Fully Automatic Bi-Atria Segmentation from Gadolinium-Enhanced MRIs Using Double Convolutional Neural Networks

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Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia and catheter ablation is a promising approach for treating AF. Accurate representation of the atrial anatomy and its underlying structure for patients with AF undergoing the ablation procedure provides an effective patient-specific target for diagnostics and treatment[1, 2].

Aim

To develop a robust, fully automatic algorithm to segment the atrial anatomy from clinical image data.

Methods

- 3D late gadolinium-enhanced (LGE)-MRI data (N = 20) with a spatial resolution of $0.625 \times 0.625 \times 1.25$ mm^3 from patients with AF was provided by The University of Utah[3] and contains the left atrial (LA) wall and cavity labels.
- Manually segment the right atrium (RA) with protocols consistent with The University of Utah:
  1. Delineate the RA epicardium and extend this inwards with a constant thickness towards the endocardium to obtain the RA wall.
  2. Fill the volume enclosed by the wall to obtain the RA cavity. The tricuspid valve region is defined by a linear cut to be consistent with the Utah LA mitral valve.
- Develop convolutional neural network (CNN) for atrial segmentation (**Fig 1**) on the training set (N=14).
- Evaluate the algorithm using the DICE score and surface-to-surface distance on the validation set (N=6).

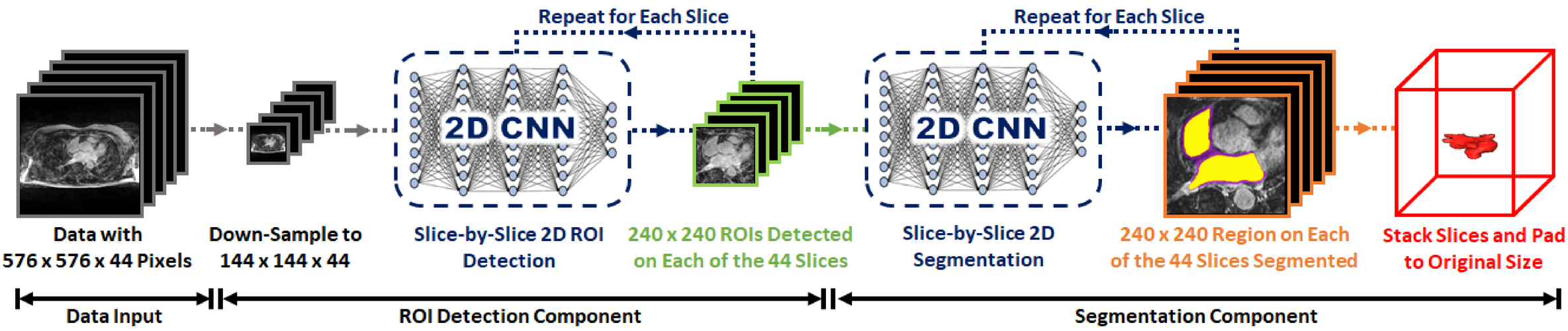

Fig 1. The workflow of the proposed pipeline. The late gadolinium-enhanced (LGE)-MRI is inputted into a 2D convolutional neural network (CNN) with a U-Net architecture. The first CNN performs slice-by-slice localization to determine the region of interest (ROI) containing the atria. The ROIs are then inputted into a second CNN for slice-by-slice segmentation of the atria. The 2D segmentations are stacked together and padded to the original dimensions to obtain the final 3D reconstruction.

Results

The first CNN computed the position of the region of interest containing the atria within 5mm, or 8 pixels, of the ground truth. The second CNN achieved a DICE score of 92.9% and surface-to-surface distance of 0.63mm for the atrial cavity, and 94.0% and surface-to-surface distance of 0.68mm for the atrial wall + cavity segmentations.

Visualizations of reconstructed atria in 2D and 3D are shown in **Fig. 2** and **3** respectively. **Fig. 2** showed the most erroneous regions of the LA predictions were at the pulmonary veins, and there were minimal errors in the RA. **Fig. 3** showed that predictions were also more erroneous in the regions of the valves joining the atria to the ventricles.

