Title: Deep learning-based automatic prostate segmentation on clinically diverse 3D transrectal ultrasound images

Trainee Name: Nathan Orlando

Supervisor(s): Dr. Aaron Fenster

Structured Abstract:

Introduction: Needle-based procedures for diagnosing and treating prostate cancer, such as biopsy and brachytherapy, have incorporated three-dimensional (3D) transrectal ultrasound (TRUS) imaging to improve needle guidance. Using these images effectively typically requires the physician to manually segment the prostate to define the margins used for accurate registration and targeting. However, manual prostate segmentation is a time-consuming and difficult intraoperative process, often occurring while the patient is under sedation (biopsy) or anesthetic (brachytherapy). Providing physician with a quick and accurate 3D TRUS prostate segmentation could minimize treatment time, allowing for a more efficient workflow. The purpose of this study was to develop a supervised deep learning approach to segment the prostate in 3D TRUS images from different facilities, generated using multiple acquisition methods and commercial ultrasound machine models to create a generalizable algorithm for needle-based prostate cancer procedures.

Methods: A two-dimensional (2D) U-Net was modified, trained, and validated using images from 84 end-fire and 122 side-fire 3D TRUS images acquired during clinical biopsies and brachytherapy procedures. Our proposed method for 3D segmentation involved prediction on 2D slices sampled radially around the approximate central axis of the prostate, followed by reconstruction into a 3D surface. Manual contours provided the annotations needed for the training, validation, and testing datasets, with the testing dataset consisting of 20 end-fire and 20 side-fire unseen 3D TRUS images. A comparison to an optimized 3D V-Net was performed following an investigation into different loss functions. An extended selection of absolute and signed error metrics was computed, including Dice similarity coefficient (DSC), volume percent differences (VPD), mean surface distance (MSD), and Hausdorff distance (HD), to assess 3D segmentation accuracy.

Results: Overall, our proposed reconstructed modified U-Net performed with a median [first quartile, third quartile] absolute DSC, VPD, MSD, and HD of 94.1 [92.6, 94.9] %, 5.78 [2.49, 11.50] %, 0.89 [0.73, 1.09] mm, and 2.89 [2.37, 4.35] mm, respectively. When compared to a 3D V-Net with a Dice plus cross-entropy loss function, our proposed method performed with a significant improvement across nearly all metrics. A computation time <0.7 s per prostate was observed, which is a sufficiently short segmentation time for intraoperative implementation.

Discussion: Our proposed algorithm was able to provide a fast and accurate 3D segmentation across variable 3D TRUS prostate images, enabling a generalizable intraoperative solution for needle-based prostate cancer procedures. This method has the potential to decrease procedure times, supporting the increasing interest in needle-based 3D TRUS approaches.