INTERNATIONAL JOURNAL OF ADVANCED RESEARCH
ISSN: 3106-7980 : 3106-7972
Volume 3, Issue 3 [July, 2026]

DOSIMETRIC IMPACT ON BLADDER AND RECTUM BY INDUCING COUCH SHIFTS IN ALL THREE AXES OF PROSTATE VMAT_SIB TREATMENT PLANS.

Shoukat Ali[1,2], Murad Ali Khaskheli[*1], Mazhar Ali Abbasi[1], Abdul Majid Soomro[1], Angela Waweru[2], Amjad Hussain [3], Waseem Ahmed Bhutto[1]

[1]*Institute of Physics, University of Sindh, Jamshoro*
[2]*Aga Khan University Hospital Nairobi, Kenya*
[3]*Tawam, Al Ain, Abu Dhabi, UAE*

[*1]nuclearphyzer@hotmail.com, [*2]muradkhaskheli@usindh.edu.pk

DOI: https://doi.org/10.5281/zenodo.22158487

Keywords
Volumetric modulated arc therapy, setup uncertainty; induce couch shifts, image-guided radiotherapy, dose-volume histogram; planning target volume

Article History
Received: 11 May 2026
Accepted: 15 July 2026
Published: 31 July 2026

Corresponding Author: *
Shoukat Ali, Murad Ali Khaskheli

Abstract

Purpose:

Accurate patient positioning is essential in prostate radiotherapy because modern volumetric modulated arc therapy (VMAT) produces highly conformal dose distributions with steep dose gradients. Residual setup uncertainties may compromise target coverage and alter the dose delivered to surrounding organs at risk (OARs). This study evaluated the dosimetric impact of translational couch shifts ranging from 1 to 5 mm along the left-right (LR), superior-inferior (SI), and anterior-posterior (AP) directions on target coverage and OAR doses in prostate VMAT plans.

Materials and Methods:

Ten patients with locally advanced prostate cancer (T3–T4N0M0) treated with radical VMAT using the simultaneous integrated boost (SIB) technique were retrospectively included. Clinically approved treatment plans generated in Eclipse Treatment Planning System (Version 18.1) and delivered on a Varian TrueBeam linear accelerator were selected for analysis. Systematic translational setup uncertainties of 1–5 mm were introduced independently in the LR, SI, and AP directions while maintaining the original beam parameters and multileaf collimator fluence. A total of 300 recalculated treatment plans were generated. Dose-volume histogram (DVH) parameters were analyzed to evaluate changes in planning target volume (PTV) coverage, conformity index, and dosimetric indices for the bladder, rectum, and femoral heads. All dosimetric data were recorded in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Descriptive statistical analysis was performed to quantify the variation in target coverage and OAR doses resulting from translational setup uncertainties ranging from 1 mm to 5 mm in the LR, SI, and AP directions.

Results:

Increasing setup uncertainty produced a progressive reduction in target coverage in all three directions. The largest deterioration occurred following AP

displacement, where the deviation in PTV70 coverage reached 9.28% at a 5 mm shift. LR shifts produced the greatest increase in femoral head, whereas SI and AP shifts resulted in increase in bladder and rectum dose-volume parameters. Bladder dose-volume parameters demonstrated a directional dependence. During LR shifts, only modest increases were observed, with V40Gy, V50Gy and V60Gy increasing by 3.28%, 5.13%, and 2.94%, respectively, at 5 mm couch displacement. Rectal dosimetry exhibited greater sensitivity to translational uncertainties than bladder dosimetry. LR shifts resulted in gradual increases in rectal dose-volume parameters, with rectal V60Gy increasing from 1.62% at 1 mm to 10.84% at 5 mm. Mean rectal dose increased from 0.19% to 2.78% over the same range of displacement.

Conclusion:

Induced setup errors significantly influence target dose coverage and OAR dosimetry in prostate VMAT. AP displacement has the greatest impact on target coverage, bladder and rectum doses whereas LR displacement predominantly affects femoral head. Dosimetric deviations increased with the magnitude of positional error, emphasizing the importance of accurate patient positioning, daily image guidance, and consistent bladder and rectal preparation. These findings support maintaining setup reproducibility within 3 mm to preserve target coverage and minimize unnecessary irradiation of adjacent normal tissues.

