

Comparison of Interfractional Setup Reproducibility between Two Types of Patient Immobilization Devices in Image-Guided Radiation Therapy for Prostate Cancer

Shoki Inui¹, Yoshihiro Ueda^{1,2}, Shingo Ohira^{1,3}, Masaru Isono¹, Akira Masaoka¹, Seiya Murata¹, Yuya Nitta¹, Tsukasa Karino¹, Masayoshi Miyazaki¹, Teruki Teshima¹

¹Department of Radiation Oncology, Osaka International Cancer Institute, Osaka, Departments of ²Radiation Oncology and ³Medical Physics and Engineering, Osaka University Graduate School of Medicine, Suita, Japan

Abstract

Purpose: The aim of this study is to compare the interfractional setup reproducibility of two types of patient immobilization devices for prostate cancer receiving image-guided radiation therapy (IGRT). **Materials and Methods:** The MOLDCARE (MC) involves hydraulic fixation, whereas the BlueBAG (BB) and Vac-Lock (VL) involve vacuum fixation. For 72 patients, each immobilization device was individually customized during computed tomography (CT) simulation. Before the treatment, bony registration was performed using orthogonal kV images and digitally reconstructed radiographs. The shift of the treatment couch was recorded as a benchmark in the first session. In subsequent sessions, the shifts from the benchmark were measured and analyzed. Soft-tissue registration was performed weekly by cone-beam CT and CT images, and the shifts were measured and analyzed. **Results:** In the superior-inferior and left-right directions, there were nearly no changes in the overall mean among the immobilization devices. In the anterior-posterior (AP) direction, the overall mean for the MC, BB, and VL were 0.34 ± 1.33 , -0.47 ± 1.27 , and -1.82 ± 1.65 mm, respectively. The mean shifts along the AP direction were approximately 1 mm more in patients immobilized on the BB and 2.5 mm more in those on the VL, compared to those on the MC, after the twentieth treatment. No significant changes were observed among the patients immobilized on those devices, respectively, in soft-tissue registration. **Conclusion:** It can be concluded that the settling of the vacuum fixation was caused by air leakage in the latter-half treatment, and the immobilization device type has no effect on the treatment-position reproducibility in IGRT.

Keywords: Hydraulic fixation, image-guided radiation therapy, immobilization device, setup error, vacuum fixation

Received on: 15-02-2018

Review completed on: 26-09-2018

Accepted on: 26-09-2018

INTRODUCTION

Intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) are being extensively used to treat prostate cancer.^[1,2] These techniques can create a steep dose gradient, which increases the target dose and decreases the irradiated volume of the normal tissue and organ at risk (OAR), such as the rectum and bladder.^[3-5] Therefore, geometrical uncertainties such as patient-setup variation, internal-organ movement, and target delineation should be controlled within limits in IMRT and VMAT.^[6]

These uncertainties are classified into systematic and random errors, which require the precise design of the treatment margin.^[7,8] Treatment margin determination is complicated because this margin must be sufficiently large to incorporate

geometrical uncertainties, but sufficiently small to limit the exposure of normal tissue within the tolerated levels. With respect to the reduction of the treatment margin, it is critical to use suitable immobilization devices for the patient.

Immobilization devices play a key role in high-precision radiation therapy because they assist patients in constantly maintaining their posture during therapy. Recently, there are many immobilization devices for the pelvic region, and the

Address for correspondence: Mr. Yoshihiro Ueda,
Department of Radiation Oncology, Osaka International Cancer Institute,
3-1-69, Otemae, Chuo-ku, Osaka 537-8511, Japan.
E-mail: ueda-yo@mc.pref.osaka.jp

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How to cite this article: Inui S, Ueda Y, Ohira S, Isono M, Masaoka A, Murata S, *et al.* Comparison of interfractional setup reproducibility between two types of patient immobilization devices in image-guided radiation therapy for prostate cancer. *J Med Phys* 2018;43:230-5.

