Rectal Content and Intrafractional Prostate Gland Motion Assessed by Magnetic Resonance Imaging

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Prostate cancer/Radiotherapy/MRI/Intrafraction/Rectal gas.

We evaluated the interrelationship between rectal content and intrafraction motion of the prostate. Forty-seven prostate cancer patients instructed to remove their rectal gas were imaged by planning CT and MRI before radiotherapy (RT) and during RT. The total scan time was comparable to our cone-beam CT scanning and treatment times. Rectal content was qualitatively assessed into four different categories by T2-weighted axial MRI: empty (Group E), gas (Group G), combination of gas and feces (Group C), and feces (Group F). Eleven anatomic points of interest (POI) were determined on subsequent sagittal cine-MRI slices. The incidence of displacement of more than 3 mm for more than 10% of time (> 10% time over 3 mm) at least in one of the prostate POIs in Group E was 6.3%, Group G 40.9%, Group C 6.3%, and Group F 0%, respectively. Except for Group G, the mean probability of > 3 mm displacement was < 3%. More than 10% time over 3 mm displacement of the superior prostate in the AP direction (SAP) was noted in only Group G patients and was 45.5% before RT and 18.2% during RT. Only Group G patients were significantly related to both the mean of means and the mean of maxs of prostate displacement of SAP by multivariate analysis. Group G patients were also significantly related to the mean of the standard deviation of rectum width of superior rectum and mid-rectum by multivariate analysis. Patients with rectal gas only were significantly related to prostate displacement and rectal movement.

INTRODUCTION

Improved freedom from biochemical and clinical progression for prostate cancer has been achieved by using higher doses,1,2 and smaller margins are required to avoid complications in surrounding critical organs.3 Image-guided radiotherapy (IGRT) is increasingly used to aid precise dose delivery to the target. These image-guidance methods for prostate localization include daily abdominal ultrasound,4,5 cone-beam CT (CBCT) imaging,6 and fiducial markers with an electronic portal imaging device or on-board kV X-ray imaging.7-11 Using these IGRT, the margin required for setup errors and interfractional organ motion is reduced. Intrafraction organ motion has been intensely studied in recent years.12-14 Some studies have monitored intrafraction motion of the prostate in real time during treatment delivery using implanted electromagnetic transponders15,16 or X-ray imaging of implanted fiducial markers.17 Other studies have used anatomic information from serial magnetic resonance imaging (MRI) to evaluate prostate intrafraction motion.13,18-20 Several studies have reported a correlation between the rectal filling status and prostate intrafraction motion by MRI.15,18-20 Rectal gas was recently suggested to be a predictor of prostate intrafraction motion requiring further investigation.13 The objective of this study was to evaluate the interrelationship between rectal gas and intrafraction motion of the prostate using axial images acquired for T2-weighted axial MRI and subsequent sagittal cine-MRI scans. T2 axial MRI images were used to categorize rectal filling. Changes in the position of the prostate and rectum were analyzed using sagittal cine-MRI scans. The total scan time was comparable to our CBCT scanning time and treatment times for intensity-modulated radiation therapy (IMRT) patients. Patients were instructed to remove their rectal gas before MRI scanning by the procedure we previously reported to reduce interfraction motion.21
MATERIALS AND METHODS

Patients
We investigated 47 prostate cancer patients managed with definitive RT between April 2007 and March 2009 at Yokohama City University Medical Center. The age of patients ranged from 60 to 82 (mean 74). All patients were imaged by planning CT and MRI on the initial treatment planning day and at 23 fractions of radiotherapy (RT) as part of an institutional review board–approved study.

MRI
A 1.5 Tesla open MRI system (Magnetom Avanto; Siemens, Erlangen, Germany) was used to collect sequential axial and sagittal images of 47 prostate cancer patients. Patients were instructed to remove their rectal gas before MRI scanning by inserting their index finger and washing their rectum using a bidet-style toilet.21) We did not confirm the time interval between gas removal and MRI scan. Twenty-five axial images were acquired in 2.56 min for T2-weighted turbo spin-echo sequences (TR = 3800 ms, TE = 95 ms, slice thickness = 5 mm, 143° flip angle, matrix 256 × 256, FOV 180 mm, 1.8 mm pixels). Subsequently, HASTE (half-Fourier acquisition single-shot turbo spin echo) techniques were used to obtain a set of sagittal cine-MRI scans (TR 3500 ms, TE 95 ms, slice thickness 8 mm, matrix 206 × 256, FOV 220 mm, total time 7.28 min). One hundred and fifty images were acquired for the cine-MRI sequence.