INTRODUCTION:

Prostate cancer is one of the most frequently diagnosed malignancies among men and remains a major contributor to cancer related morbidity and mortality worldwide. Advances in screening, imaging, and treatment have improved disease control and survival, making radiotherapy a cornerstone in the management of localized and locally advanced prostate cancer. Modern external beam radiotherapy (EBRT), particularly intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT), enables highly conformal dose delivery to the prostate while minimizing radiation exposure to surrounding organs at risk (OARs), especially the bladder and rectum. These techniques permit dose escalation to improve tumor control but also increase the sensitivity of treatment delivery to geometric uncertainties because of the steep dose gradients around the target volume [1, 2].

Daily variations in patient positioning and internal organ motion remain significant challenges in prostate radiotherapy. Changes in bladder filling, rectal distension, bowel gas, and patient setup can alter the position of the prostate relative to the treatment isocenter, resulting in deviations between the planned and delivered dose distributions. Although image-guided radiotherapy (IGRT) substantially reduces interfraction setup errors, residual translational and rotational uncertainties persist even after daily image verification. These uncertainties may compromise planning target volume (PTV) coverage while simultaneously increasing the dose delivered to adjacent normal tissues [1,3].

The bladder and rectum are particularly susceptible to geometric uncertainties because of their close anatomical relationship with the prostate. Small positional shifts may increase the volume of these organs receiving high radiation doses, potentially leading to acute and late genitourinary (GU) and gastrointestinal (GI) toxicities. Clinical studies have demonstrated that the actual delivered doses to the bladder and rectum often exceed the planned doses owing to daily anatomical changes, despite adherence to standard treatment protocols. Consequently, evaluation of delivered dose rather than planned dose alone has become increasingly important for understanding treatment-related toxicity and optimizing adaptive radiotherapy strategies [4].

Several investigators have evaluated the effects of prostate motion and setup uncertainties on target coverage and normal tissue sparing. Most published studies have focused on interfraction motion observed during routine treatment, intrafraction prostate movement, or anatomical changes identified using cone-beam computed tomography (CBCT). However, relatively few studies have systematically quantified the dosimetric consequences of controlled translational couch shifts along the left-right (LR), anterior-posterior (AP), and superior-inferior (SI) axes while maintaining identical treatment parameters. Such investigations provide valuable information regarding the tolerance of modern treatment plans to residual setup errors and help define clinically acceptable positioning uncertainties [1,2,3].

With the advent of reduced PTV margins, hypofractionation regimes, stereotactic body radiotherapy (SBRT) and adaptive radiotherapy, the issue of sub-millimeter accuracy of treatments is even more crucial. While IGRT is a great way to increase accuracy of localization, any errors made during positioning that result in differences in the order of a few millimeters can lead to changes in DVH indices of both GTV/OAR and PTV volumes. It is extremely important to understand the magnitude of these dosimetric changes in order to minimize radiation-related toxicity while maintaining high rates of tumor control [1,2].

In this study, the dosimetric impact of simulated couch shifts ranging from 1 mm to 5 mm in the LR, AP, and SI directions was investigated for prostate VMAT treatment plans. The original clinically approved plans were systematically shifted to reproduce residual setup errors, and the resulting dose distributions were compared with the reference plans using dose-volume histogram parameters for the bladder, rectum, and target volumes. This analysis aims to quantify the sensitivity of prostate radiotherapy plans to translational positioning errors and to identify the threshold beyond which clinically significant changes in OAR dose and target coverage occur. The findings are expected to contribute to improved treatment accuracy, optimization of setup tolerances, and enhancement of patient safety in modern prostate radiotherapy.

Materials and Methods:

This retrospective dosimetric study included ten patients with locally advanced prostate cancer (clinical stage T3–T4N0M0) who underwent radical external beam radiotherapy at our institution between April 2024 and August 2025. All patients were treated using volumetric modulated arc therapy with simultaneous integrated boost (VMAT-SIB). Treatment plans were generated in the Eclipse Treatment Planning System (Version 18.1, Varian Medical Systems, Palo Alto, CA, USA) and delivered using a Varian TrueBeam linear accelerator equipped with a Millennium 120 multileaf collimator (MLC) and on-board imaging (OBI) system. Only clinically approved treatment plans that fulfilled institutional planning objectives for target coverage and organ-at-risk (OAR) dose constraints were included in this study.

