HU.