Toward optimization of needle target planning for 3D TRUS-guided prostate biopsy

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Background: The current clinical standard for definitive diagnosis of prostate cancer is 2D transrectal ultrasound (TRUS)-guided biopsy. However, this procedure has a false negative rate of 21-47% and therefore many patients must return for repeat biopsies. A potential solution for this problem is prostate “fusion” biopsy, wherein tumours are delineated on pre-procedural magnetic resonance imaging (MRI) and registered to the 3D TRUS needle guidance modality. However, fusion biopsy continues to yield false negative results and while there is currently substantial research in prostate imaging and biopsy needle guidance, there is a gap in knowledge regarding biopsy plan optimization. Within-tumour needle targets are chosen ad hoc in fusion biopsy without accounting for uncertainties due to guidance system and registration errors, and tumour sizes and shapes. Optimization of needle target planning with appropriate uncertainty propagation may lead to an improved cancer detection rate.

Methods: As an initial step toward the broader goal of optimized prostate biopsy targeting, we elucidated the impact of biopsy needle delivery error on the probability of obtaining a tumor sample, and on patient risk stratification. We simulated biopsy targets using two separate datasets; a dataset of 81 suspicious regions in 3D, contoured by a radiologist and radiology resident using multi-parametric MR images, and secondly a dataset of 99 lesions obtained from expert-contoured gold-standard prostatectomy histology. We simulated targeted biopsies using a Gaussian needle delivery error, and investigated the probability of obtaining a tumour sample, and the amount of each lesion obtained in the biopsy core as a function of this needle delivery error.

Results: We determined that for biopsy systems with a needle delivery $\geq 4$ mm, as has been observed in practice, more than one biopsy core must be taken to achieve a $\geq 95\%$ probability of a cancer-positive biopsy sample. We also determined that the presence or absence of cancer in 1/3 or more of each needle core can be attributed to a needle delivery error of 4 mm, and this amount of variability is large enough to influence treatment decision.

Conclusions: For expected needle guidance errors, repeated biopsies of the same tumour target can yield tumour size estimates with sufficient variability to influence the decision between active surveillance and treatment. However, our data showed that by making multiple biopsy attempts at selected tumour foci, we may increase the probability of correctly characterizing the extent and grade of the cancer. Using what we have learned from our experiments and the tools we have developed, we are now capable of investigating optimized tumour targeting strategies in an attempt to accurately characterize cancer burden in as few biopsy attempts as possible.