CT Simulation:

CT simulation was performed using a Toshiba Aquilion LB CT scanner (Model TSX-201A, Canon Medical Systems, Japan). Patients were positioned supine with appropriate lower limb immobilization according to the departmental prostate radiotherapy protocol. Computed tomography images were acquired from the first lumbar vertebra (L1) to the mid-femur using a slice thickness of 3 mm.

To improve reproducibility of bladder filling and rectal volume throughout treatment, patients were instructed to empty their rectum before simulation. Subsequently, they were asked to drink 300–500 mL of water and wait approximately 20 minutes before CT acquisition to achieve a comfortably full bladder. The same preparation protocol was followed before each treatment fraction.

Treatment Planning:

The prescribed dose was 70 Gy in 28 fractions to the primary planning target volume (PTV-P) and 50.4 Gy in 28 fractions to the elective pelvic nodal

planning target volume (PTV-N) using the simultaneous integrated boost (SIB) technique.

The planning objective required that at least 95% of the PTV-P and PTV-N volumes receive a minimum of 95% of their respective prescribed doses. Organ-at-risk dose constraints were based on institutional clinical guidelines, with no more than 50% of the bladder volume receiving 40 Gy (V40Gy ≤ 50%) and no more than 50% of the rectal volume receiving 45 Gy (V45Gy ≤ 50%). In addition, the global maximum dose within the treatment plan was maintained below 110% of the prescribed dose.

All treatment plans were generated using two coplanar full VMAT arcs. The plans were optimized to satisfy both target coverage and OAR sparing objectives and underwent routine pretreatment patient-specific quality assurance using portal dosimetry. A gamma passing criterion of 2%/2 mm was used for plan verification, and only plans meeting the institutional acceptance threshold were included in the analysis.

Simulation of Setup Uncertainties:

To investigate the dosimetric effect of residual setup errors, translational couch shifts ranging from 1 mm to 5 mm were systematically introduced into the original clinically approved treatment plans. Shifts were simulated independently along the three orthogonal axes: left-right (LR), superior-inferior (SI), and anterior-posterior (AP), in both positive and negative directions.

For each simulated setup error, the treatment plan was recalculated while maintaining the original monitor units, beam geometry, optimization parameters, and MLC fluence. No re-optimization was performed, allowing the dosimetric changes to represent only the effect of patient positioning uncertainty. In total, 300 treatment plans were generated and recalculated for analysis.

Dosimetric Evaluation:

Dose-volume histograms (DVHs) were extracted from each recalculated plan to evaluate changes in target coverage and doses to organs at risk. The following dosimetric parameters were analyzed:

- Target volumes (PTV-P and PTV-N): D95%, V95%, and target coverage.
- Bladder: Mean dose, maximum dose, V40Gy, V50Gy, V60Gy, and D5%.
- Rectum: Mean dose, maximum dose, V40Gy, V50Gy, V60Gy, and D5%.
- Femoral heads: Mean dose, maximum dose and D50%.

All dosimetric data were recorded in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Descriptive statistical analysis was performed to quantify the variation in target coverage and OAR doses resulting from translational setup uncertainties ranging from 1 mm to 5 mm in the LR, SI, and AP directions.

Results:

A total of 300 recalculated VMAT treatment plans were generated by introducing translational couch shifts ranging from 1 to 5 mm along the left-right (LR), superior-inferior (SI), and anterior-posterior (AP) directions. The dosimetric changes in target coverage and organs at risk were evaluated relative to the original clinically approved treatment plans. Fig 1. Show the isodose lines shifted towards right when induce shifting (0,0, -5).

