Electrical Property Based Image Guided Prostate Biopsy
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1. INTRODUCTION
Clinical Standard: Transrectal Ultrasound (TRUS) guided biopsy is the standard approach employed to confirm a diagnosis of prostate cancer. Unfortunately, TRUS does not have sufficient sensitivity and specificity to accurately identify malignant lesions. Instead a standard 12-core template-based biopsy procedure is typically used. This template only samples ~0.95% of a typical prostate gland. As a result, TRUS-guided biopsies miss 10-30% of all cancers. Further, on average 43% of preparatory biopsy specimens are under-graded when compared to the final post-prostatectomy pathological assessment because of the severe undersampling.

Clinical Need: An imaging device for use during biopsy procedures that provides better sensitivity and specificity to cancer detection.

Potential Benefits of Electrical property imaging: We have demonstrated that the electrical properties of different prostate tissues provide significant contrast for discriminating between benign and malignant morphologies. These properties can be imaged with transrectal electrical impedance tomography (TREIT). By combining TREIT with TRUS we propose to enhance the biopsy guidance procedure.

Objective: Develop a TREIT/TRUS system for use in biopsy guidance and assess the clinical potential of this technology.

2. BIOIMPEDEANCE
The electrical conductivity (σ) and permittivity (ε) of tissue are largely dependent on morphology and as a result pathology. When collected over a range of frequencies these property spectra can be parameterized with a Cole model (modified Debye model) into four terms that can be used to describe the trajectory of the electrical properties in the frequency domain.

Bioparameter Spectroscopy
Cole model Parameterization

Electrical Properties: Biophysical Parameters
m: measure of extracellular and intercellular fluids
ε: measure of total cell membrane quantity and viability
σ_c: composite measure of extra and intracellular conductivities
ε_v: measure of extra and intracellular volumes
σ_f: measure of cell membrane quantity and viability
σ_m: measure of variability in cell size

3. PROSTATE BIOIMPEDEANCE
We gauged electrical properties from 50 radical prostatectomy specimens and evaluated the impedance values in terms of the histologically assessed tissue types. The regions probed were categorized as stroma (Str), non-hyperplastic glandular (Gl), benign prostatic hyperplasia (BPH), and cancer (CaP). The four spectral parameters were extracted from the impedance spectra using a least-squares fitting approach.

4. TRUS/TREIT
A clinical 3D TRUS probe from Envisioneering Inc has been retrofitted with an array of 30 electrodes through which a transrectal electrical impedance tomography (TREIT) system is able to image the electrical properties internal to the prostate. Electrical property maps can be co-registered to the ultrasound image to provide a multi-modal approach to identifying malignant lesions. In TREIT, the boundary measurements gauged from around the prostate are input to a finite element method (FEM) based algorithm to estimate the electrical property distribution within. The system operates from 400 Hz to 102.5 KHz. α and σ maps are reconstructed at each frequency and spectral parameters (m, ε, f, σ) are extracted on a nodal basis to produces spectral property maps.

5. CONDUCTIVITY IMAGING

6. IN VIVO IMAGING
TREIT/TRUS are currently being acquired from men undergoing radical prostatectomy immediately prior to the start of surgery. A rigid articulating arm interface to the surgical table and is positioned intra-rectally by the surgeon. Once in position the arm is fixed in place and a full-volume US image is acquired followed by TREIT data acquisition. US-images are segmented post-procedurally and embedded into an FEM mesh. Electrical properties are reconstructed with the embedded prostate.

7. TOWARD PROSTATE BIOPSY GUIDANCE
To increase the far-field sensitivity we have electrically insulated standard biopsy needles so that just the tip of the needle is exposed. The needles will be electrically interfaced to our TREIT system. We plan on using this needle as an internal electrode during routine biopsy procedures. During a standard 12-core biopsy procedure we will collect TREIT images simultaneously with tissue core extraction. This will provide 12 additional internal points of sensing for use in electrical property image reconstruction. Following a standard biopsy procedure these electrical property maps will be rapidly reconstructed on Graphical Processing Units and overlaid on the US image to provide additional guidance to urologists.

8. CONCLUSIONS
While this investigation is in the early stages of development, there is significant evidence suggesting that imaging the electrical properties of prostate may provide enhanced lesion identification to assist in accurately guiding clinicians to sample suspicious prostate regions. Over the next two years, the developed TRUS/TREIT system will be used in a pre-clinical trial during routine prostate biopsy procedures to gauge the efficacy of this approach.

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Prostatic Electrical Properties

Clinical Metrics

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PROSTATE BIOIMPEDEANCE

σ (mS/m)

Intraoperative TRUS/TREIT

TRUS Overlay with Electrical Property Imaging

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