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Preferred treatment position between supine and prone for pelvic radiation therapy; quantification of the intrafractional body motion component by 3D surface imaging system

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Original Article

Abstract

Purpose: We investigated the preferred treatment position between supine and prone during pelvic radiation treatment using real time tracking data from AlignRT. Our findings will provide valuable information regarding the role of intrafractional body motion in answering the question of prone versus supine position for pelvis radiation. **Methods:** Ten patients receiving pelvic radiation were enrolled in this study. For each patient, two simulation helical CT scans were performed, one in supine and one in prone position. Body surface contours were automatically generated and then exported to the AlignRT system as reference images. AlignRT continuous patient body motion tracking (1.5 to 2 minutes) was performed for both positions for each patient once per week for five weeks. The equivalent patient body motion along three principle directions was calculated from the six degree of freedom real time patient displacements data. The maximum and the standard deviation (STD) of equivalent patient body motion were calculated, so as the average of maximum and STD of equivalent patient motion over five fractions. These were then compared between supine and prone orientations. **Results:** A correlation was observed between the intrafractional body motion and large BMI. For overweight/obese patients, the intrafractional body motion was smaller for the supine position in both vertical and longitudinal directions. For normal range BMI patients, we observed no clear advantage for either supine or prone position in both vertical and longitudinal directions. In lateral direction, the intrafractional motion did not have statistically difference between two positions. **Conclusion:** Our study shows that the amount of intrafractional body motion between supine and prone orientation is correlated with patient BMI. Overweight/obese patients experienced significantly less overall body motion in supine orientation. The preferred treatment position for normal BMI patients was seen to be individually variable.

Keywords: AlignRT, Intrafractional motion, Supine, Prone

1. Introduction

It is an ongoing question to investigate whether to treat certain pelvic patients in supine or prone position.[1-4] In addition to dosimetric differences, the magnitude and variation of inter- and intrafractional motion of target and organs at risk (OARs) plays a very important role in this debate. Supine vs prone patient position may alter the relative internal geometry between target and OARs, which can subsequently affect the quality of achievable treatment plan.[5-6] But supine versus prone positioning can also have important implications for how much the target and internal organs move together from day to day (interfractional motion), and also from moment to moment (intrafractional motion). To answer this question, researchers have studied inter- and intrafractional motion of bony anatomy for pelvic patients using electronic portal imaging (EPID) and the

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stereo-planar ExacTrac system.[7-8] Such studies have shed valuable light on the question of patient motion, but are limited by the fact that both EPID and ExacTrac systems operate by taking single, 'snapshot' radiographs of patient position at specific moments in time. Additionally, because each image delivers radiation dose to the patient, the number of images acquired must be limited to manage patient exposure.

Intrafractional motion of the target and OARs in pelvis RT is generally comprised of two components: Patient body motion and independent, internal organ motion (not correlated with body motion). Because any motion of the body during treatment will reposition all structures, both target and OAR's, body motion arguably holds the greatest potential for negatively impacting the overall quality of the delivered radiation treatment. And supine vs prone positioning is very likely to have important implications for how stable the entire patient body is.

In this study, we investigated intrafractional body motion for both supine and prone patient positions during pelvic radiation therapy by using a 'continuous' acquisition (up to 7 frames per second), 3-dimensional (3D) surface imaging system - AlignRT® (Vision RT, London, UK). Multiple studies have shown that AlignRT is an accurate and effective surface imaging system, and also an effective image guidance modality for multiple radiation therapy treatment sites, including breast and intracranial stereotactic radiosurgery (SRS).[9-15] The general advantages of a surface imaging approach are three fold: no radiation imaging dose delivered, availability of 'complete' 3D surface information versus a few limited marker positions, and multi-frame per second 'continuous' patient motion tracking during radiation treatment.

This is the first study that we are aware of investigating intrafractional body motion during pelvic radiation treatment using what can be reasonably described as "real time" tracking data from a 3D surface imaging system. Our findings will provide valuable information regarding the role of intrafractional motion in answering the question of prone versus supine position for radiation treatment of the pelvis.