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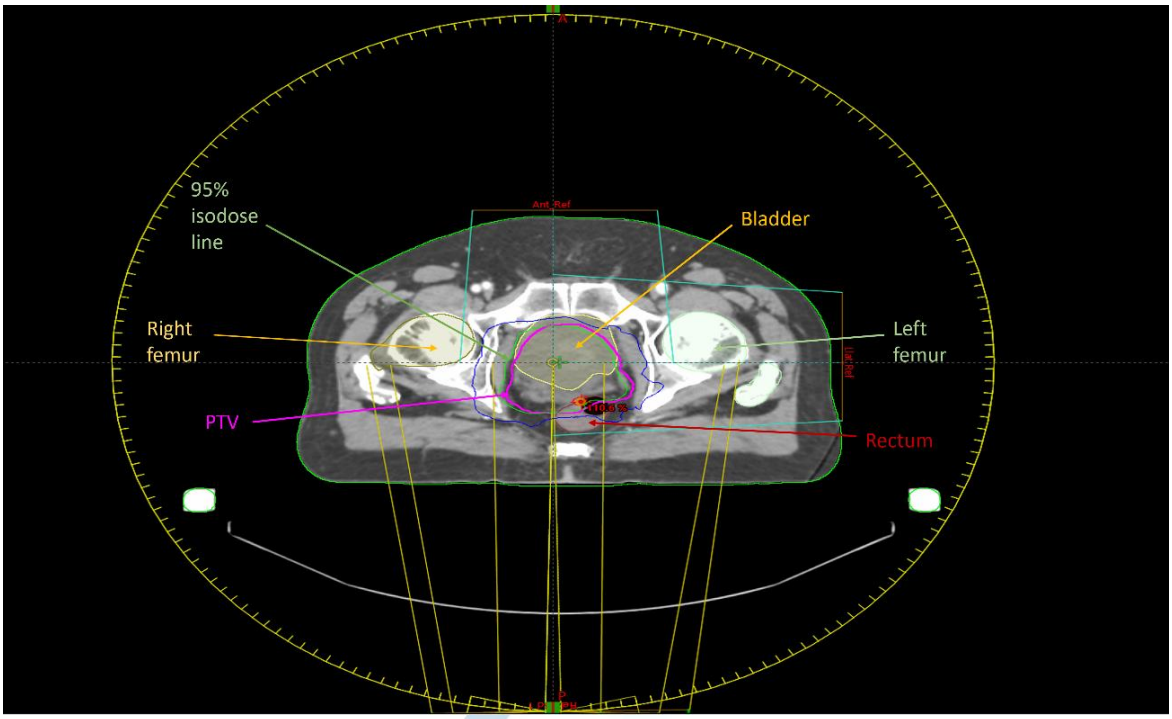

Fig 1. Show the isodose lines shifted towards right when induce shifting (0,0,-5).

Target coverage decreased progressively with increasing setup uncertainty in all three directions. The reduction was relatively small for 1 mm shifts but became more pronounced as the magnitude of displacement increased. For LR shifts, the deviation in PTV50.4 increased from −0.81% at 1 mm to −4.07% at 5 mm, while PTV70_{70}70 decreased from −0.61% to −4.20%. Similar reductions were observed for SI shifts, where PTV50.4 and PTV70 deviations reached −4.41% and −8.76%, respectively, at a 5 mm displacement. The greatest deterioration in target coverage occurred following AP shifts. At 5 mm, the deviation in PTV70 reached −9.28%, indicating that prostate target coverage was most sensitive to positioning errors in the anterior-posterior direction. Fig 2. Shows DVH comparison of standard and induced shifting plan.

