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A sector-based dosimetric analysis of dose heterogeneity in high-dose-rate prostate brachytherapy

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ABSTRACT

PURPOSE: High-dose-rate (HDR) prostate brachytherapy delivers a heterogeneous dose distribution throughout the prostate gland. There is however limited information regarding the spatial distribution of this dose heterogeneity. To this end, we analyzed the magnitude and location of intraprostatic dose heterogeneity in HDR prostate brachytherapy.

METHODS AND MATERIALS: Five consecutive prostate cancer patients treated with HDR were analyzed. Based on CT-simulation images, each prostate was divided into three sections (apex, base, and mid-gland). These were further subdivided into eight symmetrical sections to give a total of 24 sections. Dose–volume histograms were analyzed from V100–V200% for these 24 sections comparing the means of individual regions, left vs right, apex vs base vs mid-gland, lateral vs medial, and anterior vs posterior. A separate analysis on dose as a function of individual region volume was also performed.

RESULTS: Analyses comparing the 24 regions showed a maximum 62% difference (range, 21.9–83.9%) at V130% and 19.9% (1.9–20.8%) at V200%. Seven regions were significantly decreased and one significantly elevated from V130–V180% when compared with the mean. The means for lateral sections were 1.57-fold higher than medial sections from V110–V200% ($p < 0.0001$). The dose at the base was significantly higher than the rest of the gland from V120–V200 (V150, 35.6 ± 16.2% vs 20.9 ± 13.1%, $p < 0.0001$).

CONCLUSIONS: There is significant intra-prostatic dose heterogeneity in prostate HDR brachytherapy. This is most notable in the increased dose to base and lateral portions of the gland. Further studies are needed to determine the impact of heterogeneity on clinical outcomes.

Keywords: High-dose-rate; Prostate; Brachytherapy

Introduction

High-dose-rate (HDR) brachytherapy is an important treatment modality for all risk groups of prostate cancer. It provides the unique combination of hypofractionation with heterogeneous dose delivery. Stereotactic body radiation therapy (SBRT) is a non-invasive alternative to HDR that combines hypofractionation but with typically homogeneous dose delivery. Given the fact that SBRT is non-invasive and more accessible, it serves as a compelling alternative to brachytherapy, particularly if dose hypofractionation is the most important component of treatment. On the other hand, SBRT may be inferior to brachytherapy if heterogeneity is more important. Understanding the trends in the dose variation of brachytherapy is crucial in facilitating ongoing comparisons between the two modalities.

There are no prospective clinical comparisons of SBRT vs HDR to date. Most assessments at this time are dosimetric and in general demonstrate that HDR delivers an overall higher dose to the prostate for relatively lower doses to organs at risk compared with SBRT (1–6). Few dosimetry studies have actually tried to reproduce the exact distribution of HDR dose heterogeneity, which is at least partially related to the limited data available on HDR spatial dose distribution.

To truly understand the dosimetric differences between HDR brachytherapy and SBRT, a greater understanding

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of HDR dose distribution is needed. We sought to quantify the location and magnitude of dose heterogeneity in HDR brachytherapy to help better understand the heterogeneous dose distribution of prostate HDR.

Methods

This was an institutional review board-approved study of five consecutive patients treated with HDR monotherapy for prostate cancer in the Department of Radiation Oncology at the University of California Los Angeles. All five men underwent CT simulation planning and were treated with a dose of 7.25 Gy x 6 fractions. One experienced radiation oncologist performed all implants. Dose constraints for HDR monotherapy in terms of target coverage were comparable to consensus guidelines and included a CTV D90: 100–115%, CTV V100: 97–100%, CTV 150: <35%, rectal wall D0.1 cc: < 85%, bladder wall: 80% < D0.1 cc < 95%, and urethra: D0.1 cc < 110% (trans-urethral resection of the prostate [TURP] < 105%), D1 cc < 105% (7). The treatment target included the prostate and the proximal seminal vesicles. Planning was performed using inverse planning simulation annealing algorithm using Oncentra Brachy Treatment Planning System Version 4.3 (Nucletron an Elekta company, Veenendaal, Netherlands) followed by graphical optimization.

