Original paper

Dosimetric effects of prone and supine positions on post-implant assessments for prostate brachytherapy

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Abstract

Purpose: Post-implant dosimetric assessment is essential for optimal care of patients receiving prostate brachytherapy. In most institutions, post-implant computed tomography (CT) is performed in the supine position. This study aimed to assess variability in dosimetric parameters with postural changes during acquisition of post-implant CT scans.

Material and methods: In total, 85 consecutive patients were enrolled in this study. Fifty-three patients underwent seed implantation alone, and the remaining 32 received a combination of seed implantation and external beam radiotherapy. For post-implant analyses, CT scans were obtained in two patient positions, supine and prone. To evaluate differences in dosimetric parameters associated with postural change, the dosimetric data obtained in the supine position were defined as the standard.

Results: The median prostate volume was 22.4 ml in the supine and 22.5 ml in the prone position ($p = 0.51$). The median prostate D_{90} was 120.1% in the supine and 120.3% in the prone position, not significantly different. The mean prostate V_{100} was 97.1% in the supine and 97.0% in the prone position, again not significantly different. Median rectal V_{100} in supine and prone positions were 0.42 ml and 0.33 ml, respectively ($p < 0.01$). Rectal D_{2cc} was also significantly decreased in the prone as compared with the supine position (median, 59.1% vs. 63.6%; $p < 0.01$). A larger post-implant prostate volume was associated with decreased rectal doses in the prone position.

Conclusions: Though there were no significant differences among prostate D_{90} assessments according to postural changes, our results suggest that post-implant rectal doses decreased in the prone position.

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Key words: prostate cancer, brachytherapy, post-implant, position, prone.

Purpose

Post-implant dosimetric analysis is the standard practice following permanent prostate brachytherapy. Both the American Brachytherapy Society (ABS) and the American Association of Physicists in Medicine (AAPM) recommend performing post-implant dosimetric analysis for all patients undergoing permanent seed implantation [1,2]. Currently, computed tomography (CT)-based analysis is the most widely used post-implant evaluation method [2]. In most institutions, post-implant CT scans are obtained with the patient in the supine position.

Which patient set-up method, supine or prone, is better for prostate external beam radiotherapy (EBRT) has long been a subject of debate [3-7]. Zelefsky *et al*. demonstrated a significant reduction in the dose delivered to the rectum and small bowel with the prone set-up [5], while Bayley *et al*. found doses to the rectal and bladder walls to be higher with the prone set-up [6]. Dosimetric differences were thought to be attributable to inter-fractional organ shape and position changes. The two situations are fundamentally different. For EBRT, the treatment technique and patient position can be decided together, and the treatment can be delivered completely in one or other position.

For prostate brachytherapy with implanted seeds, the patient will be in a variety of positions during the time of highest dose delivery, including supine and prone, but also potentially sitting and being in other upright positions. However, as for post-implant dosimetric assessments, there are no reports describing dosimetric differences resulting from changing positions. Understanding dosimetric result differences among positions, if present, would be useful for evaluating post-implant quality and predicting late complications. This study aimed to assess variability in dosimetric parameters from prone and supine positions at the acquisition of post-implant CT scans.

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Material and methods

Between January 2010 and October 2010, 85 patients with localized prostate carcinoma receiving ^{125}I brachytherapy at the National Hospital Organization Saitama Hospital agreed to participate in this study. The following risk factors related to prostate cancer were assessed: serum levels of prostate specific antigen (PSA), Gleason score, and TNM stage. The subjects were divided into low-risk (T1-2a, PSA < 10 ng/ml and Gleason score ≤ 6), intermediate-risk (T2b, PSA 10-20 ng/ml, or Gleason score = 7), and high-risk (T2c-3, PSA > 20 ng/ml, or Gleason score ≥ 8) groups. Clinically negative lymph nodes or metastasis were confirmed in all 85 study subjects. For the low-risk group, seed implantation alone (monotherapy) was performed, while for the intermediate and high-risk groups, ^{125}I seed implantation at a reduced radiation dose was combined with EBRT (combined therapy). The intermediate-risk group of patients with PSA < 10 ng/ml, Gleason score = 3 + 4, and positive core needle biopsy rates < 33% received monotherapy. Written informed consent was obtained from each patient prior to permanent ^{125}I seed implantation.