2. Methods and Materials

Ten patients with gynecologic or gastrointestinal malignancies treated at our center were enrolled and analyzed in this IRB approved study (IRB #39913); six were treated in supine position and four were treated prone. Median age was 60 (range 28 - 85), median height was 165.6 cm (range 150.0 – 185.0 cm), median weight was 153 lbs (range 99 - 211 lbs), and median body mass index (BMI) was 25.1 kg/m^2 (range 19.7-32.1 kg/m^2). Individual patients' BMIs are listed in Table 1.

In this study, two simulation helical CT scans were performed, one in supine and one in prone position, for each patient on a GE LightSpeed RT CT scanner (GE Health Care, Waukesha, WI). In the supine position, patients were immobilized using alpha cradles; in the prone position, patients were immobilized in a prone belly board (Radiation Products Design, Albertville, MN). After the CT images were imported into the treatment planning system, body surface contours were automatically generated and then exported to the AlignRT system as reference images. It is noted that this process was performed for both CT data sets.

On the treatment day, once patients were aligned to their treatment position using skin marks and room lasers, the AlignRT system was initiated to record continuous patient body motion tracking for 1.5 to 2 minutes (two non-HD camera system, software version 4.5). The AlignRT software continuously compares the real-time topographic surface contour with the reference body surface contour generated from initial simulation CT (within the user defined region of interest), and the 6 degree of freedom (6DOF) real time patient displacements (translations and rotations) along/around vertical, longitudinal and lateral axes are calculated and displayed on the system screen. The region of interest (ROI) in this study was defined over the pelvic region while excluding the legs, to eliminate discrepancies stemming from minor day to day leg position variation. The lateral portion of the pelvis surface anatomy, above the alpha cradle / prone belly board, was also included in the ROI for more accurate vertical alignment.

After treatment of the patient in the planned treatment position, the patient was then set up in the alternate orientation, e.g., supine if treated in prone position. For purposes of measuring the intrafractional motion in the alternate treatment orientation, AlignRT real time patient body displacement tracking was again recorded for 1.5 – 2 minutes, in the same way as for the treated orientation. These procedures were performed for each patient once a week for five weeks, resulting in 10 total sets of displacement tracking for each patient (5 supine, 5 prone), for a total of 100 intrafractional motion data sets. In an effort to characterize the 'noise' introduced to the tracking signal by the AlignRT tracking process we also collected two minutes of tracking data for a static anthropomorphic phantom.

If the AlignRT-generated 6DOF translational and rotational body displacements are represented using x, y and z for the lateral, longitudinal and vertical directions and α, β, and γ for pitch, yaw and roll respectively, an equivalent set of translations for body motion can be calculated using the equations below[16], where X, Y and Z represent the equivalent motion in the lateral, longitudinal and vertical directions respectively.

$$X = (\cos\beta\cos\gamma - \sin\beta\cos\alpha\sin\gamma)\mathbf{x} + (\sin\beta\cos\gamma + \cos\beta\cos\alpha\sin\gamma)\mathbf{y} + \sin\alpha\sin\gamma\mathbf{z}$$

$$Y = -(\cos\beta\sin\gamma + \sin\beta\cos\alpha\cos\gamma)\mathbf{x} - (\sin\beta\sin\gamma - \cos\beta\cos\alpha\cos\gamma)\mathbf{y} + \sin\alpha\cos\gamma\mathbf{z}$$

$$Z = \sin\beta\sin\alpha\mathbf{x} - \cos\beta\sin\alpha\mathbf{y} + \cos\alpha\mathbf{z}$$

The maximum equivalent patient body motion and the standard deviation (STD) of equivalent patient body motion were calculated for each fraction in vertical, longitudinal and lateral directions for both supine and prone orientations of each patient. The maximum equivalent motion represents the body motion magnitude and the STD represents a measure of the amplitude of the continuous patient body motion. The average of maximum and STD of equivalent patient motion over five fractions were also calculated for each patient in all three principle directions. These were then compared between supine and prone orientations. The idea of averaging maximum motion and the STD of motion is to condense the patient motion and relative amplitude of the continuous patient motion to two single values for each patient, and these two numbers were then used for comparison of patient body motion in supine versus prone orientations.

3. Results

Analysis of the static phantom tracking data showed that a maximum noise level of 0.4 mm was introduced by the tracking system along vertical, longitudinal and lateral directions (mean = 0.18, 0.05, 0.04 mm, respectively). Because the average patient motion in this study ranged from 1.2 mm to 18.9 mm in all three principal directions, we deemed the noise component small enough to ignore for these patient measurements.