Access this article online

Quick Response Code:



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DOI:
10.4103/jmp.JMP_20_18

setup-error reduction for these devices has been studied in the past.^[9-12] Some reports have indicated that the use of the Alpha Cradle and Uvex cast, which perform as representative immobilization devices, significantly reduces the setup errors compared to a free setup for prostate cancer patients.^[9-11] Lee *et al.* have addressed that in patients immobilized with pelvic thermoplastics, the interfractional variability was reduced, compared to nonimmobilized patients.^[12] However, there are very few studies comparing the proportion of interfractional setup errors between different types of immobilization devices. Therefore, we investigate interfractional setup reproducibility of two types of immobilization devices: the hydraulic and vacuum fixations, which are extensively used for IMRT and image-guided radiation therapy (IGRT) in prostate cancer patients. The hydraulic fixation is a throwaway, whereas the vacuum fixation is reusable for each patient. Amro *et al.* suggested that the rotational setup error should be managed within tolerance.^[13] Certain treatment couches cannot correct the rotational setup error in IGRT. Therefore, this study also aims to compare the rotational setup errors of two types of immobilization devices in IGRT for prostate cancer.

MATERIALS AND METHODS

Patient characteristics

Between August 2007 and February 2016, 72 patients with T1–T3 prostate cancer received IGRT in our institute. The mean value of the patients' age was 68.4 (53–84) years and that of their weight was 63.7 (45.2–81.0) kg.

Immobilization devices

During computed tomography (CT) simulation, immobilization devices were fixed to each patient. Twenty-four patients were immobilized on the MOLDCARE (MC) RI II-BR (ALCARE, Tokyo, Japan), 24 on the BlueBAG (BB) (Medical Intelligence, Schwabmuenchen, Germany), and the others on the Vac-Lock (VL) (Civco Medical Solutions, Iowa, USA). The selection was not based on the tumor stage or body habitus. The MC is hydraulic fixation composed of polystyrene beads and hydraulic urethane resin [Figure 1a]. It was individually customized, constructed on the Hipfix[®] (Civco Medical Solutions, Iowa, USA) by adding a small quantity of water and conformed to the patient's body. A thermoplastic sheet was heated in a water bath and stretched and molded to the patient's body and rigidly locked into the Hipfix at each therapy. The BB and the VL are vacuum fixations and made of beads and nylon. At each therapy, the BB was individually customized by extending it from the mid-thorax to below the feet and rigidly locking into the couch [Figure 1b]. The VL was individually customized and constructed and rigidly locked into the Hipfix at each therapy [Figure 1c]. Patients immobilized with the MC or VL used leg support and pillows. After the immobilization devices were fixed, a treatment-planning CT scan using a GE LightSpeed instrument (16 slices, General Electric Co., Waukesha, WI) was performed with 2.5 mm thickness, and skin marks were placed on the patient's body.

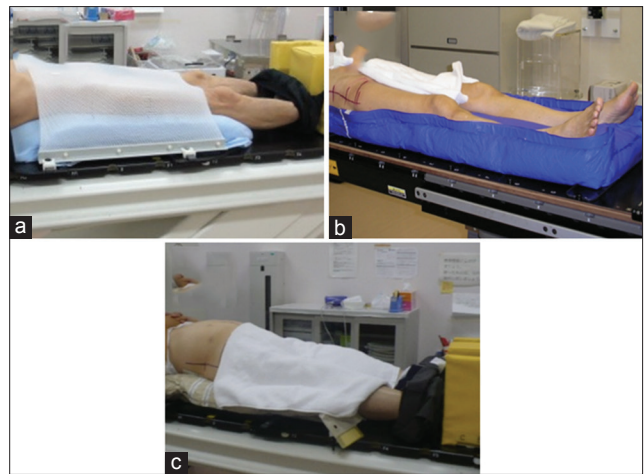


Figure 1: Two types of immobilization devices for prostate cancer patients. (a): MOLDCARE (b): BlueBAG (c): Vac-Lock. The MOLDCARE is a hydraulic fixation, whereas the BlueBAG and Vac-Lock are vacuum fixations