In terms of computational cost, the proposed pipeline segmented each 3D LGE-MRI within 2 seconds on an NVidia Titan V GPU.

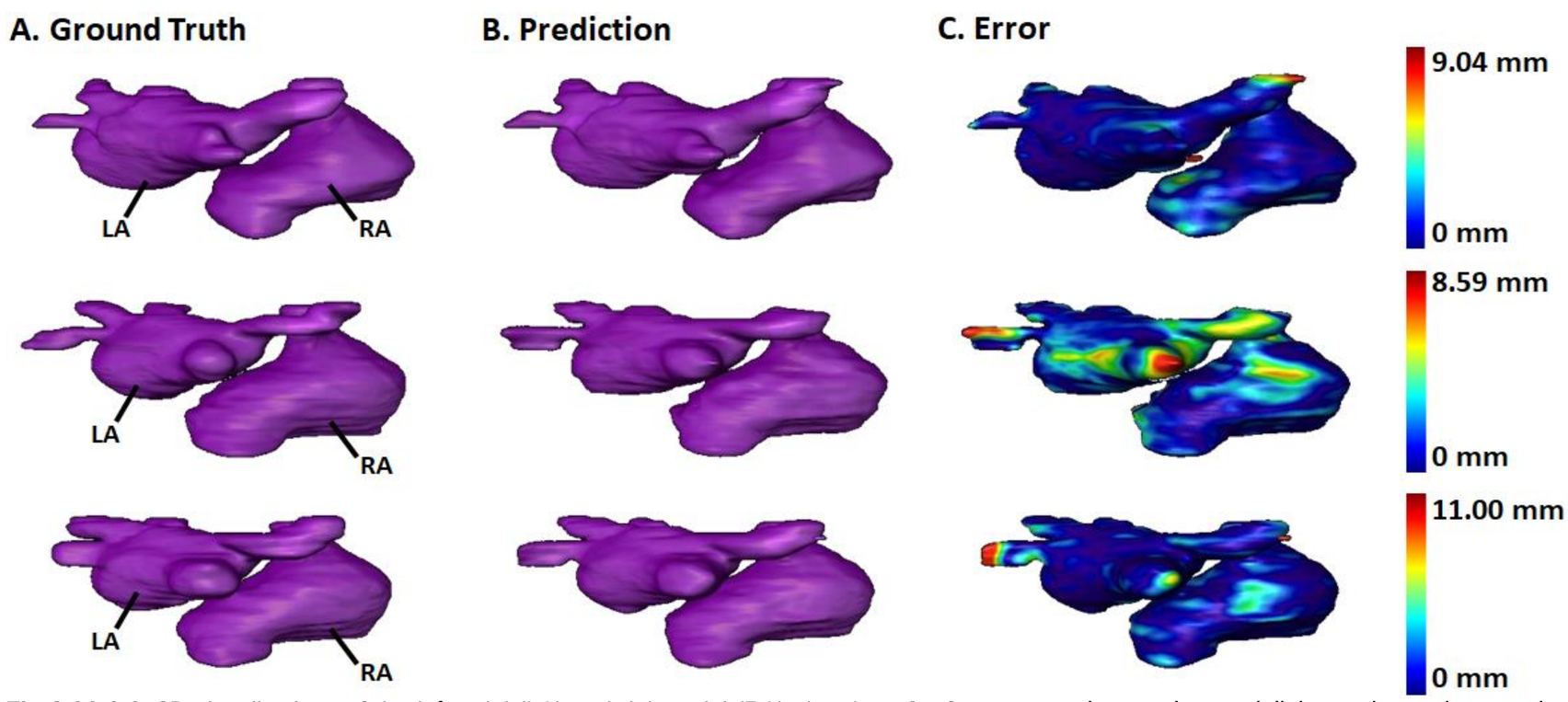

Fig 2 (right). 3D visualizations of the left atrial (LA) and right atrial (RA) chambers for 3 representative test late gadolinium-enhanced magnetic resonance imaging (LGE-MRI). **A)** Ground truth provided. **B)** Predictions segmented by the convolutional neural network (CNN). **C)** Surface-to-surface error of the predictions from the ground truth in millimeters (mm).

