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Original research article

Immobilization versus no immobilization for pelvic external beam radiotherapy

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ABSTRACT

Aim: To identify the most reproducible technique of patient positioning and immobilization during pelvic radiotherapy.

Background: Radiotherapy plays an important role in the treatment of pelvic malignancies. Errors in positioning of patient are an integral component of treatment. The present study compares two methods of immobilization with no immobilization with an aim of identifying the most reproducible method.

Materials and methods: 65 consecutive patients receiving pelvic external beam radiotherapy were retrospectively analyzed. 30, 21 and 14 patients were treated with no-immobilization with a leg separator, whole body vacuum bag cushion (VBC) and six point aquaplast immobilization system, respectively. The systematic error, random error and the planning target volume (PTV) margins were calculated for all the three techniques and statistically analyzed.

Results: The systematic errors were the highest in the VBC and random errors were the highest in the aquaplast group. Both systematic and random errors were the lowest in patients treated with no-immobilization. 3D Systematic error (mm, mean ± 1SD) was 4.31 ± 3.84, 3.39 ± 1.71 and 2.42 ± 0.97 for VBC, aquaplast and no-immobilization, respectively. 3D random error (mm, 1SD) was 2.96, 3.59 and 1.39 for VBC, aquaplast and no-immobilization, respectively. The differences were statistically significant between all the three groups. The calculated PTV margins were the smallest for the no-immobilization technique with 4.56, 4.69 and 4.59 mm, respectively, in *x*, *y* and *z* axes, respectively.

Conclusions: Among the three techniques, no-immobilization technique with leg separator was the most reproducible technique with the smallest PTV margins. For obvious reasons, this technique is the least time consuming and most economically viable in developing countries.

Abbreviations: 3DCRT, three dimensional conformal radiotherapy; IMRT, intensity modulated radiotherapy; VBC, vacuum bag cushion; EPID, electronic portal imaging device; CBCT, cone beam computed tomography; PTV, planning target volume; CTV, clinical target volume; SD, standard deviation; TE, total error.

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1. Background

Pelvic external beam radiotherapy plays an integral part in the management of gynaecologic, genitourinary and gastrointestinal malignancies. Carcinoma of uterine cervix, endometrium, rectum and prostate are the most common pelvic malignancies treated in radiation oncology departments of developing countries like India.[1] Three dimensional conformal radiotherapy (3DCRT) is the minimum standard of care, although higher technologies like intensity modulated radiotherapy (IMRT) are a recommended standard in the treatment of carcinoma prostate and postoperative cases.

Variation in the patient positioning is a major problem during radiotherapy for pelvic malignancies. Higher patient setup errors will compel Radiation oncologist to give a larger planning target volume (PTV) margins, i.e. irradiate more normal tissues. Smaller PTV margins may lead to potential geographic miss of the target volume and, hence, may lead to recurrence.[2]

Several patient positioning and immobilizing techniques are being practiced in our country in the radiotherapy for the pelvis.[3,4] With huge workload in most of the radiotherapy centres in India, frequent onboard image verifications with EPID (electronic portal imaging device) or kv-CBCT (kilovoltage cone beam computed tomography) is not feasible in most of the centres. Hence it is ideal to adapt to most favourable, less time consuming and most economically viable technique for patient positioning with maximum reproducibility. There are conflicting pieces of evidence and lack of consensus as to the ideal method of patient immobilization for pelvic radiotherapy.[4–6] Therefore, in the present study we compare two most commonly utilized modalities of patient immobilization, namely whole body vacuum bag cushion (VBC) and six-point pelvic aquaplast system with no immobilization with a leg separator.

2. Aim

The aim of the present study is to identify the most appropriate patient positioning technique for treatment of pelvic malignancies. The objective of the present study is to quantify systematic error, random error and planning target volume for each of the techniques of patient positioning by periodic EPID imaging and derive the most optimal technique of patient positioning in external beam radiotherapy for pelvic malignancies.

