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Intraoperative factors associated with stranded source placement accuracy in low−dose rate prostate brachytherapy

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ABSTRACT

PURPOSE: The quality of a low−dose rate prostate brachytherapy implant depends on the accurate placement of sources in their planned locations. This study investigates intraoperative factors that potentially contribute to stranded source placement inaccuracy in prostate brachytherapy.

METHODS AND MATERIALS: Intraoperative video images of the brachytherapist's hand motions and needle insertions during the implant procedure were acquired for analysis. Using video analysis software, maximum and average needle insertion velocities were determined. The number of needle insertion attempts and the use of the brachytherapist's other hand to manipulate the needle direction were also recorded. Sources misplacements were analyzed using an ultrasound-based method described elsewhere.

RESULTS: Fifteen patients agreed to undergo this study; 1619 ^{125}I seeds were inserted using 357 needles; 1197 seeds were confidently identified using ultrasound images and included in the analysis. The mean overall misplacement was 0.49 cm (0−2 cm, 95% CI = 0.47−0.51); 614 seeds were delivered with a single pass and 583 seeds with >1 passes (range 2−6). The mean maximum needle velocity was 12.34 cm s^{-1} (range 4−28 cm s^{-1}) and mean average velocity was 4.76 cm s^{-1} (range 0.4−17.4 cm s^{-1}); 747 seeds were delivered with manipulation of the needle. The generalized linear model test was used to analyze factors contributing to seed misplacement, and it was found that a maximum speed <12 cm s^{-1} was associated with a decrease in seed misplacement by 0.049 cm vs. a maximum speed >12 cm s^{-1}, p = 0.0121). Other evaluated factors were found to have no statistically significant correlation with seed misplacement: average speed (p = 0.4947), manual manipulation of needle (p = 0.9264), and number of needle passes (p = 0.8907).

CONCLUSIONS: This study identified that needles inserted with lower maximum velocity were associated with less seed misplacement. Manual manipulation of the needle, number of passes, and average speed did not show statistically significant correlation with seed misplacement.

Keywords: Prostate; Brachytherapy; Low dose rate; Misplacement; Intraoperative factors; Transrectal ultrasound

Introduction

Accuracy and good quality implant

Accuracy of radioactive source placement is important for optimal dose delivery to the prostate gland, while sparing organs at risk (1). In contemporary transperineal low−dose rate prostate brachytherapy procedures, the grid holes in a template allow the operator to insert needles at specified co-ordinates based on transrectal ultrasound (TRUS) pre- or intraoperative plans. Sources do not always end up in the intended locations because of factors such as needle deflection, prostate movement during insertion, intraoperative edema, prostate deformation by the ultrasound probe, and the effect of drag on sources on withdrawal of the needle (2). Only limited actions can be taken by the operator to steer a needle to its desired location including manual manipulation of the needle shaft, rotating the beveled tip, and varying the speed of insertion.

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Many researchers have studied needle insertion parameters in phantom and laboratory settings and developed robotic systems to assist in needle steering and source delivery. However, there are some limitations in performing phantom studies and in laboratory settings. Phantom models (agarose, gelatin, polyvinylchloride [PVC], various animal tissues) have all been used to study needle steering and deflection. However, except for animal tissues, phantoms are mostly homogenous and differ from real clinical cases where a needle must penetrate through several layers of different types of tissue (skin, muscle, fascia, prostate capsule, and prostate gland), each with different tissue densities and mechanical properties (3). Studying needle steering from *in vitro* experiments to create a model of needle steering for real cases can be challenging.

None of the existing experimental models can accurately predict the parameters while the needle is inserted into prostate gland. Attempts to measure parameters involved *in vivo* has been done but for limited numbers (4).

Using a novel approach, our study aims to establish the intraoperative parameters that may contribute to seed placement inaccuracy in permanent prostate brachytherapy implants done with stranded ^{125}I sources, using video analysis.

Methods and materials

Patient selection

This study was approved by the local institutional ethics committee. Patients with low-risk prostate cancer (Gleason score of 6 and less, prostate-specific antigen less than 10 ng/mL, and clinical staging T1a to T2b) and low-tier intermediate-risk prostate cancer (defined as organ-confined disease and either Gleason score of 7 and PSA of 10 ng/mL or lower or PSA of 10–20 ng/mL and Gleason score of 6 or lower) using brachytherapy as monotherapy (i.e., without androgen deprivation therapy or external beam radiotherapy) for their treatment were eligible for the study.

Implant technique and image acquisition

Our technique has been described in detail before (5). Briefly, 4–6 weeks before the prostate brachytherapy implant, a planning TRUS of the prostate was performed with the patient in the dorsal lithotomy position. Axial and sagittal images of the prostate were taken with a TRUS probe operating at 6 MHz (8088 Biplane Transducer on BK Pro Focus UltraView 800; BK Ultrasound, Peabody, MA, USA). The clinical target volume was the prostate gland and with a 3-mm lateral and anterior margin and a 5-mm inferior margin was expanded to the planning target volume. A nonuniform distribution of sources in the prostate and periprostatic tissue was used to deliver a minimum peripheral dose of 145 Gy, while limiting the periurethral tissue to <150% of the prescription dose, and rectal D_{1cc} to less than or equal to the reference/prescription dose of 145 Gy.

For the implantation, patients underwent general anesthesia in the dorsal lithotomy position. The planning setup was replicated by matching the intraoperative TRUS images with the planning TRUS. Stranded ^{125}I sources, model AgX100 in VariStrand sleeve material (Theragenics Corporation, Buford, GA), of strength 0.400 mCi (0.508 U), loaded into 18 g beveled tip 20-cm-long SeedLock3 needles (Theragenics Corporation) were inserted with a transperineal approach using a template for guidance. A single experienced brachytherapist (NU) inserted all the needles analyzed for this study.

Video setup

A video camera was mounted on a tripod to the left of the operator, 2 m away from the template, perpendicular to the direction of needle travel/trajectory. The camera was set up at the implant template height so that the operator's hands and the needle being inserted were clearly visualized. The video camera was set to capture video images at 1080p resolution, 30 frames per second, and using *.avi* format. In each case, the operator displayed a 15-cm ruler parallel to the needle trajectory just before the first needle insertion for the purpose of calibration. The video recorded the entire procedure.

Analysis software

The video images were then analyzed using the motion analysis software Kinovea 0.8.15, available from: <http://www.kinovea.org>. Initial calibration involved measuring the length of the ruler displayed at the beginning of the procedure using the measurement tool in the software so that the number of pixels corresponded to a physical distance. The software's capability to track user-defined points allowed accurate determination of penetration distance, average velocity (V_{avg}), and maximum velocity (V_{max}) (Figs. 1a–1e).

Parameters considered

The parameters analyzed as factors associated with seed placement accuracy included the V_{max} of the needle at any particular point during insertion, the V_{avg} of the needle insertion, the number of insertion attempts made, any manipulation of the needle, and the distance traversed by the needle (penetration distance) during insertion.

Measuring source accuracy

At the end of each procedure, a series of axial images was taken at 5 mm intervals from the base cranially down to 5 mm below the apex of the prostate gland caudally and imported into the VariSeed 8.0.1 planning software (Varian Medical Systems, Inc., Palo Alto, CA). Using the contouring tool, prostate gland and urethra structures were reconstructed. Using the preoperative VariSeed plan as a