Treatment planning

Treatment planning was performed with the Eclipse planning system (version 11, Varian Medical Systems, Palo Alto, CA, USA), using the analytical anisotropic algorithm for dose calculation with inhomogeneity corrections. The target volumes and OARs (i.e., the rectum, bladder, and small and large bowels) were contoured by radiation oncologists, following the recommendations in Reports 50 and 62 of the International Commission on Radiation Units.^[6,14] All the patients were treated with 6-MV photons in a one-arc VMAT and received a dose of 74 Gy in 37 fractions. The delivered doses were set at the mean of the planning target volume.

Treatment and data analysis

The treatment was delivered using a Varian 23EX linear accelerator equipped with a gantry-mounted on-board imager (Varian Medical Systems). Figure 2 illustrates the workflow for the treatment and analysis. In the first treatment session, each patient was aligned using skin marks, by an in-room laser. Thereafter, bony registration was performed by means of a pair of orthogonal kilovoltage X-ray image and corresponding digitally reconstructed radiographs generated from the CT image during simulation, and the shift of the treatment couch was measured as an interfractional setup error. The position of the treatment couch after the registration was recorded as a benchmark. In subsequent sessions, patients were positioned on the benchmark after skin-mark alignment and the shifts were measured. In addition, soft-tissue registration was performed weekly using the cone-beam CT (CBCT) and CT images during simulation. The rotational shifts in the patients immobilized on each device were calculated by the offline review (Varian software), by matching the CBCT and CT images during simulation.

Statistical analysis

To determine the remaining position errors in each immobilization device, the parameters were calculated using

the method introduced by van Herk *et al.*^[7,15] The mean errors and their standard deviation (SD) in each direction, for each patient, were calculated. The overall mean (μ) was calculated by averaging the mean and the systematic errors (Σ) were calculated by calculating the SD values of the mean errors. The random errors (σ) were calculated by calculating the root mean square of the SD values of the mean errors. One-way analysis of variance was used for comparing the overall mean (μ) in each direction for each immobilization. The statistical significance was tested using Student's *t*-test between pairs of immobilization devices. $P < 0.05$ was considered to be statistically significant.

RESULTS

A total of 5328 X-ray images from 72 patients were obtained in this study. Table 1 presents a summary of the daily shifts from the benchmark in the image-guided session for patients immobilized on the MC, BB, and VL. In the superior-inferior (SI) and left-right (LR) directions, there

were nearly no changes in the overall mean among the immobilization devices. In anterior-posterior (AP) direction, the overall mean of the VL was significantly greater than those of the MC and BB in the negative side. The systematic errors in the VL were greater than those in the MC and BB. The random errors were approximately 1–4 mm and in agreement with the previously reported random errors for prostate cancer patients, though the previous report was different from our report in the physique of patients and the immobilization methods.^[16]

Figure 3 illustrates the daily mean shifts in every treatment session for each immobilization device. The mean shifts of the VL, along the SI and LR directions, had greater fluctuations than those of the MC and BB. Moreover, the mean shifts along the AP direction were approximately 1 mm more for patients immobilized on the BB and 2.5 mm more for those on the VL, compared to those on the MC, after the twentieth treatment. To assess whether there is a significant change in the AP direction

Table 1: Patient setup variation for three immobilization devices

	μ (mm)	SD (mm)	Σ (mm)	σ (mm)	<i>P</i> versus MC	<i>P</i> versus BB
AP						
MC	0.34	1.33	1.98	1.98	-	-
BB	-0.47	1.27	1.73	1.73	0.13	-
VL	-1.82	1.65	1.93	2.20	<0.05	<0.05
SI						
MC	0.75	2.20	2.34	2.25	-	-
BB	0.36	1.96	1.47	1.83	0.50	-
VL	0.04	3.38	4.36	4.63	0.48	0.73
LR						
MC	0.48	1.56	1.41	1.66	-	-
BB	0.65	1.29	1.38	1.34	0.67	-
VL	0.00	3.42	3.31	4.84	0.15	0.09

