Radiomics and Image Segmentation of Urinary Stones by Artificial Intelligence (RISUS-AI)

Study protocol and Statistical Analysis Plan

Principal Investigator: Peter Lauritzen

This document is a translated version of the document reviewed by the Regional Committee for medical and health research ethics in South-East Norway and approved March 12 2024.

Translated document date: April 30 2024

Abstract:

Kidney stone disease causes significant morbidity, and stones obstructing the ureter can have serious consequences. Imaging diagnostics with computed tomography (CT) are crucial for diagnosis, treatment selection, and follow-up. Segmentation of CT images can provide objective data on stone burden and signs of obstruction. Artificial intelligence (AI) can automate such segmentation but can also be used for the diagnosis of stone disease and obstruction.

In this project, we aim to investigate if:

- Manual segmentation of CT scans can provide more accurate information about kidney stone disease compared to conventional interpretation.
- AI segmentation yields valid results compared to manual segmentation.
- AI can detect ureteral stones and obstruction or predict spontaneous passage.

Background:

Prevalence:

In industrialized countries, 5-13% of the population experiences acute renal colic caused by kidney stones. The prevalence of urolithiasis is increasing, with approximately 10-15% of individuals experiencing recurrent attacks. Kidney stones cause significant morbidity due to pain, obstruction, or infection. Different chemical compositions of kidney stones, such as calcium oxalate, calcium phosphate, uric acid, and struvite, can impact treatment.

Treatment:

Conservative (non-surgical) treatment, such as lifestyle advice, dietary changes, or medication, may be sufficient for small, uncomplicated stones. Surgical intervention may be necessary for larger stones or those causing complications, with various treatment methods available.

Examination:

Computed tomography (CT) plays a significant role in the examination, monitoring, and selection of treatment strategies. The CT protocol used for the assessment and follow-up of these patients is a low-dose scan from the upper pole of the kidney to the pelvic floor, without intravenous contrast medium. The presence of kidney stones is indicated, and stone burden is typically assessed, along with signs of complications such as obstruction.

Segmentation and Radiomics:

Image segmentation involves annotating specific objects in images, such as anatomical structures or pathologies like kidney stones. Through segmentation, large amounts of quantitative data can be extracted from radiological images, often referred to as "radiomics."

Artificial Intelligence:

Deep learning (DL) using convolutional neural networks (CNN) is a form of artificial intelligence (AI) that mimics the structure of neurons in the human brain. This technology is well-suited for processing large amounts of image data and has revolutionized automated image segmentation. Manual segmentation data is suitable for developing an AI tool for fully automated segmentation of the same structures. These methods show great potential for medical applications but are still not well explored and exploited. Integrating advanced AI techniques, we aim to offer enhanced image solutions that not only improve diagnostic accuracy but also advance the field of radiomics in kidney stone disease.

Goals and Objectives:

The project aims to contribute to personalized and improved treatment and follow-up of patients with kidney stones using radiomics and the development of an artificial intelligence tool for CT examination assessment. The objectives are to assess:

- Whether manual segmentation of CT images of the urinary tract provides equivalent or more accurate information about kidney stone disease compared to conventional interpretation and reporting.
- Whether segmentation performed with AI yields valid results compared to manual segmentation.
- Whether AI can detect ureteral stones and obstruction and/or predict spontaneous passage of stones.

Method:

Inclusion and Exclusion:

Inclusion criteria:

- Newly occurring colic pain and clinical suspicion of kidney stones or
- Known kidney stone with new/increasing symptoms
- Age ≥ 18 years
- Exclusion criteria:
- Controls of asymptomatic patients with known kidney stone disease or
- Follow-up after treatment of kidney stone disease or
- Controls for spontaneous stone passage (before URS) or
- Lack of informed consent, regardless of reason.

Cohort:

Patients are recruited to the study at Oslo University Hospital, Radiology Department, Section Aker, which performs approximately 1350 CT examinations for urinary tract stones in approximately 1000 patients each year. Approximately 500 patients with a new episode or newly occurring colic pain and clinical suspicion of kidney stones are expected to be included.

Clinical data (where available):

- Baseline CT: date and image data
- Initial treatment (conservative, URS, PCN, ESWL) decision after baseline CT
- Follow-up CT: date and image data
- Time to spontaneous stone passage (negative control CT) or completed surgical intervention (URS)
- Any other surgical/invasive procedure
- Stone chemical analysis
- Clinical biochemistry: creatinine/eGFR, CRP, leukocytes (at baseline and follow-ups).

Image data:

Clinical radiology report:

- Stone: (largest calculus and any obstructing calculus): largest diameter in any plane, density (ROI set by clinical judgment, largest possible ROI - in the slice where the stone is largest), location (upper ureter: above crossing of vessels, lower ureter: below crossing of vessels, ostial: in bladder wall)
- Renal pelvis: largest diameter of calyx neck lower calyx, clinical assessment of dilation (not dilated/slight/moderate/severe).
- Segmentation:
- Stone: total segmented stone volume, largest diameter, and density of segmented stone.
- Collecting system: total segmented volume of the collecting system and renal pelvis.

Endpoints:

- Paper I: Descriptive statistics for manual segmentation data and comparison with clinical radiology report.
    - Null hypothesis: There is no significant difference in diameter or density of stone between manual segmentation and clinical radiology report.
    - Analysis: Paired T-test, or Wilcoxon rank-sum test for non-normally distributed data.
- Paper II: Validation of AI segmentation of stone, renal pelvis, and renal parenchyma against manually segmented gold standard.
    - Null hypothesis: There is no difference between manual segmentation and AI segmentation of stone, renal pelvis, and renal parenchyma.
    - Analysis: DICE score, Hausdorff distance, sensitivity/specificity (of AI segmentation against manual gold standard), comparison of segmented volume and largest diameter.
- Paper III: Prospective application and clinical utility of AI tool (including baseline and follow-up CT) compared to clinical radiology report. Diagnostic accuracy for: ureteral stone and obstruction.
    - Null hypothesis: There is no difference in diagnostic accuracy for ureteral stone and obstruction.
    - Analysis: Comparison of difference in dichotomous proportions in paired data (Newcombe).

Prediction of spontaneous passage is reported with descriptive data as there is no gold standard for comparison.