Development of an open-source system for prostate biopsy training in Senegal

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ABSTRACT

PURPOSE: Prostate cancer is the second most common cancer diagnosed in men. The rate is disproportionately high among men in sub-Saharan Africa where, unlike in North America and Western Europe, the screening process for prostate cancer has historically not been routine. Currently, as awareness regarding prostate health increases, more patients in this region are being referred to trans-rectal ultrasound guided prostate biopsy, a diagnosis procedure which requires a strong understanding of prostate zonal anatomy. To aid in the instruction of this procedure, prostate biopsy training programs need to be implemented. Unfortunately, current TRUS-guided training tools are not ideal for reproducibility in these Western African countries. To answer this challenge, we are developing an affordable and open-source training simulator for TRUS-guided prostate biopsy, for use in Senegal. In this paper, we present the implementation of the training simulator's virtual interface, highlighting the generation and evaluation of the critical training component of zonal anatomy overlaid on TRUS.

METHODS: For the simulator's dataset, we registered TRUS and MRI volumes together to obtain the zonal segmentation from the MRI volumes. After generating ten pairings of TRUS overlaid with zonal segmentation, we designed and implemented a virtual TRUS training system, developed in open-source software. The objective of our simulator is to teach trainees to accurately identify the prostate's anatomical zones in TRUS. To confirm the system's usability for training zonal identification, we conducted a two-part survey on the quality of the zonal overlays with 7 urology experts. In the first part, they assessed the zonal overlay for visual correctness by rating 10 images from one patient's TRUS with registered overlay on a 5-point Likert scale. For the second part, they labelled 10 plain TRUS volumes with zonal anatomy and the labels were compared to the labels of our overlay.

RESULTS: On average, experts rated the zonal overlay's visual accuracy at 4 out of 5. Furthermore, 7 out of 7 experts labelled the peripheral, anterior, and transitional zones in the same regions we overlaid them, and 5 out of 7 labelled the central zone in the same region we overlaid it.

CONCLUSION: We created the prototype of a TRUS imaging simulator in open-source software. A vital training component, zonal overlay, was generated using publicly accessible data and validated by expert urologists for prostate zone identification, confirming the concept.

1. PURPOSE

Prostate cancer is the second most common malignancy diagnosed in males globally, with men of African and Caribbean descent being noted to have disproportionately higher incidences compared to males of any other race or ethnicity. Furthermore, the International Agency for Cancer Research has reported that the estimated yearly deaths due to prostate cancer in sub-Saharan Africa is more than five times the number of deaths among African Americans[1].

Currently, many patients in sub-Saharan Africa are being referred to prostate biopsy, a diagnosis procedure performed using trans-rectal ultrasound (TRUS) guidance[2]. The first step in this procedure is for physicians to identify the four prostate zones on TRUS: the central zone (CZ), transition zone (TZ), peripheral zone (PZ), and anterior fibromuscular stroma (AFS)[3]. Then, they evaluate the position of their TRUS probe in relation to the prostate and perform the biopsy, ensuring that the samples are well-distributed in the targeted zone[4].

In response to the increased number of patients requiring this procedure in Western Africa, TRUS-guided training programs need to be introduced. While many prostate biopsy simulators currently exist[5,6], these technologies are not ideal for use in developing countries. They often consist of a rectum phantom to produce simulated TRUS-guidance along with electromagnetically tracked tools which unfortunately increase the cost of the training simulator substantially, preventing it from being a feasible option for mass reproducibility in sub-Saharan African countries.

Since 2017, Queen's University has partaken in an international program called "Train the Trainers" which partners historically privileged academic institutes and several countries in Western Africa to establish and sustain technologies for medical training in those regions[7]. The training program is based in open-source and accessible platform, highlighting the importance of easily translatable and distributable technologies towards sustainable development.

In partnership with the "Train the Trainers" program, we are developing a TRUS-guided biopsy training tool to be implemented in Senegal that is affordable, and able to be locally assembled and distributed through an open-source software. For training this biopsy procedure, senior urologists recognize that the greatest challenge is the mental estimation of the zones which are sometimes abnormal and not visible. Thus, to produce a beneficial learning process, the training system will teach users to identify zones on TRUS to perform proper zonal sampling. This paper presents the concept of the interface implementation for an open-source prostate biopsy simulator, highlighting the generation and evaluation of the critical component of zonal anatomy overlay on TRUS.