Loose ^{125}I radioactive seeds (Oncoseed model 6711®; GE Healthcare, Medi-Physics Inc., Arlington Heights, IL, USA) were implanted in all 85 patients, using a Mick applicator® (Mick Radio-Nuclear Instruments, Inc., Bronx, NY, USA). The mean activity per seed was 0.36 mCi (range, 0.28-0.4 mCi). Implantation was carried out using the interactive ultrasound (US)-guided technique with a peripheral loading pattern. Details of the planning technique were described in a previous report [8]. The planned target volume (PTV) was defined as the entire prostate. The prescribed dose to the PTV was 160 Gy in the monotherapy group, and 110 Gy in the combined therapy group for intraoperative planning.

For post-implant dosimetric analysis, CT scans were performed approximately 4 to 5 weeks after seed implantation. CT scans were obtained in two patient positions, supine and prone, with 64 detector arrays (Aquilion 64®; Toshiba Medical Systems, Corp., Tochigi, Japan). Axial CT images of the pelvic area were taken at a 3-mm thickness and 3-mm intervals. The treatment was planned using the VariSeed 8.0® (Varian Medical Systems, Inc., Palo Alto, CA, USA) planning system. Post-implant dosimetry was performed by one radiation oncologist experienced in prostate brachytherapy and post-implant analysis.

The urethra was generally defined as being at the center of the prostate. Since a urinary catheter was not used for post-implant dosimetry in this study, it was not possible to identify urethral position. In patients with prostatic hyperplasia, we modified the post-implant urethral position by employing intraoperative US findings. The rectum was contoured as a solid structure defined by the outer wall on all the slices showing seeds, without attempting to differentiate the inner wall or the contents. Rectal volumes were outlined from 9 mm above the seminal vesicles to 9 mm below the prostate apex.

The calculated dosimetric parameters included the percent volume of the post-implant prostate receiving 100% and 150% of the prescribed dose (V_{100} and V_{150}, respectively), and the minimum dose received by 90% of the prostate volume (D_{90}). In addition, the minimum doses received by 10% and 30% of the urethral volume (UD_{10} and UD_{30}, respectively) were determined and, as with the rectal dose, were expressed as the rectal volume in cubic centimeters that received > 100% of the prescribed dose (RV_{100}), and the minimum dose received by 2 cc of the rectum (RD_{2cc}), as recommended by AAPM Task Group 137 [9]. As a representing value of bladder dose, the bladder dose was expressed as the minimum dose received by 1 cc of the bladder (BD_{1cc}). To analyze the entire cohort of 85 patients, the delivered doses were converted to percentages of the prescribed dose. To evaluate differences in dosimetric parameters associated with postural change, the dosimetric data obtained with the patient in the supine position for CT were defined as the standard. Group comparisons of prostate volumes and dosimetric parameters were performed using the paired-sample *t* test. The intra-class correlation coefficient (ICC) was calculated as a measure of the linear correlation. Analyses were carried out using SPSS, version 18.0® (SPSS Inc., Chicago, IL, USA). Differences were regarded as statistically significant at $p < 0.05$.

Results

The clinical characteristics of the 85 patients are shown in Table 1. The median serum PSA concentration was 6.9 ng/ml (range: 2.3-20.0 ng/ml). The clinical T stage was T1c-T2a in all patients. Of the 85 enrolled subjects, 44 (51.8%) were classified as low-risk, 33 (38.8%) as intermediate-risk, and 8 (9.4%) as high-risk patients.

The estimated prostate volumes and results of the analysis of dose-volume histograms (DVHs) were compared between prone and supine position dosimetry (Table 2). There was a strong correlation between the estimated post-implant prostate volumes by prone- and supine-position dosimetry (ICC = 0.993). Correlations of the estimated prostate V_{100}, V_{150}, and D_{90} values by prone and supine

Table 1. Clinical characteristics of the 85 patients

Factor	Value
Age	
Median (range)	71 (57–82)
Initial PSA (ng/ml)	
< 10	66 (77.6%)
10-20	18 (21.2%)
> 20	1 (1.2%)
Gleason score	
≤ 6	54 (63.5%)
7	25 (29.4 %)
≥ 8	6 (7.1%)
Radiotherapy	
Seed implant alone	46 (54.1%)
Seed implant + supplemental EBRT	39 (45.9%)
Neoadjuvant hormone therapy	
Yes	30 (35.3%)

PSA – prostate-specific antigen, EBRT – external beam radiotherapy

Table 2. Estimated prostate volumes and dose-volume histograms for prone and supine position dosimetry