The total scan time was approximately 10 min for both sequences, which is comparable to our CBCT scanning and matching time of 2.5 min and treatment times for IMRT patients of 7 to 8 min.

Categories of rectal content
T2 axial MRI images were used to categorize rectal filling located from the superior bladder to the prostate apex in a superior-inferior (SI) direction. Rectal content was qualitatively assessed into four different categories: empty (Group E), gas (Group G), combination of gas and feces (Group C) and feces (Group F). The rectum was considered empty if there was no sign of content within the rectal lumen; gas-filled rectums had no signal (dark) within the rectal lumen; a feces-filled rectum had distension and some signal (brightness) within the rectal lumen; and a combination of gas and feces was defined as having both some signal and no signal in the rectal lumen (Fig. 1).

Fig. 1. T2-weighted turbo spin-echo sequences images classified rectal filling. (a) empty, (b) gas, (c) combination of gas and feces and (d) feces.
### Points of interest

The sagittal plane by cine-MRI scans was positioned through the pubic symphysis and the coccygeal bone assessed on the transverse scout image. Displacement over time from the initial location was determined in the anterior-posterior (AP) and SI directions. Changes in the position of the prostate and rectum were analyzed using changes in this coordinate system separately. Eleven anatomic points of interest (POIs) were determined on each cine-MRI slice to characterize the prostate, rectum, and bony pelvis, as represented in Fig. 2. POIs for all image sequences for each patient were identified by one observer (I.O.) and corrected for all patients at least a week later to determine the reproducibility of POI. POI was verified by a single diagnostic radiologist (T.S.) after correction to present how we determined POI. The pubic symphysis superior was used as a bony landmark. The superior prostate (the most superior site of the prostate, usually at the posterior prostate base), apex of the prostate, mid-anterior prostate, mid-posterior prostate, superior anterior rectum, superior posterior rectum, mid-anterior rectum, mid-posterior rectum, inferior anterior rectum, and inferior posterior rectum were tracked. Because of difficulty in tracking rectal points and mid prostate points in the SI direction, displacement of these points was measured only in the AP direction. The superior line of the rectum was fixed at the initial superior prostate in the SI direction and the inferior line of the rectum was also fixed at the initial apex of the prostate in the SI direction. Mid-line of the prostate or rectum was fixed in the middle of the initial superior prostate and initial apex of the prostate in the SI direction. The cine movement studies were analyzed using measurement software PV studio 2D (OA Science, Miyazaki, Japan).

### Prostate displacement

The mean of the means of prostate displacement (MM) was then defined as the mean of the average distance displaced from its initial position in all patients. The mean of max prostate displacement (MX) was then defined as the mean of the maximal distance displaced from its initial position in all patients. We chose a 3-mm displacement of interest because it was the threshold for online setup correction using fiducial markers with CBCT at our institution.

### Rectal movement

The degree of rectal movement was measured between the superior anterior rectum and superior posterior rectum (superior rectum width), mid-anterior rectum and mid-posterior rectum (mid rectum width), and inferior anterior rectum and inferior posterior rectum (inferior rectum width).

### Statistical methods

All statistical analyses were carried out using SAS system version 9 (SAS Institute Inc., Cary, NC, USA). Comparisons

| POI (direction)       | Displacement (mm) before radiotherapy | Displacement (mm) during radiotherapy |
|-----------------------|--------------------------------------|--------------------------------------|
|                       | MM        | SD (MM) | MX        | SD (MX) | maximum | MM        | SD (MM) | MX        | SD (MX) | maximum |
| Superior (AP)         | 0.99      | 0.86    | 2.23      | 1.52    | 7.04     | 0.72      | 0.46    | 1.92      | 1.29    | 6.49     |
| Superior (SI)         | 0.72      | 0.41    | 1.76      | 0.74    | 3.30     | 0.69      | 0.56    | 1.68      | 0.97    | 4.80     |
| Apex (AP)             | 0.61      | 0.32    | 1.36      | 0.60    | 3.26     | 0.65      | 0.37    | 1.46      | 0.64    | 3.09     |
| Apex (SI)             | 0.40      | 0.26    | 1.10      | 0.56    | 3.39     | 0.47      | 0.31    | 1.17      | 0.57    | 2.69     |
| Mid anterior (AP)     | 0.56      | 0.41    | 1.38      | 0.86    | 4.79     | 0.55      | 0.41    | 1.35      | 0.88    | 4.11     |
| Mid posterior (AP)    | 0.81      | 0.56    | 2.25      | 1.38    | 6.11     | 0.81      | 0.47    | 2.01      | 1.26    | 6.03     |