2. METHODS

2.1 Generation of simulator dataset

For the simulator's dataset, we used anonymized TRUS volumes and prostate MRIs with zonal segmentation from separate sources which made their data available for research purposes [8,9]. To confirm the validity of using data from separate patients, we needed to evaluate the visual accuracy and anatomical conceivability of overlaying prostate zonal anatomy on TRUS. In 3D Slicer, an open-source platform for medical imaging and visualization[10], we deformably registered pairings of an MRI with zonal segmentation and a TRUS volume. This was performed by placing fiducials along the gland outline and the urethra of both the TRUS and the zonal segmentation to drive a deformable fiducial registration[11]. This registration process resulted in the prostate zonal anatomy overlaying on the TRUS (Figure 1). We completed this process on ten TRUS patients to generate our dataset.

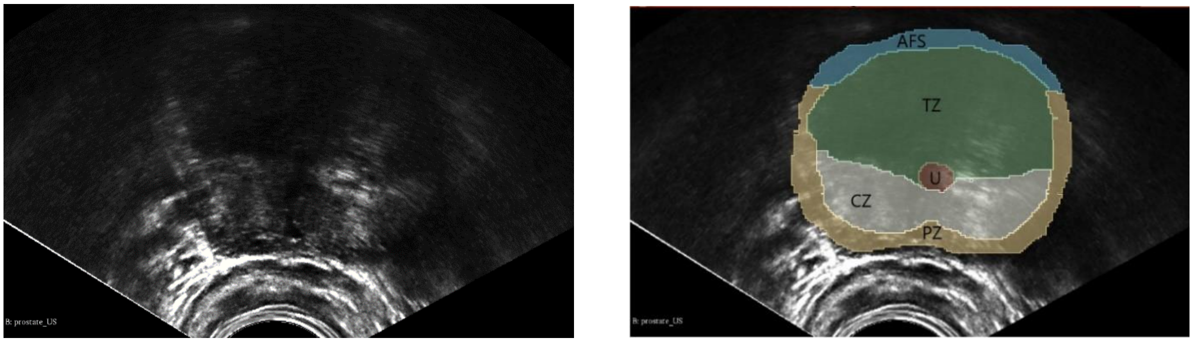


Figure 1: Prostate ultrasound image *(left)* with labelled zonal anatomy registered and overlaid *(right)*.

2.2 Design and implementation of training module

We designed and built a scripted Python module to simulate the TRUS procedure. Implemented in 3D Slicer, our interface serves as a tool for training TRUS-guided prostate biopsy. Once loaded, the simulation scene shows the probe model and a slice of the TRUS volume in 3D, as well as the sagittal view of the prostate according to their probe position (Figure 2). Additionally, it consists of a hidden copy of the generated prostate zonal segmentation for the given patient, as well as a transform hierarchy to facilitate the ultrasound simulation. Transforms are applied to the probe and triggered using the keyboard arrow keys or clickable buttons. Consequently, the patient TRUS volume is resliced. Complete code for the module can be found at https://github.com/PerkLab/ProstateBiopsySim.

The user interface for the module is intuitive, allowing users to select one of ten different TRUS patients to train on, move the probe, toggle zone visibility, practice scanning and identifying the prostate zones, and finally, save their progress (Figure 3).