	Prone position		Supine position		Mean difference[1]	95% CI[2]	*p* value
	Mean	Range	Mean	Range			
Prostate							
Volume (ml)	22.5	7.9-38.4	22.4	6.8-38.4	0.03	–0.09 to 0.15	0.51
D_{90} (%)[3]	120.3	100.4-148.1	120.1	100.9-145.6	0.15	–0.79 to 1.09	0.76
V_{100} (%)[4]	97.0	90.2-99.9	97.1	90.6-100	–0.08	–0.36 to 0.19	0.56
V_{150} (%)[4]	62.7	32.4-87.1	61.6	30.3-87.3	1.17	–0.10 to 2.46	0.07
Urethra							
UD_{10} (%)[5]	136.1	110.4-176.9	133.3	105.2-170.4	2.72	1.27 to 4.18	< 0.01
UD_{30} (%)[5]	130.9	105.3-170.9	128.7	102.8-157.3	2.29	1.15 to 3.43	< 0.01
Rectum							
RV_{100} (ml)[6]	0.33	0-1.96	0.42	0-1.74	–0.10	–0.13 to –0.06	< 0.01
RD_{2cc} (%)[7]	59.1	33.5-99.9	63.6	36.0-95.0	–3.20	–4.60 to –1.81	< 0.01
Bladder							
BD_{1cc} (%)[8]	79.8	64.7-103.1	79.3	60.9-99.8	0.58	–5.73 to 4.57	0.81

[1]Comparisons with supine position dosimetry, [2]CI – confidence interval, [3]D_{90} – the minimum dose received by 90% of the prostate volume, [4]V_{100} and V_{150} – the percent volume of the post-implant prostate receiving 100% and 150% of the prescribed dose, [5]UD_{10} and UD_{30} – the minimum doses received by 10% and 30% of the urethral volume, [6]RV_{100} – the rectal volume in cubic centimeters that received > 100% of the prescribed dose, [7]RD_{2cc} – the minimum dose received by 2 cc of the rectum, [8]BD_{1cc} – the minimum dose received by 1 cc of the bladder.

dosimetry were also significant (ICC = 0.852, 0.730, and 0.823, respectively; Figs. 1 and 2), but there were no significant differences in prostate dosimetric values.

Differences in the estimated urethral and rectal doses between prone and supine position dosimetry were statistically significant. UD_{10} and UD_{30} were significantly higher in the prone than in the supine position. The RV_{100} and RD_{2cc} values were significantly lower in the prone than in the supine position. The BD_{1cc} for the supine and prone position did not differ significantly ($p = 0.81$). Next, factors associated with increased UD_{10} and decreased RD_{2cc} in the prone position were analyzed. Univariate and multivariate analyses were performed using logistic regression. The factors analyzed were patient age, body mass index (BMI), risk group, the utilization of neoadjuvant hormonal manipulation, the number of seeds inserted, and the post-implant prostate volume in the supine position. Neither univariate nor multivariate analyses (Table 3) identified any significant factors affecting increased UD_{10}, and the only factor significantly associated with decreased RD_{2cc} was the

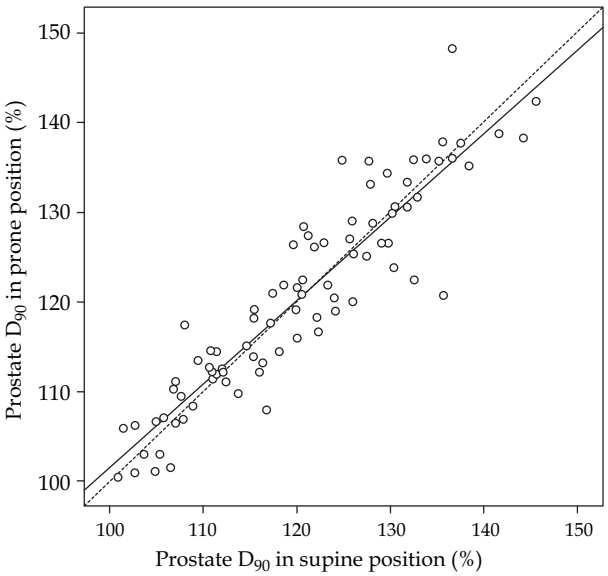

Fig. 1. Scatter plot of prostate D_{90} obtained by CT in the supine and prone positions. The solid line represents best linear fit to the scattered plots, and the dotted line represents the line with a slope of 1