POI: points of interest, AP: anterior-posterior, SI: superior-inferior, MM: mean-of means prostate displacement, SD (MM): standard deviation of mean of mean prostate displacement, MX: mean-of maxs prostate displacement, SD (MX): standard deviation of mean of max prostate displacement.
between groups were carried out using a general linear model. The generalized estimating equation (GEE) approach was used to analyze repeated measurement data. Differences were judged as significant at the 5% (two sides) level.

RESULTS

Prostate displacement

MM and MX in different POI are presented in Table 1. We did not correct for bone displacement, because MM and MX of the pubic symphysis superior were less than 5% of prostate displacement. Of all prostate POI displacement in each group, more than 1 mm MM was noted only in Group G in the superior prostate in the AP direction (SAP) before RT and during RT, and in the mid-posterior prostate in the AP direction (MPAP) before RT. More than 2.2 mm MX was noted only in Group G in the SAP and MPAP before RT and during RT. Results of prostate displacement of each group in SAP and MPAP were presented in Table 2. Compared with the MX in other groups, the MX in Group G was larger

| POI (direction) | Group | Displacement (mm) before radiotherapy | Displacement (mm) during radiotherapy |
|-----------------|-------|---------------------------------------|---------------------------------------|
|                 |       | No | MM | SD (MM) | MX | SD (MX) | maximum | No | MM | SD (MM) | MX | SD (MX) | maximum |
| Superior (AP)   | E     | 9  | 0.73 | 0.48 | 1.63 | 0.89 | 2.85 | 23 | 0.58 | 0.36 | 1.65 | 1.25 | 6.10 |
|                 | G     | 11 | 1.90 | 1.29 | 3.83 | 2.00 | 7.04 | 11 | 1.12 | 0.63 | 2.77 | 1.65 | 6.49 |
|                 | C     | 10 | 0.78 | 0.45 | 2.15 | 1.29 | 4.90 | 6  | 0.60 | 0.26 | 1.66 | 0.75 | 2.65 |
|                 | F     | 17 | 0.66 | 0.36 | 1.57 | 0.63 | 2.94 | 7  | 0.68 | 0.30 | 1.72 | 0.63 | 2.79 |
| Mid posterior (AP) | E     | 9  | 0.87 | 0.55 | 2.29 | 1.38 | 4.84 | 23 | 0.68 | 0.47 | 1.67 | 1.20 | 5.89 |
|                 | G     | 11 | 1.27 | 0.77 | 3.12 | 1.74 | 6.11 | 11 | 0.94 | 0.49 | 2.75 | 1.62 | 6.03 |
|                 | C     | 10 | 0.55 | 0.17 | 1.86 | 1.37 | 5.31 | 6  | 0.97 | 0.55 | 1.95 | 1.07 | 3.58 |
|                 | F     | 17 | 0.63 | 0.39 | 1.88 | 0.92 | 3.32 | 7  | 0.94 | 0.31 | 2.05 | 0.44 | 2.64 |

POI: points of interest, No: Number, AP: anterior-posterior, MM: mean-of-means prostate displacement, SD (MM): standard deviation of mean of mean prostate displacement, MX: mean-of-maxs prostate displacement, SD (MX): standard deviation of mean of max prostate displacement.

Fig. 3. Plot of each patient’s superior prostate displacement in the AP direction over time (before radiotherapy). Patients were classified by rectal filling: (a) empty, (b) gas, (c) combination of gas and feces and (d) feces.
Fig. 4. Plot of each patient’s superior prostate displacement in the AP direction over time (during radiotherapy). Patients were classified by rectal filling: (a) empty, (b) gas, (c) combination of gas and feces and (d) feces.

