Title: Power Doppler Ultrasound Imaging with Mechanical Perturbation for Improved Intraoperative Needle Tip Identification During Prostate Brachytherapy

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Structured Abstract:
Introduction: Ultrasound (US)-guided high-dose-rate (HDR) brachytherapy (BT) is a common treatment technique for intermediate and high-risk localized prostate cancer. This minimally invasive procedure uses a radioactive source passed through multiple hollow needles to deliver radiation. Accurate identification of needle tips is a key component of both patient safety and treatment effectiveness for HDR-BT. Unfortunately, image artifacts from nearby needles and the surrounding tissue often limit the accuracy of needle tip identification when using standard 2D brightness (B)-mode US guidance. To overcome these limitations and improve the accuracy of intraoperative needle tip identification, we propose the use of power Doppler (pD) US imaging while a mechanical perturbation is applied to the needle of interest.

Methods: A mock HDR-BT procedure was completed in a tissue-mimicking agar phantom. In total, 16 needles (8 plastic and 8 metal) were inserted in the phantom. The chosen implant pattern, insertion depth, and number of needles were representative of what might be seen in a real HDR-BT procedure. For each needle, the tip location was selected by two observers using in-house software, first using B-mode US and then using pD US while the needle in question was vibrated using a mechanical device developed in our laboratory, capable of oscillating at a fixed and controllable frequency. Physical measurement of the distance from the needle template to the distal end of the needle (end length) served as the gold standard when evaluating the accuracy of our tip identifications.

Results: Mean ± SD tip errors, averaged between observers, were 1.2 ± 0.5 mm and 0.7 ± 0.5 mm for plastic needles, and 2.5 ± 0.9 mm and 3 ± 1 mm for metal needles, using B-mode and pD US respectively. Correlation of tip errors between observers was found to be r = 0.835, with a paired t-test showing no statistically significant difference. A two-way ANOVA showed a statistically significant main effect for the needle type on tip error (p < .0001), but no statistically significant main effect was observed for ultrasound modality. No correlation was found between tip error and needle insertion depth, and no statistically significant differences in tip error were found for needles inserted at different distances from the US probe.

Discussion: For plastic needles, our pD US method reduced tip error when compared to standard B-mode US. For metal needles, we observed increased tip error using B-mode US when compared to plastic needles, and we found that our pD US method did not result in decreased tip error. These preliminary results were observed in a phantom, where needle visualization is ideal, suggesting that our technique may be useful in reducing tip identification error in clinical HDR-BT procedures. Future work will focus on assessing trajectory error and optimizing our technique for metal needles, with the goal being successful translation to clinical procedures.