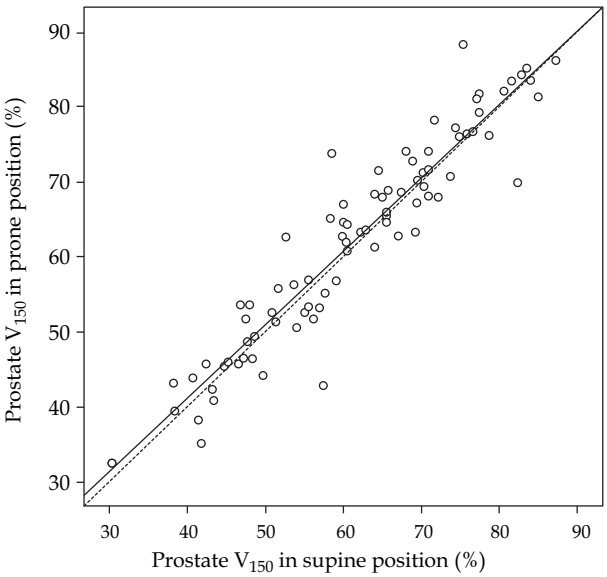

Fig. 2. Scatter plot of prostate V_{150} obtained by CT in the supine and prone positions. The solid line represents best linear fit to the scattered plots, and the dotted line represents the line with a slope of 1

post-implant prostate volume ($p = 0.025$). The post-implant prostate volume was analyzed in two patient subgroups: one in which the prostate volume was < 22 ml and the other in which it was ≥ 22 ml. As shown in Figure 3, the RD_{2cc} difference between the prone and supine positions for prostate volume ≥ 22 ml was significantly smaller than that for prostate volume < 22 ml (mean: –4.73% vs. –1.94%; $p < 0.01$).

To obtain spatial information on rectal doses, sector analyses were performed. We divided the rectum into three regions in the cranial-caudal direction (upper, middle, and lower) and analyzed dose-volume histograms for each region separately. As shown in Table 4, the differences between the prone and supine positions for the RV_{100} and RD_{2cc} varied across the sectors. The RV_{100} differences between the prone and supine positions were significantly smaller for the middle region than for the other sectors, while the RD_{2cc} for the upper and middle regions significantly decreased in the prone position in comparison with supine position. In all of the 5 patients (5.9%) in whom the RD_{2cc} in the prone position were at least 5% higher than the supine position, prostate volume were < 22 ml, and the RD_{2cc} for the middle and lower regions in the prone position were significantly higher than in the supine position based on prostatic rotation.

Discussion

In this study, we employed dosimetric assessments to demonstrate dosimetric changes in the prone versus the supine position after permanent prostate seed implantation for brachytherapy. Previous studies demonstrated differences between the prone and supine positions for EBRT [3, 5-7,10]. The choice of position can alter the external contour of the treated area, and may even alter the spatial relationships among internal organs. In most institutions, post-implant CT scans are performed with patients in the supine position, but patients are not always in this position. Therefore, post-implant dosimetry in the supine position might not reflect the actual doses to the prostate, urethra, and rectum. To the best of our knowledge, this is the first report on dosimetric differences resulting from pelvic anatomical differences between the supine and prone positions. These differences are potentially of major significance for post-implant dosimetric assessments.

Our data indicate that prostate dose coverage in the prone position does not differ significantly from than in the supine position. A rotational or deformational change in the prostate in the supine versus the prone position was reported by Liu *et al*. [3]. Despite such changes, the effect of postural change on post-implant prostate dosimetry seemed to be minimal. A similar pattern was exhibited about bladder dose, because the bladder wall was located in immediate proximity to the base of prostate regardless of postural change. On the other hand, urethral doses were higher in the prone than in the supine position. This was attributed to deformational changes of the prostate. No factors significantly affecting increased UD_{10} were identified. However, since a urinary catheter was not used for post-implant dosimetry in this study, it was not possible to accurately determine urethral doses.