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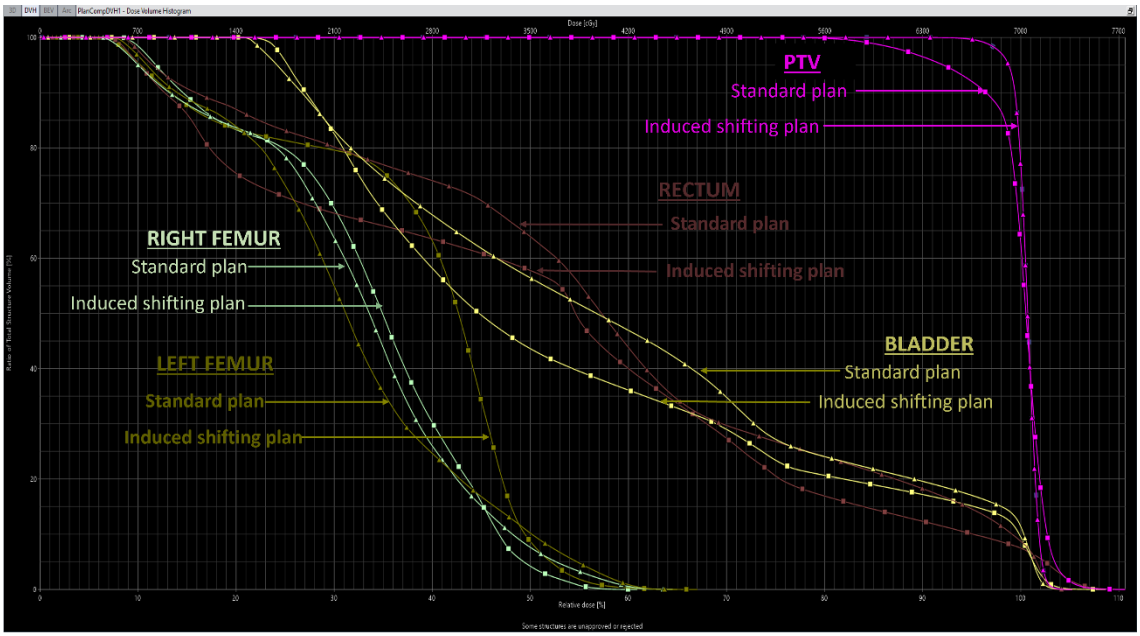

Fig 2. Shows DVH comparison of standard and induced shifting plan.

Bladder dose-volume parameters demonstrated a directional dependence. During LR shifts, only modest increases were observed, with V40Gy, V50Gy and V60Gy increasing by 3.28%, 5.13%, and 2.94%, respectively, at 5 mm couch displacement. In contrast, SI and AP shifts produced a progressive increase in bladder dose-volume parameters. Following a 5 mm AP shift, bladder V40Gy, V50Gy and V60Gy decreased by 13.37%, 21.6%, and 27.37%, respectively as shown in Table 1. The mean bladder dose showed a gradual increase with increasing SI and AP shifts, whereas only minor changes were observed following LR displacement. The maximum bladder dose remained relatively stable throughout all simulated shifts, with variations generally below 1%.

Rectal dosimetry exhibited greater sensitivity to translational uncertainties than bladder dosimetry. LR shifts resulted in gradual increases in rectal dose-volume parameters, with rectal V60Gy increasing from 1.62% at 1 mm to 10.84% at 5 mm. Mean rectal dose increased from 0.19% to 2.78% over the same range of displacement. Conversely, SI and AP shifts increased rectal dose-volume parameters, and the magnitude increased with larger positional errors.

The femoral heads were minimally affected by setup uncertainties. Small variations in mean and maximum doses were observed irrespective of shift direction. Although percentage differences in the low-dose regions increased slightly with larger displacements in lateral movement. The absolute dose variations to both femoral heads remained clinically insignificant compared with those observed for the prostate, bladder, and rectum.

Table:1 Shows PTV_50.4, PTV_70 and bladder deviation from the standard treatment plan.

Induce Shifting (x,y,z) axis	PTV_50.4 Deviation %	PTV_70 Deviation %	Bladder (Deviation from standard plan%)					
			40(Gy) Deviation %	50(Gy) Deviation %	60(Gy) Deviation %	5% Vol. Deviation %	Mean dose Deviation %	Max dose Deviation %