AP: Anterior-posterior, SI: Superior-inferior, LR: Left-right, μ : Overall mean, SD: Standard deviation, Σ : Systematic error, σ : Random error, MC: MOLDCARE, BB: BlueBAG, VL: Vac-Lock

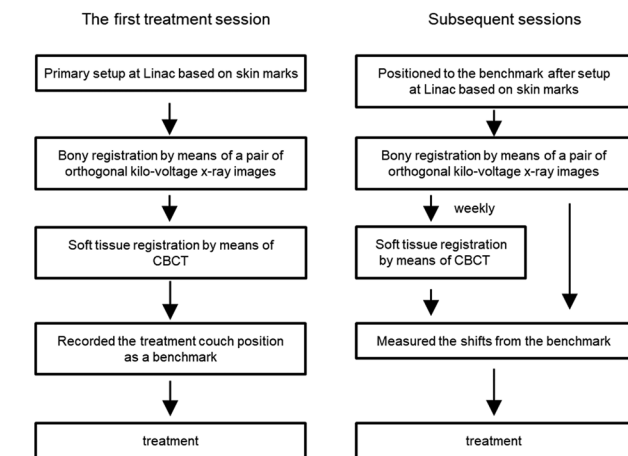


Figure 2: Workflow for treatment and analysis of patients immobilized on each device

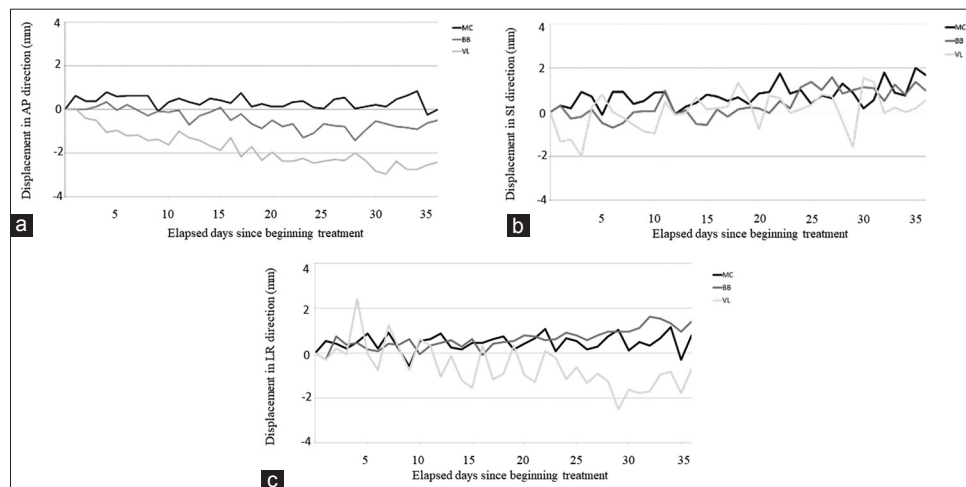


Figure 3: Displacement of the mean shifts in every treatment session for each immobilization device in the (a) anterior-posterior, (b) superior-inferior, and (c) left-right directions. The black line is the MOLDCARE, the dark gray is the BlueBAG, and the light gray is the Vac-Lock

among the different immobilizations, we investigated the shifts in the first- and latter-half series [Table 2]. The mean shifts in the latter-half series of treatment were greater than those in the first-half series, for patients immobilized on the BB and VL. There were no significant changes between the BB and the MC; however, the difference of the overall mean was approximately 1 mm. There were nearly no changes in the systematic and random errors among the three immobilization devices.

