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(I) A Generalizable and Efficient Deep Learning Algorithm for Automatic Prostate Segmentation in 3D Ultrasound

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Introduction: Three-dimensional transrectal ultrasound (3D TRUS) imaging is utilized in prostate cancer diagnosis and treatment, necessitating manual prostate segmentation which is time-consuming and difficult. The purpose of this work was to develop a generalizable and efficient deep learning approach for automatic prostate segmentation in 3D TRUS, trained using a diverse dataset of clinical images. Large and diverse datasets are rare in medical imaging, so this work also examines the performance of our method when trained with less diverse and smaller datasets.

Methods: Our training dataset consisted of 206 3D TRUS images acquired in biopsy & brachytherapy procedures using two acquisition methods (end-fire (EF) and side-fire (SF)), resliced at random planes resulting in 6,773 2D images used to train a 2D network. Our proposed 3D segmentation algorithm involved deep-learning prediction on 2D slices sampled radially around the approximate centre of the prostate, followed by reconstruction into a 3D surface. A modified U-Net and U-Net++ architecture were implemented for deep learning prediction, as the latter has been shown to perform well with small datasets. Our training dataset was split to train separate EF and SF networks. These split datasets were then reduced in size to 1000, 500, 250, and 100 2D images. Manual contours provided the ground truth for training and testing, with the testing set consisting of 20 EF and 20 SF 3D TRUS images unseen during training.

Results: For the full training set, the U-Net and U-Net++ performed with an equivalent median[Q1,Q3] Dice similarity coefficient (DSC) of 94.8[93.2,95.5]% and 94.7[92.6,95.4]%, respectively, higher than a 3D V-Net and state-of-the-art algorithms in the literature. When trained only on EF or SF images, the U-Net++ demonstrated equivalent performance to the network trained with the full dataset. When trained on EF and SF datasets of 1000, 500, 250, and 100 images, the U-Net++ performed with DSC of 93.7%, 93.9%, 93.2%, 90.1% [EF] and 90.3%, 90.3%, 89.2%, 81.0% [SF], respectively.

Conclusions: Our proposed algorithm provided fast (<1s) and accurate 3D segmentations across clinically diverse 3D TRUS images, demonstrating generalizability, while strong performance with smaller datasets demonstrated the efficiency of our approach, providing the potential for widespread use, even when data is scarce.

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