Table 3. Proportion of time and number of patients with prostate displacement more than 3 mm in different POI.

| POI (direction) | Before radiotherapy | During radiotherapy |
|-----------------|---------------------|---------------------|
|                 | Mean % of time | over 3 mm | No (%) | > 10% time over 3 mm | No (%) | Mean % of time | over 3 mm | No (%) | > 10% time over 3 mm | No (%) |
| Superior (AP)   | 5.9 8 (17.0) | 5 (10.6) | 1.3 6 (12.8) | 2 (4.3) |
| Superior (SI)   | 0.1 4 (8.5) | 0 (0.0) | 1.2 7 (14.9) | 1 (2.1) |
| Apex (AP)       | 0.0 1 (2.1) | 0 (0.0) | 0.0 1 (2.1) | 0 (0.0) |
| Apex (SI)       | 0.5 1 (2.1) | 1 (2.1) | 0.0 0 (0.0) | 0 (0.0) |
| Mid anterior (AP) | 0.2 3 (6.4) | 0 (0.0) | 0.4 3 (6.4) | 1 (2.1) |
| Mid posterior (AP) | 2.6 10 (21.3) | 4 (8.5) | 1.6 7 (14.9) | 4 (8.5) |

POI: points of interest, AP: anterior-posterior, SI: superior-inferior.

Table 4. Proportion of time and number of patients with prostate displacement more than 3 mm in SAP and MPAP.

| POI (direction) | Group | Before radiotherapy | During radiotherapy |
|-----------------|-------|---------------------|---------------------|
|                 |       | Mean % of time | over 3 mm | No (%) | > 10% time over 3 mm | No (%) | Mean % of time | over 3 mm | No (%) | > 10% time over 3 mm | No (%) |
| Superior (AP)   | E     | 9 0.0 0 (0.0) | 0 (0.0) | 23 0.3 | 2 (8.7) | 0 (0.0) |
|                 | G     | 11 24.5 6 (54.5) | 5 (45.5) | 11 4.8 | 4 (36.4) | 2 (18.2) |
|                 | C     | 10 0.5 2 (20.0) | 0 (0.0) | 6 0.0 | 0 (0.0) | 0 (0.0) |
|                 | F     | 17 0.0 0 (0.0) | 0 (0.0) | 7 0.0 | 0 (0.0) | 0 (0.0) |
| Mid posterior (AP) | E     | 9 1.8 2 (22.2) | 1 (11.1) | 23 1.0 | 2 (8.7) | 1 (4.3) |
|                 | G     | 11 9.0 5 (45.5) | 3 (27.3) | 11 3.2 | 4 (36.4) | 2 (18.2) |
|                 | C     | 10 0.6 1 (10.0) | 0 (0.0) | 6 2.7 | 1 (16.8) | 1 (16.7) |
|                 | F     | 17 0.1 2 (11.8) | 0 (0.0) | 7 0.0 | 0 (0.0) | 0 (0.0) |

POI: points of interest, No: Number, AP: anterior-posterior.
### Table 5. Degree of rectal movement.

| Location                  | Group | Before radiotherapy | During radiotherapy |
|--------------------------|-------|---------------------|---------------------|
|                          |       | No | MRW (mm) | SD (mm) | No | MRW (mm) | SD (mm) |
| Superior rectum width    | E 9   | 0.95 | 0.61    |         | 23 | 1.10     | 0.46    |
|                          | G 11  | 2.10 | 1.98    |         | 11 | 1.66     | 0.79    |
|                          | C 10  | 1.16 | 0.76    |         | 6  | 1.34     | 0.59    |
|                          | F 17  | 0.85 | 0.66    |         | 7  | 1.08     | 0.35    |
| Mid rectum width         | E 9   | 0.70 | 0.25    |         | 23 | 0.71     | 0.44    |
|                          | G 11  | 1.08 | 0.74    |         | 11 | 1.18     | 0.72    |
|                          | C 10  | 0.73 | 0.42    |         | 6  | 0.85     | 0.23    |
|                          | F 17  | 0.76 | 0.42    |         | 7  | 0.98     | 0.57    |
| Inferior rectum width    | E 9   | 0.63 | 0.16    |         | 23 | 0.71     | 0.24    |
|                          | G 11  | 0.68 | 0.34    |         | 11 | 0.90     | 0.30    |
|                          | C 10  | 0.78 | 0.22    |         | 6  | 0.57     | 0.18    |
|                          | F 17  | 0.69 | 0.25    |         | 7  | 0.65     | 0.26    |

No: Number, MRW: Mean of standard deviation of rectum width (mean of each individual standard deviation of rectum width during the 7.5 minute measurement period), SD: standard deviation of MRW.