1,0,0	-0.81	-0.61	0.45	0.58	0.4	0.08	0.1	0.23
2,0,0	-1.21	-0.9	0.9	1.26	0.81	0.22	0.52	0.18
3,0,0	-1.44	-1.75	1.46	2.39	1.4	0.13	0.33	0.17
4,0,0	-2.63	-3.22	2.25	3.62	2.12	0.18	0.5	0.28
5,0,0	-4.07	-4.2	3.28	5.13	2.94	0.25	0.89	0.16
0,1,0	-0.86	-0.53	2.78	6.14	10.74	0.69	1.51	0.43
0,2,0	-1.4	-0.93	5.71	12.46	22.17	1.17	3.09	0.56
0,3,0	-1.83	-2.77	8.69	18.93	33.49	1.52	4.71	0.5
0,4,0	-2.96	-4.95	11.84	25.62	44.83	1.81	6.37	0.78
0,5,0	-4.41	-8.76	14.99	32.35	56.2	2.04	8.06	0.5
0,0,1	-0.66	-0.39	2.59	4.11	5.43	0.42	1.13	0.41
0,0,2	-0.83	-1.56	5.33	8.39	10.82	0.78	2.33	0.43
0,0,3	-0.93	-3.59	8.01	12.86	16.42	1.12	3.39	0.37
0,0,4	-1.65	-5.28	10.68	17.3	21.87	1.38	4.52	0.52
0,0,5	-2.61	-9.28	13.37	21.6	27.37	1.61	5.64	0.72
-1,0,0	-2.23	-2.17	0.54	0.76	0.95	0.31	0.11	0.14
-2,0,0	-2.38	-2.28	0.78	0.79	1.13	0.09	0.16	0.15
-3,0,0	-2.47	-2.61	1	0.78	1.24	0.14	0.23	0.21
-4,0,0	-3.2	-3.56	1.39	1.4	1.42	0.2	0.35	0.28
-5,0,0	-4.21	-3.98	1.93	2.21	1.5	0.25	0.47	0.51
0,-1,0	-0.85	-1.12	-2.72	-6.07	-10.75	-0.96	-1.45	-0.35
0,-2,0	-1.13	-2.14	-5.22	-11.71	-11.23	-2.32	-2.83	-0.5
0,-3,0	-1.12	-4.59	-7.8	-17.46	-15.17	-3.6	-4.22	-0.38
0,-4,0	-2.03	-7.63	-9.7	-22.29	-18.78	-6.35	-5.32	-0.51
0,-5,0	-3.3	-12.59	-11.78	-27.2	-19.15	-8.96	-6.44	-1.05
0,0,-1	-0.9	-0.63	-2.72	-4.29	-5.43	-0.47	-1.09	-0.23
0,0,-2	-1.38	-1.23	-5.53	-9.05	-11.42	-1.03	-2.41	-0.22
0,0,-3	-6.49	-6.02	-7.95	-12.53	-16.15	-1.59	-3.34	-0.25
0,0,-4	-2.62	-3.44	-10.49	-16.47	-21.28	-2.31	-4.42	-0.34
0,0,-5	-3.82	-6.64	-12.78	-22.06	-26.39	-4.16	-5.5	-0.55

Table 2. Shows deviation of 40Gy,50, Gy,60Gy, 5% Volume, Mean and Maximum dose of rectum from standard plan.

Induce Shifting (x,y,z) axis	Rectum					
	40(Gy) Deviation %	50(Gy) Deviation %	60(Gy) Deviation %	5% Vol. Deviation %	Mean dose Deviation %	Max dose Deviation %
1,0,0	0.5	1.24	1.62	0.16	0.19	0.38
2,0,0	1.17	2.82	3.49	0.37	0.63	0.28
3,0,0	2.66	5.67	5.63	0.53	1.19	0.25
4,0,0	4.55	9.06	8.05	0.74	1.83	0.9

5,0,0	6.92	13.20	10.84	0.92	2.78	0.42
0,1,0	-4.42	-4.72	-6.96	-0.61	-2.03	-0.72
0,2,0	-8.51	-9.08	-12.18	-2.4	-3.98	-0.5
0,3,0	-12.17	-13.22	-17.95	-2.39	-5.87	-0.7
0,4,0	-15.58	-17.14	-23.41	-3.55	-7.75	-1.01
0,5,0	-18.74	-21.14	-28.59	-4.76	-9.46	-0.81
0,0,1	-5	-10.7	-12.56	-1.81	-2.76	-0.65
0,0,2	-10.07	-12.22	-17.33	-4.32	-5.46	-0.57
0,0,3	-14.63	-15.79	-19.25	-7.5	-8.03	-0.76
0,0,4	-19.30	-18.33	-21.44	-11.27	-10.48	-0.67
0,0,5	-23.71	-20.27	-25.21	-15.20	-12.78	-1.50
-1,0,0	0.87	2.09	1.95	0.18	0.39	0.41
-2,0,0	1.09	2.08	2.67	0.29	0.43	0.28
-3,0,0	1.85	2.85	3.08	0.37	0.59	0.4
-4,0,0	3.01	4.07	3.76	0.45	0.93	0.56
-5,0,0	4.79	6.65	4.94	0.51	1.49	0.72
0,-1,0	4.56	4.92	6.3	0.54	2.08	0.59
0,-2,0	9.46	10.84	12.79	0.95	4.24	1.21
0,-3,0	14.03	17.61	33.85	1.27	6.42	0.87
0,-4,0	19.32	25.23	25.94	1.56	8.69	0.81
0,-5,0	24.23	33.45	32.52	1.76	10.78	0.73
0,0,-1	5.07	11.24	12.3	1.27	2.89	0.17
0,0,-2	10.36	15.3	15.4	2.11	5.77	0.31
0,0,-3	15.4	18.4	19.22	2.45	8.83	1.06
0,0,-4	20.66	21.50	22.35	2.72	11.86	0.74
0,0,-5	26.03	25.60	25.67	2.69	14.91	0.93