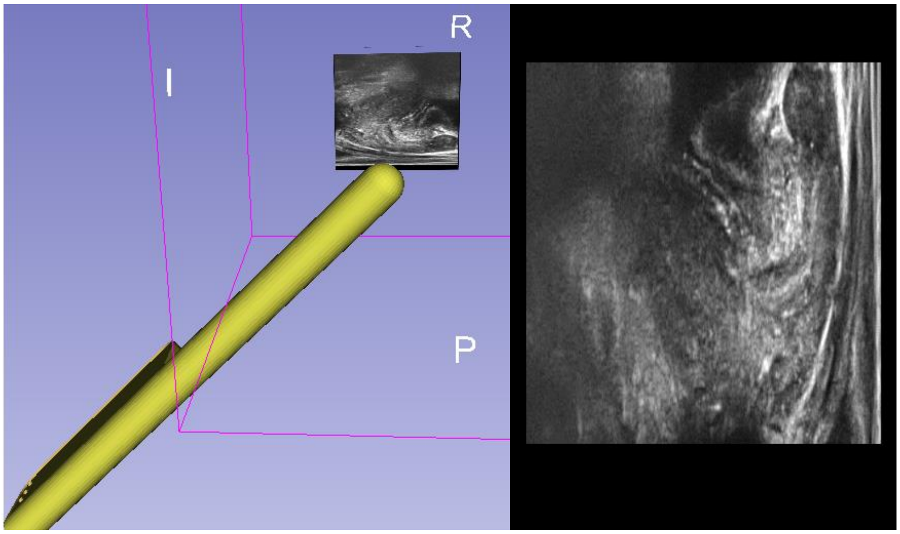
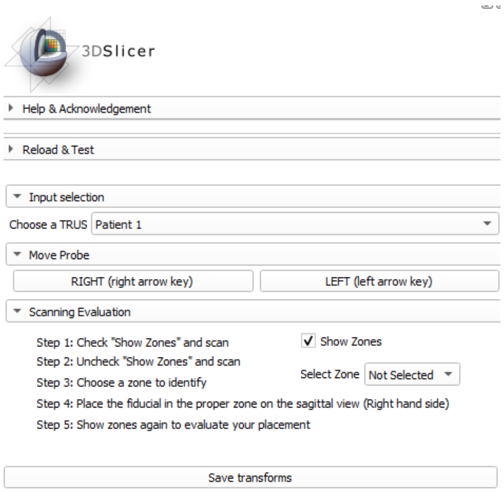


Figure 2: Screen shot consisting of 3D view with movable TRUS probe (*left*) and corresponding 2D sagittal US slice (*right*).



Choose a TRUS: Patient 1

Step 1: Check "Show Zones" and scan
Step 2: Uncheck "Show Zones" and scan
Step 3: Choose a zone to identify
Step 4: Place the fiducial in the proper zone on the sagittal view (Right hand side)
Step 5: Show zones again to evaluate your placement

☑ Show Zones
Select Zone: Not Selected

Figure 3: Screenshot of the module UI. Facilitates probe movement, zone overlay visibility, and zonal identification.

2.3 Training objectives

The ability to visualize zonal anatomy on patient TRUS data is critical to the training process for TRUS-guided prostate biopsy. We designed our simulator with the objective to train users to accurately estimate prostate zonal anatomy and therefore, accurately map biopsy cores in the intended zones.

Our training program begins by allowing the user to view the prostate zonal map that corresponds to the patient's TRUS (Figure 4). Users will use the visual cues from the segmentation in the early stages of training to familiarize themselves with the positioning and location of the zones. They can manipulate the probe and view the anatomy overlaid on the TRUS. Eventually, they hide the zonal overlay, and must accurately locate each zone based solely on the TRUS. This evaluation is performed by the program which provides the user with a fiducial marker to place in each zone and then reports whether the placement was within the intended zone or not.

Prostate zonal overlay is therefore a critical component of the interface since it enables the zonal identification step and allows users' performance to be evaluated.