Using these planning images, each prostate was divided by equal lengths into three sections: apex, mid-gland, and base. Each of these three sections was further subdivided into eight symmetrical sections, by equal widths, to give a total of 24 sections (Fig. 1). Dose–volume histograms were then analyzed for each section from V100–V200% in delineations of 10%. For example, V100% was defined as the percentage of the given region's volume receiving 100% of the prescription dose, whereas V200% was the volume receiving double the prescription dose. Analyses were performed to determine if any prostate regions received significantly higher or lower doses by comparing the means of the 24 individual regions at each of the 10 cutoffs from V100–V200%. Similar analyses were also performed on apex vs base vs mid-gland, lateral vs medial, left vs right, and anterior vs posterior. A separate analysis on dose as a function of section volume was conducted by calculating the mean volume of all individual sections and comparing sections above vs below the mean from V100–V200%.

Single-factor analysis of variance (ANOVA) and two-sample Student's t-tests assuming unequal variances were used to evaluate the means for statistical significance, which was set at p-value < 0.05.

Results

The mean age, trans-rectal ultrasound volume, and PSA of the five patients was 65.6 ± 3.8 years, 26.4 ± 9.0 cc, and 4.8 ± 3.1 ng/mL, respectively. Patients had either T1c or T2a disease.

The mean ± SD doses for all five patients for the V100, V150, and V200 were 98.7 ± 0.6%, 23.6 ± 4.9%, and 8.5 ± 1.4%. The mean doses for the lateral sections were significantly higher than medial ones at all dose levels from V100–V200 (Table 1). On average, the lateral regions received 1.57 times the dose compared with the medial regions from V100–V200 (Fig. 2). Analysis of base vs apex vs mid-gland showed a significant difference (ANOVA, $p < 0.001$), with the base receiving significantly higher dose than the rest of the gland from V120–V200. Fig. 3 provides a graphical illustration of the data from V100–V200% in each prostatic region. There was no significant difference in dose when comparing left vs right or anterior vs posterior from V100–V200.

The mean volume per individual section was 2.00 ± 1.04 cc. The mean volume of the base, mid-gland, and apex were significantly different at 2.57 ± 1.22 cc, 2.16 ± 0.75 cc, and 1.26 ± 0.60 cc, respectively (ANOVA, $p < 0.001$). There was no significant difference in V100–V200% for regions ≥2.00 cc vs <1.99 cc.

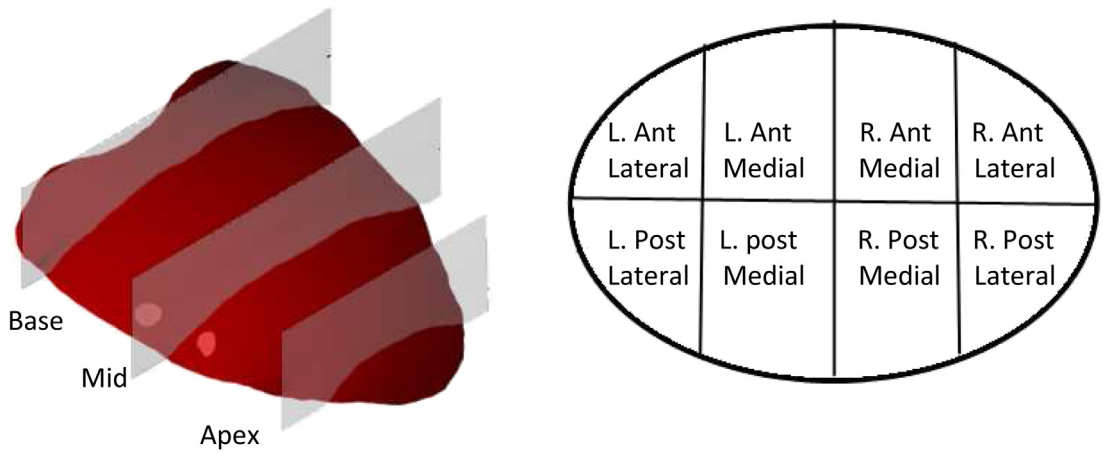

Fig. 1. Illustrates prostate division used for analyses; apex, mid-gland, and base each divided into eight 3-dimensional sections to give 24 total regions.