During data analysis, it was observed that the amplitude of equivalent patient motion along lateral direction was much smaller than it was along vertical and longitudinal directions. Additionally, there was no significant difference of equivalent patient lateral motion between supine and prone patient position. The averaged maximum equivalent lateral motion for all patients was 2.4 mm and 3.5 mm for supine position and prone position, respectively. Therefore, the lateral motion was excluded from further data analysis.

Table 1 shows the averaged maximum equivalent patient motion and the STD of equivalent patient motion along vertical and longitudinal directions for both supine and prone positions for each patient over the five-week treatment.

Table 2 shows the difference between the averaged maximum equivalent patient motion and STD of equivalent patient motion between supine and prone positions for each patient over the five weeks of treatment, with positive numbers indicating that the motion is larger for supine orientation, and negative numbers meaning that the patient motion is larger for prone orientation. The data was used to identify a "Preferred patient treatment position", defined as the position with minimal intrafractional body motion (column 4).

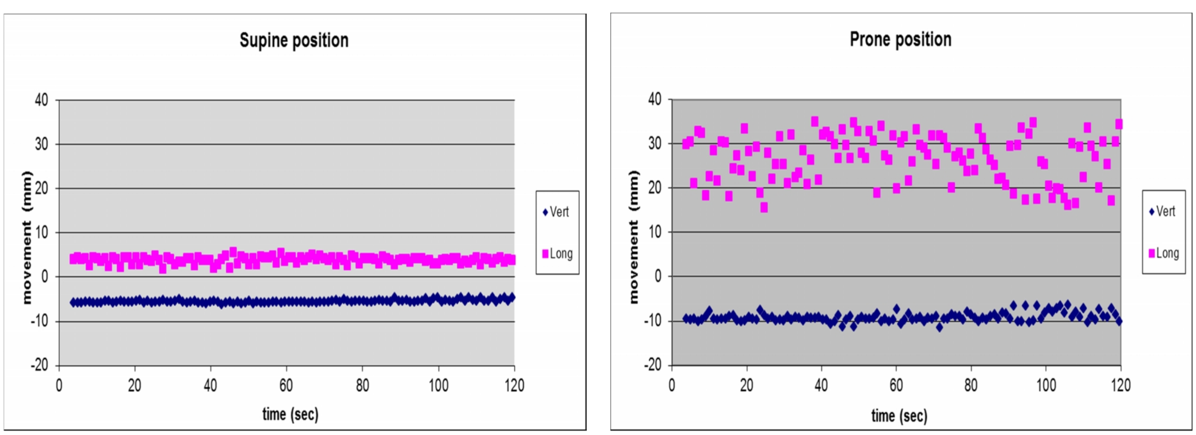

Figure 1: Supine and prone equivalent position displacement tracked by AlignRT for patient #7 (BMI 29.2) on week 3. The ranges of the equivalent motion were smaller for the supine position.

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Table 1: Averages over five-week treatment of maximum equivalent patient translational motion, and standard deviation (STD) of equivalent patient translational motion along vertical and longitudinal directions for supine and prone positions.

Patient number	BMI (kg/m^2)	Average	Supine position average (mm)		Prone position average (mm)	
			Vert	Long	Vert	Long
1	19.7	Max motion	5.2	8.6	2.9	3.1
		STD	1.22	1.66	0.70	0.60
2	21.0	Max motion	3.1	4.1	2.5	3.2
		STD	0.70	1.07	0.58	0.79
3	21.1	Max motion	2.3	3.3	3.4	16.5
		STD	0.41	0.55	0.60	2.47
4	22.2	Max motion	1.5	6.6	1.9	4.9
		STD	0.29	1.29	0.43	0.98
5	23.2	Max motion	4.3	5.3	2.8	2.1
		STD	0.98	1.03	0.71	0.40
6	23.2	Max motion	1.7	6.3	2.0	12.4
		STD	0.41	1.19	0.44	2.71
7	29.2	Max motion	1.9	4.8	7.2	13.2
		STD	0.41	0.94	2.15	2.81
8	29.6	Max motion	1.9	5.4	3.4	9.7
		STD	0.41	1.30	0.74	2.29
9	30.0	Max motion	1.6	2.1	3.1	9.6
		STD	0.38	0.46	0.66	1.96
10	32.1	Max motion	3.3	4.0	4.5	7.1
		STD	0.64	0.73	0.99	1.32