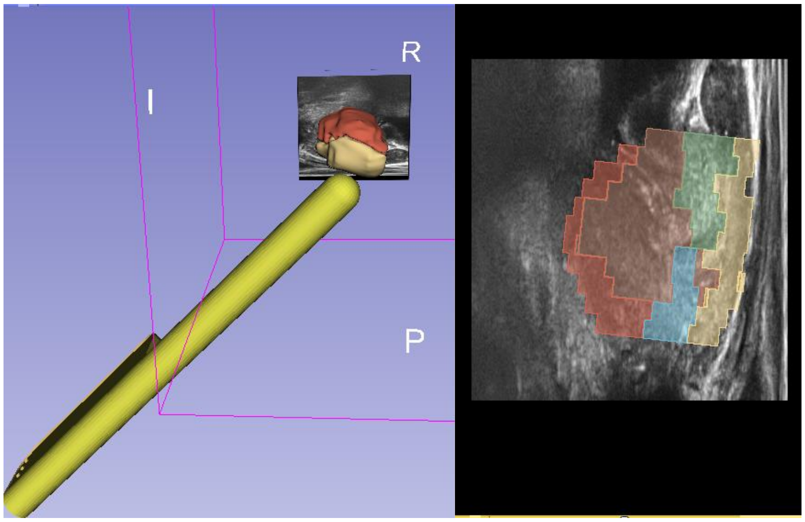


Figure 4: Screen shot of early training stages where prostate zones are visible for trainee.

2.4 Physical simulator concept

Furthermore, to promote a realistic biopsy simulation and train the haptics of the procedure, we propose a concept for the physical simulator. The major components are a plastic mock TRUS probe, a mock rectum built with dense sponge-like material, a webcam, and a laptop running our training module in 3D Slicer. ArUco markers, which have been shown to be sufficiently reliable for visual localization[12] and have been integrated in 3D Slicer with the Public Library of Ultrasound (PLUS)[13], are attached to the mock probe to facilitate tracking of the user's movement (Figure 5). Due to the modularity of our virtual prototype, these physical components will be easily connected to the training system, allowing the trainee's tracked physical movement with the probe to re-slice the virtual TRUS volume.

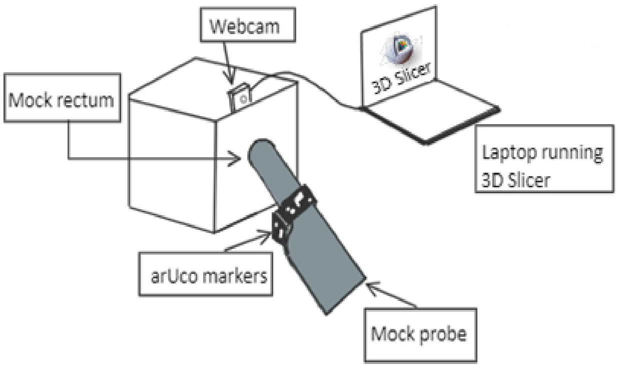
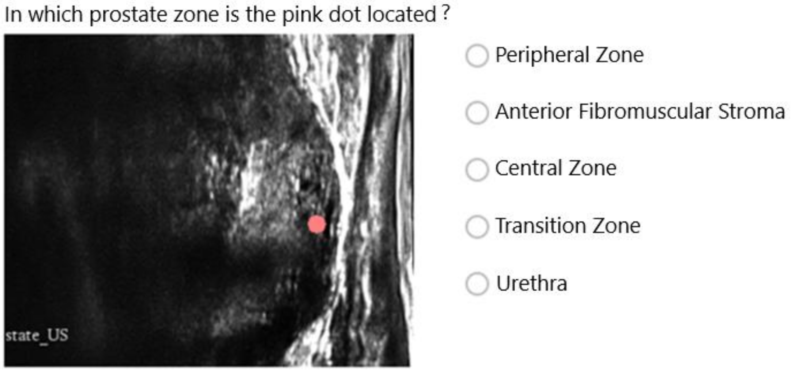


Figure 5: TRUS biopsy simulator design.

2.5 Evaluation of zonal anatomy overlay

To confirm the concept of our system as a tool to train prostate zone identification, we created a 2-part survey which 7 urologists answered to evaluate the zonal overlay on the TRUS as suitable for use in our TRUS-guided biopsy training simulator. Evaluators were first presented with 10 TRUS images from the same patient, overlaid with zones, as depicted above in Figure 1. On a 5-point Likert scale, they assessed the quality of the zonal overlay based on how accurately it reflected their own interpretation of the prostate zones on that TRUS image. After rating accuracy, evaluators were shown 10 plain TRUS images with pointers and asked to label the zone in which the pointer was positioned, allowing us to compare their interpretation to our zonal overlay (Figure 6).



In which prostate zone is the pink dot located ?