A total of 576 CBCT studies were available for this report. The analysis of soft-tissue registration after bony registration, from the CBCT images, is presented in Table 3. No significant changes were observed among the patients immobilized on each device in the overall mean, and the systematic and random errors. Table 4 illustrates the rotational mean shifts in the pitch, yaw, and roll for the patients immobilized on each device, by matching the CBCT scans with the planning CT scans during the offline review. No differences were found among the rotational shifts for each device. The absolute values of the overall mean of the pitch correction for the MC, BB, and VL were 0.46 ± 0.28 , 0.52 ± 0.28 , and $0.64 \pm 0.39^\circ$, respectively, those of the roll correction were 0.38 ± 0.26 , 0.45 ± 0.25 , and $0.47 \pm 0.30^\circ$, respectively, and those of the yaw correction were 0.32 ± 0.24 , 0.24 ± 0.18 , and $0.38 \pm 0.30^\circ$, respectively.

DISCUSSION

In recent years, several immobilization devices have been developed for enhancing the accuracy of the patient setup in high-precision radiation therapy such as IMRT and IGRT. It is obvious from several reports that these immobilization devices significantly improve the setup errors in contrast to a free setup in the pelvic region.^[9-12] In 2000, a comparison of the patient-setup accuracy among three immobilizations, in three-dimensional conformal radiation therapy for prostate cancer, was reported.^[17] However, the patient-setup reproducibility between different types of immobilization devices used for IMRT and IGRT has not been explored in detail in recent studies. For this reason, this study aims to examine the interfractional setup reproducibility of two types of immobilization devices in IGRT for prostate cancer. As certain high-precision radiation therapy devices cannot completely correct the rotational setup error in IGRT, it is important to evaluate rotational setup error in different types of immobilization devices. In this regard, the present study was also undertaken to investigate the rotational setup error in two types of immobilization devices.

In this analysis, the interfractional setup errors for all the treatments were examined using the X-ray images in bony registration among three patient immobilization devices: the MC (hydraulic fixation) and the BB and VL (vacuum fixation) [Figure 1]. There were nearly no significant differences in the μ among the three devices in the SI and LR direction [Table 1]; however, daily deviations along the SI and LR directions in the VL were greater than those in the MC and BB [Figure 3]. This may be because the treatment position of the patient slid

Table 2: Patient setup variation for anterior-posterior direction in the first half versus latter half

AP	μ (mm)	SD (mm)	Σ (mm)	σ (mm)	P versus MC	P versus BB
First half						
MC	0.43	1.26	1.89	1.33	-	-
BB	-0.17	1.14	1.85	1.16	0.27	-
VL	-1.28	1.44	1.81	1.93	<0.05	<0.05
Latter half						
MC	0.25	1.32	2.14	1.38	-	-
BB	-0.81	1.12	1.78	1.21	0.06	-
VL	-2.43	1.48	2.21	2.01	<0.05	<0.05

AP: Anterior-posterior, μ : Overall mean, SD: Standard deviation, Σ : Systematic error, σ : Random error, MC: MOLDCARE, BB: BlueBAG, VL: Vac-Lock

Table 3: The shifts of soft-tissue registration after bony registration in cone-beam computed tomography images

	μ (mm)	SD (mm)	Σ (mm)	σ (mm)
AP				
MC	-0.18	1.57	0.90	1.72
BB	-0.62	1.15	0.94	1.29
VL	-0.38	1.22	0.86	1.74
SI				
MC	0.16	1.40	0.67	1.52
BB	0.38	1.20	1.07	1.25
VL	0.17	1.11	0.65	1.70
LR				
MC	-0.02	0.68	0.41	0.78
BB	-0.15	0.69	0.30	0.76
VL	0.00	0.69	0.40	0.99

AP: Anterior-posterior, SI: Superior-inferior, LR: Left-right, μ : Overall mean, SD: Standard deviation, Σ : Systematic error, σ : Random error, MC: MOLDCARE, BB: BlueBAG, VL: Vac-Lock

Table 4: The rotational setup errors in matching cone-beam computed tomography images

	μ (°)	SD (°)	Σ (°)	σ (°)
Pitch				
MC	0.39	0.33	0.35	0.35
BB	0.48	0.31	0.40	0.32
VL	0.21	0.56	0.58	0.80
Roll				
MC	-0.01	0.38	0.32	0.35
BB	0.11	0.31	0.50	0.25
VL	-0.09	0.39	0.49	0.52
Yaw				
MC	0.07	0.32	0.28	0.35
BB	-0.01	0.22	0.24	0.25
VL	-0.02	0.39	0.31	0.51

μ : Overall mean, SD: Standard deviation, Σ : Systematic error, σ : Random error, MC: MOLDCARE, BB: BlueBAG, VL: Vac-Lock

was away from the benchmark because VL and Hipfix have low adhesion.