### Table 6. Effects of rectal content on the logarithm of MM and MX of prostate POI.

| POI (direction) | Variable | MM | |  | MX | |
|-----------------|----------|----|----|----|----|---|
|                 |          | Estimate | p-value | Estimate | p-value |
| Superior (AP)   | E        | – | – | – | – |
|                 | G        | 0.3442 | < 0.0001 | 0.2988 | 0.0002 |
|                 | C        | 0.0209 | 0.8223  | 0.0621 | 0.4396 |
|                 | F        | 0.0119 | 0.8534  | 0.0015 | 0.9778 |
|                 | Age      | 0.0066 | 0.3383  | 0.0084 | 0.1573 |
|                 | Before radiotherapy | – | – | – | – |
|                 | During radiotherapy | –0.0889 | 0.0856 | –0.0578 | 0.1911 |
|                 | Intercept | –0.7057 | 0.1773 | –0.4388 | 0.3132 |
| Mid posterior (AP)| E        | – | – | – | – |
|                 | G        | 0.1981 | 0.0026 | 0.1965 | 0.0020 |
|                 | C        | –0.0272 | 0.7390 | –0.0274 | 0.7303 |
|                 | F        | 0.0014 | 0.9816 | 0.0229 | 0.6960 |
|                 | Age      | 0.0064 | 0.3133 | 0.0083 | 0.1139 |
|                 | Before radiotherapy | – | – | – | – |
|                 | During radiotherapy | 0.0099 | 0.8513 | –0.0393 | 0.4289 |
|                 | Intercept | –0.6880 | 0.1331 | –0.3882 | 0.2869 |

Generalized estimating equation (GEE) approach is used to analyze repeated measurement data which has a correlation structure due to using the same patient; the compound symmetry structure was assumed as a working correlation matrix.

MM: mean of means of prostate displacement, MX: mean of maxs of prostate displacement, POI: points of interest, AP: anterior-posterior.
than 1 mm in the SAP and larger than 0.7 mm in the MPAP.
The time course of SAP, relative to the initial superior prostate position (baseline), is presented in Figs. 3 and 4. 30.9% (29/94) of patients had displacement of more than 3 mm at least one of the prostate POIs. The incidence of displacement of more than 3 mm for more than 10% of time (>10% time over 3 mm) for at least one of the prostate POIs in all patients was 12.8% (12/94), Group E 6.3% (2/32), Group G 40.9% (9/22), Group C 6.3% (1/16), and Group F 0% (0/24), respectively. The proportion of time and number of patients with displacement more than 3 mm in different POI are presented in Table 3. Except for MPAP, more than 10% time over 3 mm prostate displacement was noted in only Group G patients. The proportion of time and number of patients with displacement more than 3 mm in SAP and MPAP are presented in Table 4. Except for Group G, the mean probability of >3 mm displacement was <3%. The mean proportion of time that the SAP was displaced >3 mm from its initial position was 5.9% before RT and 1.3% during RT. For Group G, the mean probability of >3 mm displacement of SAP was 24.5% before RT and 4.8% during RT. More than 10% time over 3 mm of SAP was noted in only Group G patients and was 45.5% before RT and 18.2% during RT.