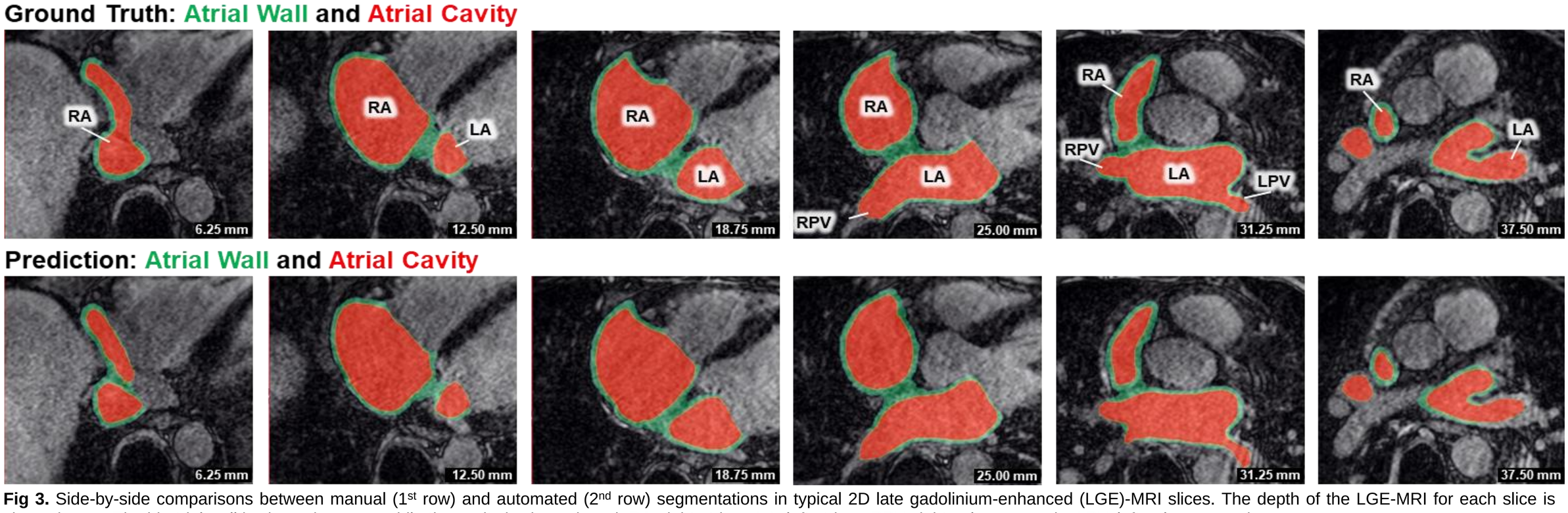

Fig 3. Side-by-side comparisons between manual (1st row) and automated (2nd row) segmentations in typical 2D late gadolinium-enhanced (LGE)-MRI slices. The depth of the LGE-MRI for each slice is shown in mm. The bi-atrial wall is shown in green, while the cavity is shown in red. RA, right atrium; LA, left atrium; RPV, right pulmonary vein; LPV, left pulmonary vein.

Conclusion

We have proposed and validated an effective framework for robust bi-atrial chamber segmentation from clinical LGE-MRIs. Our study can potentially be used for improved clinical diagnosis, patient stratification and clinical guidance during ablation treatment for patients with AF.

References

[1] Xiong et al. (2019). *IEEE Transactions on Medical Imaging.*
[2] Zhao et al. (2017). *Journal of American Heart Association.*
[3] McGann et al. (2014). *Circulation: Arrhythmia and Electrophysiology.*