Table3. Shows 50%volume, mean and maximum dose deviation of right and left femur from standard plan.

Induce Shifting (x,y,z) axis	Rt Femur (cGy)			Lt Femur (cGy)		
	50% Vol. Deviation %	Mean dose Deviation %	Max dose Deviation %	50% Vol. Deviation %	Mean dose Deviation %	Max dose Deviation %
1,0,0	-2.02	-1.09	-1.13	2.09	1.15	6.26
2,0,0	-1.85	-2.47	-3.46	2.13	2.77	16.68
3,0,0	-2.76	-3.66	-5.17	3.28	17.4	15.25
4,0,0	-3.66	-4.82	-6.51	4.41	5.74	11.43
5,0,0	-4.53	-5.94	-7.74	5.61	7.31	-13.42
0,1,0	1.1	2.47	-1.14	0.66	5.49	-6.21
0,2,0	2.23	2.62	-1.52	1.37	2.83	-6.15
0,3,0	3.75	12.75	-10	2.06	4.23	-6.49

0,4,0	5.14	5.28	-2.72	2.70	14.75	-15.94
0,5,0	6.78	6.63	-3.51	3.38	7.04	-6.99
0,0,1	0.33	0.35	0.9	0.46	0.44	5.32
0,0,2	0.6	0.69	1.68	0.99	0.91	5.8
0,0,3	0.94	1.05	2.01	1.49	1.37	15.38
0,0,4	1.29	1.42	2.71	2.02	1.87	6.85
0,0,5	1.64	1.80	3.36	2.61	2.75	6.83
-1,0,0	-1.91	-2.65	-3.8	2.07	2.6	7.52
-2,0,0	-2.67	-3.63	-5.09	2.84	3.55	8.47
-3,0,0	-3.46	-4.65	-6.96	3.57	4.46	18.94
-4,0,0	-4.29	-5.7	-8.52	4.29	5.33	10.4
-5,0,0	-5.14	-6.83	-10.53	4.98	6.16	10.95
0,-1,0	0.93	1.3	1.12	0.82	1.44	5.54
0,-2,0	1.86	2.59	1.47	2.27	2.88	6.14
0,-3,0	4.03	3.92	3.48	5.11	5.73	7.8
0,-4,0	3.60	5.19	3.49	3.63	5.83	8.83
0,-5,0	4.54	6.49	4.70	4.78	9.70	7.72
0,0,-1	-0.32	-14.21	-7.63	-0.5	-0.41	-5.37
0,0,-2	-0.64	-0.82	-1.59	-0.96	-0.98	-5.93
0,0,-3	-0.88	-0.99	-2.16	-1.29	-1.15	-14.97
0,0,-4	-1.16	-1.29	-2.69	-1.69	-1.50	-6.58
0,0,-5	-1.46	-1.61	-3.01	-2.05	-1.82	-6.56

Discussion:

The present study evaluated the dosimetric consequences of induced residual translational setup errors. ranging from 1 to 5 mm in the left-right (LR), superior-inferior (SI), and anterior-posterior (AP) directions on VMAT plans for locally advanced prostate cancer. By introducing systematic couch shifts into clinically approved treatment plans without re-optimization, the study isolated the effect of geometric uncertainties on target dose coverage and organ-at-risk (OAR) sparing. The findings demonstrated that increasing setup displacement resulted in a progressive deterioration of target coverage and measurable changes in bladder and rectal dose-volume parameters. Among the three directions investigated, AP shifts produced the largest reduction in planning target volume (PTV) coverage.