Table 7. Effects of rectal content on the logarithm of the average standard deviation of rectum width.

| POI (direction) | variable | estimate | p       |
|-----------------|----------|----------|---------|
| Superior rectum width | E | – | – |
|                | G       | 0.1982   | 0.0010  |
|                | C       | 0.0548   | 0.4764  |
|                | F       | -0.0494  | 0.3769  |
|                | Age     | 0.0074   | 0.0675  |
| Before radiotherapy | – | – | – |
| During radiotherapy | 0.0779  | 0.0915   |         |
| Intercept       | -0.6168 | 0.0275   |         |
| Mid-rectum width | E | – | – |
|                | G       | 0.1777   | 0.0028  |
|                | C       | 0.0593   | 0.3417  |
|                | F       | 0.0739   | 0.2374  |
|                | Age     | 0.0049   | 0.2084  |
| Before radiotherapy | – | – | – |
| During radiotherapy | 0.0481  | 0.3487   |         |
| Intercept       | -0.5938 | 0.0400   |         |
| Inferior rectum width | E | – | – |
|                | G       | 0.0370   | 0.3513  |
|                | C       | 0.0012   | 0.9791  |
|                | F       | -0.0133  | 0.7339  |
|                | Age     | 0.0055   | 0.0479  |
| Before radiotherapy | – | – | – |
| During radiotherapy | 0.0182  | 0.5622   |         |
| Intercept       | -0.5999 | 0.0055   |         |

Generalized estimating equation (GEE) approach is used to analyze repeated measurement data which has a correlation structure due to using the same patient; the compound symmetry structure was assumed as a working correlation matrix.

Rectal Content and Intrafractional Prostate Motion

The mean of the standard deviation of rectum width (MRW) in 47 patients is presented in Table 5. The largest MRW was in Group G for superior rectum width before RT and the second largest MRW was also in Group G for superior rectum width during RT.

Multiple regression analysis

Multiple regression analysis, used to determine different categories of Group compared to Group E patients (no rectal content) in relation with the MM and MX of prostate POI, is presented in Table 6. Age, before RT vs during RT, and four different categories of rectal content were included in the analysis of displacement of SAP and MPAP. Only Group G patients were significantly related to both MM and MX of SAP and MPAP. Age, before RT vs during RT, and four different categories of rectal content were also analyzed in relation to MRW by multivariate analysis and are presented in Table 7. Only Group G patients were significantly related to the MRW of superior rectum width and mid-rectum width. Before RT vs during RT was not related to MRW.

DISCUSSION

Several studies have reported that for intrafraction prostate motion the prostate moved largely in the AP and SI directions and displacement in the lateral direction was relatively small.17,19,22,23) We investigated the displacement of prostate in AP and SI directions by cine-MRI. Although MRI cannot monitor intrafraction motion of the prostate in real time during treatment delivery, information from volumetric imaging may be valuable to evaluate the relation between prostate intrafraction motion and the rectal status. The link between intrafraction prostate motion and rectal distension has been demonstrated by several authors using cine-MRI with a time window ranging between 9 min and 60 min.13,18,19) Ghilezan et al. divided the rectal filling status into 2 groups: full vs. empty rectum.18) They used a sagittal cine-MRI frame and found that the most significant predictor of intrafraction prostate motion is the status of rectal filling. Mah et al. compared rectal filling with time-averaged motion by axial cine-MRI using the nonparametric
Wilcoxon test and showed a statistically significant difference between motion that occurred with the rectum was empty compared to full \( (p = 0.01) \). We investigated the rectal status using T2 axial MRI images to categorize rectal filling into four different categories: empty, gas, combination of gas and feces, and feces. This scanning time is comparable to our CBCT scanning time and matching time. Subsequently, we investigated prostate and rectum POIs by cine-MRI. This scanning time is also comparable to our treatment times for IMRT. Comparing with other groups the MM in Group G was larger than 1 mm in SAP and larger than 0.7 mm in MPAP. Group G patients were strongly related to the MM and MX of SAP and MPAP by multiple regression analysis. We found that rectal gas was the only significant effect on prostate intrafraction motion.

Shimizu et al. reported that 81% of the movements during daily irradiation were less than 3 mm by X-ray imaging of implanted fiducial markers with a time frame of 3–4 min. Mah et al. found that 60% of all prostate motions were less than 3 mm. In their study, 20 sequential cine-MRI slices were acquired in the sagittal and axial planes through the center of the prostate. Each scan took 9 min. They tracked the posterior, lateral, and superior edges of the prostate on each frame relative to the initial prostate. In our results, 69.1% of all prostate POI motions were less than 3 mm with a time frame of 7.28 min. The probability of > 3 mm displacement increasing with longer treatment times was reported by Ghilezan et al., however, there were differences between those studies and our own study regarding the methodology and we were unable to make a statistical comparison, but the different probability of displacement over 3 mm may have been caused by the different time frame and rectal fullness.