Rectal doses were significantly lower in the prone than in supine position in this study, and the only factor significantly affecting decreased RD_{2cc} was the post-implant prostate volume. We speculate that in the prone position gravity would cause the prostate and seminal vesicles to fall anteriorly creating a significant distance between the prostate and rectal wall. In the study of Wilder *et al*. [11], intra-fractional prostate motion was typically in the anterior direction when patients were treated in the prone po-

Table 3. Multivariate analysis of factors associated with decreased Rectal D_{2cc} in the prone position

Factor	*p* value	Hazard ratio	95% CI for hazard ratio	
			Lower	Upper
Age	0.382	–	–	–
Body mass index	0.926	–	–	–
Risk group	0.533	–	–	–
Hormone therapy	0.826	–	–	–
Number of seeds inserted	0.822	–	–	–
Prostate volume on supine CT	0.025	0.279	0.048	0.335

CI – confidence interval

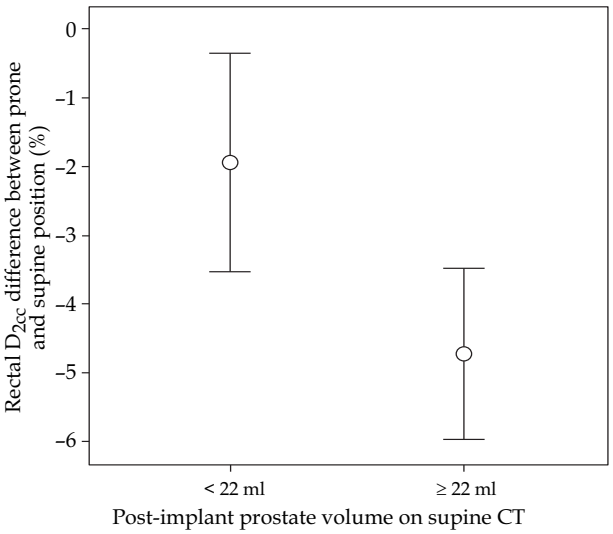

Fig. 3. Rectal D_{2cc} differences between prone and supine positions for patient subgroups with prostate volumes < 22 ml and ≥ 22 ml. Error bars indicate the 95% confidence interval of the mean values

Table 4. Differences in RV_{100} and Rectal D_{2cc} between prone and supine positions by sector analysis

	Upper region	Middle region	Lower region
RV_{100} (ml)	0.02 ± 0.02	–0.08 ± 0.01*	–0.01 ± 0.01
RD_{2cc} (%)	–5.18 ± 0.80*	–3.76 ± 0.86*	1.17 ± 0.54

RV_{100} – the rectal volume in cubic centimeters that received > 100% of the prescribed dose, RD_{2cc} – the minimum dose received by 2 cc of the rectum. Data are presented as mean ± standard deviation

**p < 0.05*

sition. In contrast, prostate motion was typically in the posterior direction when patients were treated in the supine position ($p = 0.02$). Similarly, Nederveen *et al*. [12] reported that intra-fractional prostate motion is typically in the posterior direction when patients are treated in the supine position. When a patient is placed in the prone position, the prostate is pulled away from the rectum by approximately 5 mm, meaning that there is a lower chance of irradiation of healthy rectal tissue while treating the prostate [7]. Gravity may have accounted for a 0.9 to 1.2 mm systematic error [13], and rectal gas for a 1.3 to 2.0 mm random error [14,15] in prostate motion. We speculated that larger BMI values might be associated with increased prostate shifts, thus potentially changing the dose to the rectum depending on treatment position, but there was no correlation between BMI and reduced doses to critical structures in this study.

Previous reports have suggested an association between rectal dosimetric parameters and post-implant rectal toxicities [16-19]. Although comparisons between series are hindered by differences in the timing of post-implant CT scans and variations in the way that rectal doses are described, nearly all investigators have shown a higher incidence of rectal bleeding with higher rectal doses. Snyder *et al*. [16] demonstrated rectal complications to be directly related to the volume of the rectum receiving the prescribed dose after I-125 implantation without EBRT. The 5-year likelihood of being free of Grade 2 rectal complications was 95% if the volume of the rectum irradiated by the prescribed dose (160 Gy) was ≤ 1.3 cc. Kalakota *et al*. [17] reported that observation of strict rectal sparing goals (rectal V_{100} < 0.05 ml) can help to reduce the morbidity of therapy, especially for patients undergoing supplemental EBRT. Providing that such goals are met, EBRT may not necessarily increase the risk of Grade 2 gastrointestinal toxicity. Further investigations will be needed to determine if combining post-implant assessments in the supine and prone positions correlate with occurrence of late rectal toxicity, and when the correlation is proven, it would provide more detailed information allowing the prediction of late rectal toxicity.

Conclusions

Prostate D_{90} assessments did not differ significantly according to postural changes. The results of this study suggest that post-implant rectal doses decrease in the prone position, and a larger post-implant prostate volume was associated with decreased rectal doses in the prone position.

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