The observed reduction in target coverage with increasing positional error is consistent with the steep dose gradients characteristic of modern VMAT techniques. These highly conformal dose distributions maximize target conformity while minimizing irradiation of adjacent normal tissues, making them inherently sensitive to geometric uncertainties. In the present study, target coverage remained relatively stable for 1 mm shifts but progressively decreased as displacement increased to 5 mm, indicating that induce setup errors greater than 3 mm may compromise dose delivery to the prostate and nodal area. Similar observations have been reported by several investigators, who demonstrated that even small translational deviations can reduce PTV coverage, particularly when reduced treatment margins are employed in conjunction with daily image guidance [5,6,7].

The largest deviation in target coverage occurred following AP displacement. This finding reflects the anatomical relationship between the prostate, bladder, and rectum. Variations in rectal filling and bladder volume primarily displace the prostate in the anterior posterior direction,

making this axis particularly susceptible to geometric uncertainty. Consequently, AP setup errors have a greater impact on the high-dose region surrounding the prostate than LR or SI errors. This observation agrees with reports demonstrating that prostate motion is predominantly AP and SI because of physiological changes in bladder filling and rectal distension, while LR motion remains comparatively limited [8], [9].

The dosimetric response of the bladder also depended on the direction of displacement. LR shifts produced only minor changes in bladder dose-volume parameters, whereas SI and AP shifts resulted in progressive increases in bladder V40Gy, V50Gy, and V60Gy. Previous studies using repeated cone-beam CT have shown that bladder volume variation contributes substantially to differences between planned and delivered dose distributions, even when daily image guidance is performed [10], [11]. Therefore, consistent bladder preparation remains essential for maintaining reproducible dose delivery throughout treatment.

Although maximum doses to the bladder and rectum changed only minimally, clinically relevant differences were observed in dose-volume histogram (DVH) parameters. This observation highlights the importance of volumetric dose assessment rather than reliance on point-dose metrics alone. Numerous studies have demonstrated that late genitourinary and gastrointestinal toxicities correlate more strongly with bladder and rectal dose-volume indices than with maximum dose [12], [13]. Consequently, evaluation of parameters such as V40Gy, V50Gy, V60Gy, D5%, and mean dose provides a more comprehensive assessment of treatment quality.

The femoral heads exhibited negligible dosimetric variation throughout the simulated setup errors. This finding was anticipated because these structures are located outside the steep dose gradient surrounding the prostate and pelvic lymph nodes. Similar observations have been reported in previous VMAT dosimetric investigations, where femoral head doses remained stable despite moderate translational uncertainties [14].

Daily image-guided radiotherapy has substantially improved treatment accuracy in prostate cancer by reducing interfraction positioning errors. Nevertheless, residual uncertainties remain because of organ deformation, rotational motion, and intrafraction prostate movement. The present findings indicate that even after image guidance, translational errors approaching 5 mm may produce clinically meaningful reductions in target coverage and alterations in OAR dose. These results support current recommendations advocating daily image guidance, strict bladder and rectal preparation protocols, and appropriate PTV margins to maintain treatment accuracy [6], [15].

The present study has several limitations. First, the analysis was based on simulated translational couch shifts and did not incorporate rotational errors, intrafraction motion, or anatomical deformation observed during routine clinical treatment. Second, the sample size was limited to ten patients from a single institution, which may restrict generalizability. Third, the recalculated dose distributions assumed unchanged patient anatomy and therefore did not account for daily variations in bladder and rectal filling visible on cone-beam CT. Despite these limitations, the study provides a controlled assessment of the independent dosimetric effect of residual translational setup errors and demonstrates the directional sensitivity of VMAT prostate treatment plans.

Conclusion:

The curative intent of prostate radiotherapy require highly precise radiation delivery to the target. Slightly, change in the position will significantly impact on TCP and NTCP. The setup accuracy should be within ±3mm can give adequate target coverage and minimal impact of OAR's doses. The daily setup verification should be meaningful to achieve daily treatment setup reproducibility.

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