Table 2: Difference of averages over five-week treatment of maximum equivalent patient motion and standard deviation (STD) of equivalent patient motion along vertical and longitudinal directions between supine and prone positions, and preferred patient treatment position. Positive number means that the patient motion is larger for supine position; negative number means that the patient motion is larger for prone position. Preferred patient treatment position was defined with minimal intrafractional motion.

Patient Number (#)	BMI (kg/m^2)	Difference of averaged max motion between supine and prone position (mm)		Difference of averaged STD of motion between supine and prone position (mm)		Preferred treatment position
		Vert	Long	Vert	Long	
1	19.7	2.2	5.5	0.52	1.06	Prone
2	21.0	0.6	0.9	0.13	0.28	Prone
3	21.1	-1.1	-13.2	-0.19	-1.93	Supine
4	22.2	-0.4	1.8	-0.14	0.31	Supine/Prone
5	23.2	1.4	3.2	0.27	0.63	Prone
6	23.2	-0.3	-6.1	-0.02	-1.52	Supine
7	29.2	-5.3	-8.4	-1.74	-1.87	Supine
8	29.6	-1.5	-4.3	-0.32	-0.98	Supine
9	30.0	-1.5	-7.5	-0.28	-1.50	Supine
10	32.1	-1.2	-3.1	-0.35	-0.58	Supine

Using guidelines from the Obesity Society[17, 18], the ten patients in this study were further divided into two groups: normal BMI patient (BMI less than 25, patient #1 to #6), and overweight/obese patient (BMI over 25, patient #7 to #10). In this study, a correlation was observed between the intrafractional motion and large BMI. For all four overweight/obese patients (patients #7 to #10), the intrafractional body motion was smaller for the supine position, as indicated by both translational body motion vectors along vertical and longitudinal directions (Table 1), and also note, all numbers in Table 2 (patient #7 to #10) are negative. Statistical analysis using a two-tailed t-test showed that the difference between supine and prone positions for all patients was statistically significant ($P \leq 0.05$).

Figure 1 shows a typical weekly motion-tracking data-stream for an overweight patient (patient #7 with BMI 29.2) in both supine and prone position for one fraction. As shown in the figures, the equivalent patient body motion ranges were much larger in the prone position compared to supine position.

For six patients with a BMI in the normal range, we observed no clear advantage for either supine or prone position. Patient #1, #2, and #5 showed the motion

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ranges for supine position were larger than for prone position. Patient #3 and #6 showed the opposite: the motion ranges for prone position were larger than for supine position. Patient #4 showed the motion range in prone position was larger than for supine position in vertical direction, and the motion range in supine position was larger than for prone position in longitudinal direction.

4. Discussion

The most important finding of this study is that for all overweight/obese patients observed here, the intra-fractional body motion was significantly smaller for the supine orientation. This seems reasonable when we consider that for overweight/obese patients it may be more difficult to remain stable over time when positioned prone on their (typically) large abdominal region, particularly in the presence of normal respiratory motion. For patients with a BMI in the normal range, results were mixed, with no clear advantage for either supine or prone orientation.

Additionally, we have accurately quantified intra-fractional body motion, which contributes significantly to the overall intrafractional motion of the target and organs at risk, using real-time surface tracking data. Certainly there is correlation of intrafractional body motion with the motion of the internal organs of interest (Target and OARs). However, the degree of this correlation remains a topic worthy of future work.

5. Conclusion

The results from our study show that the amount of intrafractional body motion between supine and prone orientation during pelvic radiation therapy is correlated with patient BMI. Overweight / obese patients experienced significantly less overall body motion when positioned in the supine orientation. Therefore, with regard to treatment position stability, this study suggests against treatment of obese patients in prone orientation, as the intrafractional motion vector range for prone treatment orientation could be as much as 1.6 cm along the longitudinal direction. The preferred treatment position for normal BMI patients was seen to be individually variable.

Conflict of Interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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