3. Materials and methods

3.1. *Sample collection and sample size*

After Institutional ethical clearance, a retrospective observational study was started. On assuming 'between group variance' of 1 mm, and 'within group variance' of 2 mm and an effect size of 30%, 80% power and 2-sided alpha error of 5%, the required number of instances (readings) would be 523. We therefore accrued 65 consecutive patients receiving pelvic external beam radiotherapy (radical or palliative intent) on Elekta synergy linear accelerator (Elekta®) from January 2016 to October 2016 into the present study.

3.2. *Patient positioning and immobilization*

All patients underwent computed tomographic scan for radiotherapy planning. All the patients were positioned in a supine position with hands above the head or akimbo on the chest based on the patient comfort. And for all the patients the AIO base plate (all in one base plate) was fixed on the CT couch as well as on the treatment couch. This base plate helps in indexer level marking by means of positioning indicators in all the three systems, namely: VBC, aquaplast and no-immobilization. The details of three different patient positioning techniques are as follows:

3.3. *Patient positioning using vacuum bag cushion (VBC)*

Whole body VBCs (Orfit Industries®) are nylon mattress filled with tiny polyurethane beads. Patient is made to lie down in a supine position. A comfortable cradle is formed around to conform to the body contours of the patient by using a vacuum pump for 10 min. After the VBC achieved the desirable firm consistency, the self sealing quick release valve was used to seal the mattress (Fig. 1A). The laser marks are placed on the VBC, corresponding to indexer and on the patient's body for daily setup reproducibility. The mattress was labelled and used throughout the treatment.

3.4. *Six point aquaplast immobilization system*

Six point aquaplast immobilization system (Orfit Industries®) used in the present study has a thigh separator with a knee rest. Patient is immobilized in a supine position with the knee rest. The lateral 4 clamps of the aquaplast were fixed to the carbon fibre AIO base plate and medial two clamps were fixed to the thigh separator. The laser marks were placed both on the patient's body and on the aquaplast. The upper and the lower borders of the cast were also marked on the patient body. Corresponding indexer levels were marked to match the patient's position. (Fig. 1B).

3.5. *No immobilization*

All the patients in this category were simulated in a supine position on a flat surface with a pillow or a comfortable headrest under the head. Flat zero degree sponge was fixed over the AIO base plate. A leg separator was held by the patient in between the ankle joints. Laser isocentre markings were placed directly on the patient's body (Fig. 1C).

3.6. *Image acquisition and processing*

All patients were positioned on the day of treatment and the laser markings representing simulation centres were matched. Couch shifts were given to match the treatment isocentre as per the data obtained from the treatment planning system. EPID images were acquired in 2 axes viz., antero-posterior and lateral direction. The images were

