Automated Collecting System Segmentation of Non-Contrasted CT Imaging

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Introduction

Kidney Stone disease or urinary stone disease is a common disease of the kidney.[1] It is characterized by the formation of mineral deposits within the renal collecting system i.e. the renal calyces, renal pelvis, and ureter. Over half a million emergency department visits are for kidney stone problems and these numbers are increasing each year (prevalence 10%, incidence 114–720 per 100,000).[1,2] The recurrence of kidney stones is dramatically higher in those that have had prior kidney stones. Kidney stone treatment is usually done through endoscopic surgeries (minimally invasive) or shock wave lithotripsy (non-invasive). Although these surgeries are curative for kidney stones, 25 % of patients need repeat due to residual stone fragments that can cause ureteral obstruction leading to pain, kidney injury, and urinary tract infections.[3] Despite the advancements in medical technology, the prevalence of patients that need repeat surgery has not decreased. Developing a way to better visualize the collecting system during stone surgery may improve patient outcomes and decrease the need for repeat surgeries.

Stone free rates are primarily impacted by visibility and tracking of stones during endoscopic surgery. Before performing these surgeries, surgeons mentally map the anatomy of patient kidney through CT scans then rely on the endoscope for visualization. Endoscopic visualization can be diminished by blood clots or stone fragments, leading to residual stone fragments. Some of these fragments can move and remain in the complex branch of the renal calyces making it difficult to extract these fragments. Residual stones can lead to pain, infections, and kidney injury. The ability to segment non-contrast CT scans and evaluate the collecting system (in 3D) could improve navigation during endoscopic stone surgery and help treat stones more efficiently and completely.

Currently, there are no clinically relevant navigational systems used in the endoscopic setting for kidney surgery. However, its use has been implicated in intranasal or gastrointestinal surgery.[4,5] Widya et al. were able to reconstruct a 3D model of the stomach using endoscopic video.[5] In a previous study, Lu et al. developed computer vision models which segmented stones in endoscopic surgical videos with greater than 90% accuracy.[6] Additionally, Kavoussi et al, has previously demonstrated the feasibility of a real-time, 3D navigational system during robotic partial nephrectomy for kidney tumor removal.[7] We have previously determined that computer vision models can be trained to automatically segment the collecting system during delayed phases of CT urography.[8] Deep learning-based computer vision models can be trained to identify specific anatomical and pathological targets by exposing the model to an annotated set of visual data. Utilizing computer vision techniques could allow for automatic and improved evaluation of CT images. Similar models have been previously leveraged for automatic detection of kidney cysts, stones, and tumors.[9,10]

Objectives

The primary objective of this project is to develop a 3D model of collecting system anatomy through segmentation of delayed phased computer tomography urograms. Second is to evaluate computer vision models (3DU to segment non-contrasted CT images trained from delayed phase CT images.

Methods

Study Overview

Fifty CT urograms were collected from patients at Vanderbilt urology clinic. The delayed phase scans were manually segmented using ITK-SNAP Active Contour tool.[11] The delayed phase segmented CTs were used to train a 3D Unet model. The model was exposed to associated non-contrast phase images for the creation of an ensemble model for collecting system segmentation. The results were compared to corresponding delayed phase images. Based on our preliminary work, we seek a DSC of > 0.85.

Expected Results

We successfully manually segmented 42 patients delayed phase CTs. These segmented CT scans are currently being used to train a 3D Unet model. Following training, we expect the model to automatically segment non-contrast CT images with similar accuracy to manual segmentation. We previously did this in a preliminary study with 17 patient CT and achieved a Dice similarity coefficient (DSC) of 0.85 for the collecting system (figure 1). We expect to obtain a similar DSC with our increased sample size. Additionally, we constructed ten kidney phantoms from segmented collecting systems in this dataset. These were clinically validated to be useful and will be used for future experiments.

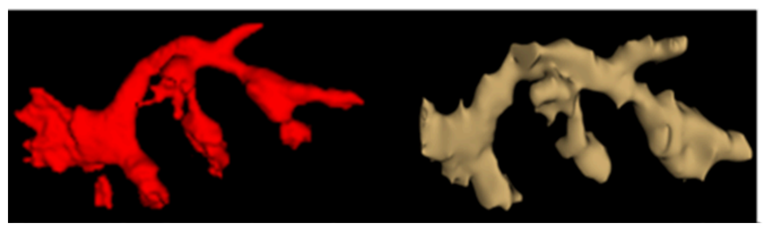

Figure SEQ Figure * ARABIC 1 Comparison of automated segmentation (left) to manual segmentation (right) from CT imaging. Visual inspection of the segmentation results suggest that we can generate 3D surface meshes which preserve the branching and continuous structure of the intrarenal collecting system.

Conclusion and Future Goals

By integrating a 3D segmentation of the collecting system from preoperative imaging (CT scan), surgeons could have a better understanding of surgical anatomy preoperatively. Additionally, integrating the segmentation into a navigational system to become could improve stone free rates. If proven correct, the next steps are to validate the technology on a large-scale clinical study. The study would explore accuracy of segmentation and how it may be used to improve stone-free rates, complication rates, repeat surgical intervention rates, and other metrics assessing outcomes (i.e. surgical accuracy, efficiency, and operative time).

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