Mah et al. reported that although the effects of interfractional prostate motion are negligible compared to interfractional motion and setup error, 5% of patients will have time-averaged motions of 4 mm or more and further investigation is required to determine this subset of patients for larger margins. In our study, the incidence of > 10% time over 3 mm for at least one displacement of prostate POI motions in Group E was 6.3%, Group G 40.9%, Group C 6.3%, and Group F 0%, respectively. The time frame for the cine-MRI sequence is comparable to our treatment times for IMRT. Intrafractional prostate displacement (> 3 mm) in Group G patients can last more than 10% of the treatment time, which could impact treatment delivery if not taken into account. The importance of displacement movement > 3 mm with rectal gas only was also reported by Nichol et al., who measured prostate movement by POIs on the central sagittal slice of cine-MRI. The cause of prostate motion was determined by qualitative assessments made by an observer. Their causes of intrafraction posterior midpoint displacement movements > 3 mm were rectal gas only (56%), rectal gas and stool (18%), stool only (8%), and bladder (18%). They did not present any additional data of prostate displacement related to rectal gas, including the proportion of time.

Padhani et al. were the first to evaluate the dynamic inter-relationship between rectal distension and rectal movements to determine the effect of rectal movement on the position of the prostatic gland using axial plane cine-MRI with a scanning time of 7 min. Their degree of rectal air/fecal distension of the rectum was graded using a subjective scale of 6 groups and their incidence of rectal movement correlated with the degree of rectal distension. We also investigated the relation of rectal status with changes in rectal width and found that rectal gas only was related to rectal movement and prostate movement by multivariate analysis. In our study, the largest MRW in Group G for superior rectum width before RT and the second largest MRW was also in Group G for superior rectum width during RT. Mah et al. reported that the base of the prostate has a larger amplitude of motion than the apex for interfractional motion and this is presumably because the levator muscles anchor the prostate at the apex. These results are consistent with the study of interfractional motion. Our results suggest that both types of motion result from changes in rectal distension.

Nicol et al. aimed to reduce intrafraction prostate motion by a bowel regimen comprising an anti-flatulent diet and daily milk of magnesia. The proportion of time that the superior prostate was displaced > 3 mm from its initial position was 9.9% without the bowel regimen before RT, 8.1% with the bowel regimen before RT, and 10.9% with the bowel regimen during RT. Langen et al. reported that by using the Calypso four-dimensional localization system averaged over all patients, the prostate was displaced > 3 mm for 13.6% of the 10 min treatment time. Compared with those studies, our results for the proportion of time that the superior prostate was displaced > 3 mm from its initial position was smaller, and was 5.9% before RT and 1.3% during RT. Except for Group G, the probability of > 3 mm displacement was < 3%.

Although the use of bowel relaxants and an anti-flatulent diet and laxatives before cine-MRI have been studied, these bowel regimens could not significantly reduce initial rectal movement or intrafraction prostate motion. We previously reported a method for rectal gas removal by instructing patients to insert their index finger and wash their rectum. The average cross-sectional area (the rectal volume divided by the rectal length) in the rectal gas removal group was significantly smaller. This resulted in reduced interfraction motion and margins for the prostate and seminal vesicles. In this study we have decreased the probability of > 3 mm displacement compared with other studies. Patients were instructed to remove their rectal gas before MRI scanning but we could not confirm the procedure and the time interval between gas removal and MRI scan. Some patients could not adequately remove their rectal gas because the interval between gas removal and MRI scan was prolonged.
In the present study we found that patients with rectal gas only were significantly related to prostate displacement and rectal movement compared with other rectal content. This prostate displacement and rectal movement occurred more in superior prostate and superior rectum and less in apex of the prostate and inferior rectum. Intrafractional prostate displacement (> 3 mm) in patients with rectal gas can last more than 10% of the treatment time, which could impact treatment delivery if not taken into account. In this study we have decreased the probability of > 3 mm displacement compared with other studies by instructing patients to remove their rectal gas before MRI scanning. We recommend rectal gas evacuation rather than stool evacuation to reduce intrafractional prostate motion for IGRT patients. Additional research is required to evaluate the effect of rectal gas removal by patients to reduce intrafractional motion of the prostate.

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