In AP direction, the overall mean of the VL was significantly lower than that of the MC in the negative side and daily deviations exhibited a trend similar to the overall mean [Table 1]. In addition, the mean shifts in the MC were approximately 1 mm more than those in the BB and 2.5 mm more than those in the VL, for the latter-half treatment [Table 2]. These results may be due to the settling of the vacuum fixation caused by air leakage for the latter-half treatment because it has been reported that patient's body shifted downward in the AP direction due to minor leaks in the vacuum fixation.^[18,19] The settling of the vacuum fixation was not correlated with the patient's weight. Considered together, it indicated that BB and VL may not maintain the vacuum characteristics for longer treatment periods.

To estimate the treatment-position reproducibility for the three patient immobilization devices in IGRT, the soft-tissue registration after bony registration in CBCT images was examined [Table 3]. Our results demonstrated that there were no significant changes in the overall mean among the three devices in all directions. Bylund *et al.* reported that the AP systematic error was mainly caused by bony misalignment in prostate cancer patients immobilized with VL;^[20] we obtained the same result. It should be noted that the immobilization device type had no effect on the treatment-position reproducibility in IGRT. The rotational setup errors for the three devices were also examined by matching CBCT and planning CT scans in the offline review [Table 4]. Our results showed that there were no significant differences in the overall means among the three devices in all directions. The systematic and random errors in each immobilization device were the same as those in a previous report.^[21] In the absolute values of the overall mean of the pitch and roll corrections, there were no significant changes among each device; however, the mean of the vacuum fixation was slightly greater than that of the hydraulic fixation. This may be related to the endurance of the immobilization devices because there is a possibility that rotational setup error is caused by the settling in the vacuum fixation. It is necessary to observe the rotational setup errors in various types of immobilization devices.

Recently, the improvements in IMRT and IGRT techniques enable further dose escalation, resulting in higher cure rates with similar or slightly higher toxicity.^[22-24] This dose escalation leads to an increase in the number of times and period of standard radiation treatment; immobilization device endurance is essential for IMRT and IGRT. In this study, the endurance of the hydraulic fixation is superior to that of vacuum fixation because of air leakage during the latter-half treatment in vacuum fixation. Our laboratory had previously reported that the reproducibility of the couch height-based patient setup is superior to that of the skin mark patient setup in the abdominal region.^[25] In view of these results, it is crucial to consider the endurance of the vacuum fixation in a couch height-based patient setup. As hydraulic fixation, which is an irreversible immobilization, is a throwaway for each patient, the treatment cost is more. However, as vacuum fixation can be repeatedly

used, the cost is reduced. It is proposed that the cost can be considered in the selection of immobilization devices for IGRT. In addition, we have not revealed the intrafractional setup error of each immobilization device in this report. Further study remains to be done regarding the intrafractional setup reproducibility for the two types of immobilization devices.

CONCLUSION

This study demonstrates that vacuum fixation has a considerably lower overall mean and daily deviation in the AP direction; these results may be due to the settling of vacuum fixation caused by air leakage. However, there are no significant changes in the interfractional setup reproducibility and rotational setup error between the hydraulic and vacuum fixations. Accordingly, either hydraulic fixation or vacuum fixation can be selected for performing high-precision radiation therapy. To select the most suitable immobilization device, further study should be conducted.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

This work was financially supported by the JSPS KAKENHI (No. 17K15817) to Yoshihiro Ueda.

Conflicts of interest

There are no conflicts of interest.

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