○ Peripheral Zone

○ Anterior Fibromuscular Stroma

○ Central Zone

○ Transition Zone

○ Urethra

Figure 6: Example from the zone labelling section of the questionnaire.

3. RESULTS AND DISCUSSION

On average, the experts rated the accuracy of the zonal overlay at 4 on a 5-point scale (Figure 7). Furthermore, the response to the zone labelling section revealed that for 10 TRUS images, 7 out of 7 experts labelled the PZ, AFS, urethra and TZ equivalently to our overlay, and 5 out of 7 labelled the CZ equivalently to our overlay (Figure 8).

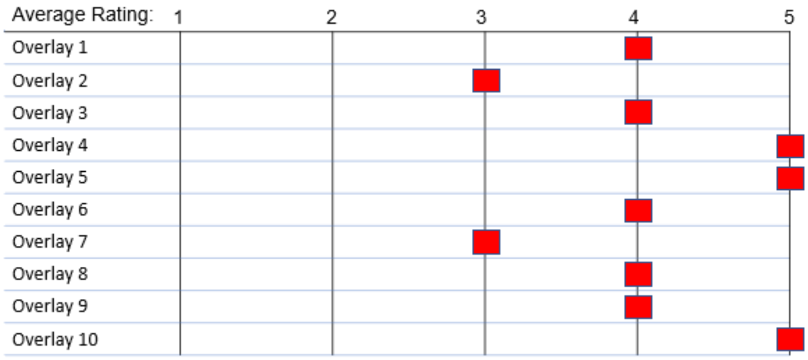


Figure 7: Results from the portion of the survey where experts rated the suitability of the overlay for prostate zone identification training

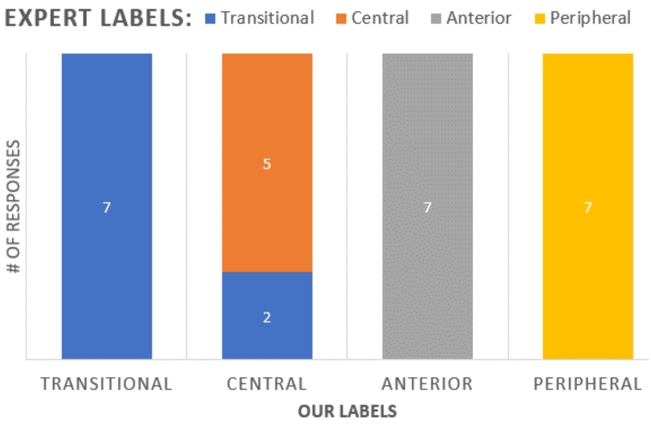


Figure 8: Results from the labelling questionnaire portion of the survey.

These values indicate the visual accuracy of our zonal overlay for 4 out of 5 anatomical regions. The only inconsistency in labelling can be noted in the CZ where 2 out of 7 evaluators labelled it as the TZ. This could be attributed to the challenge of estimating the CZ and TZ border and identifying CZ growth in TRUS.

Additionally, the need for registration of zonal anatomy to TRUS arises due to the lack of TRUS-MRI image sets in public domain because institutions continue to impose heavy restrictions on this data. These results show that a zonal anatomy overlay can be sufficiently registered to an arbitrary TRUS for biopsy training purposes.

4. NEW OR BREAKTHROUGH WORK TO BE PRESENTED

In comparison to current biopsy simulators, we designed a system that is based on tracked patient TRUS data rather than phantom images, incorporates zonal segmentations acquired from patient MRIs, and is implemented in free open-source software. Furthermore, the confirmation of the zonal overlay's visual accuracy on TRUS demonstrates the production of biopsy training material using accessible data and open-source platforms.

5. CONCLUSION

We designed and implemented the prototype of a TRUS biopsy imaging simulator in open-source software. A vital training component, zonal overlay, was generated using publicly accessible image data and was validated by expert urologists for prostate zone identification. We confirm the concept of an educational and open-source prostate biopsy training tool based on clinical patient data and continue working towards the connection to affordable and accessible components for physical simulation.

6. ACKNOWLEDGMENTS

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