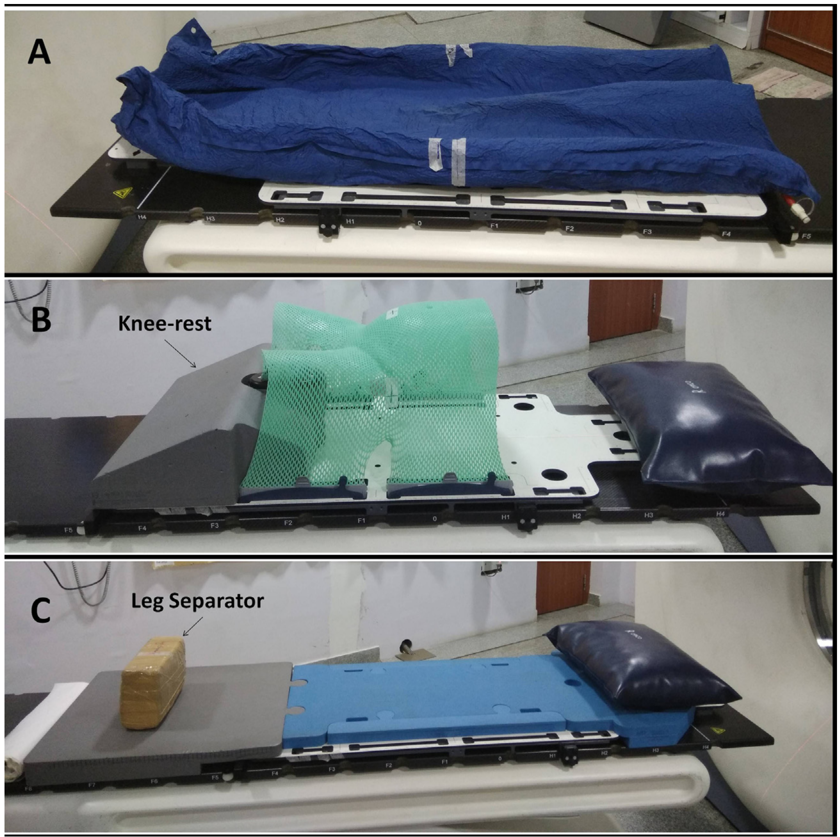

Fig. 1 – Showing the three different techniques of patient positioning. A – whole body vacuum bag cushion (VBC); B – six point aquaplast immobilization system; C – no-immobilization with a homemade leg separator.

analyzed by iview GT system (Elekta®). Bony landmarks (e.g. pubic symphysis, iliac crest, lumbo-sacral vertebrae, obturator foramen, sacro-iliac joints, acetabulum, etc.) were marked on the digitally reconstructed radiographs (DRRs), the same were digitally matched with double exposure EPID images. Our protocol is to repeat orthogonal EPID images on the first five days of treatment and later repeat the imaging once a week throughout the treatment. The displacements in the lateral direction (x-axis), cranio-caudal direction (y-axis) and yaw (the horizontal rotation around the vertical axis) were measured in antero-posterior EPID. The displacements in the cranio-caudal direction (y-axis), antero-posterior direction (z-axis) and pitch (the vertical rotation along the transverse axis) were measured in lateral EPID. The roll (the lateral rotation along the longitudinal axis) cannot be estimated in the EPID images. The translational deviations were represented in millimetres (mm) and rotational displacements were represented in degrees.

3.7. *Statistical analysis*

The deviation in the patient positioning on the treatment day as compared to the simulation day is called a total setup error. The total setup error is a combination of systematic error and random error on each day of the treatment. The setup errors were calculated and represented as per the method described in el-Gayed et al. and Gilbeau et al.[7,8] The systematic error is an error which persists throughout the course of treatment. For each patient, the systematic error in a particular direction was calculated as the mean of all the displacements measured throughout the course of treatment. For all the patients in each of the three groups, the distribution of systematic error in a particular direction and angle was expressed by the standard deviation (1SD) from the values of the mean displacements of all individual patients.[8]

The random error is an error which varies day-to-day during the treatment course. For each patient, the random error for a particular direction was assessed by subtraction of the systematic error from the daily displacement. For all the patients in each of the three groups, the distribution of random errors in each direction and angle was expressed by the standard deviation (SD) from all the individual random values.[8]

The standard deviations of total,[8] systematic and random errors are related by formula

$$\mathrm{TE}^2 = \Sigma^2 + \sigma^2$$

A three dimensional (3D) vector was calculated separately for systematic and random errors for each of the three groups of patients. The 3D vector quantifies the magnitude of error in any of the three spatial directions from the reference position. The 3D vector was calculated using the formula:

Where E_{3D} is the 3D vector error; E_x, E_y and E_z are the errors in the lateral, cranio-caudal and antero-posterior directions, respectively.[8] The difference in the 3D errors between three groups were tested with two-sample F-test of variances.

Planning target volume margins for each axis were calculated by van Herk method[2] using the formula:

$$\text{PTV (mm)} = 2.5\Sigma + 0.7\sigma$$

In the above equation, $\sum$ and σ are the standard deviations of systematic and random errors, respectively. With PTV margins calculated by the above formula, the minimum dose to CTV (clinical target volume) is 95% in 90% of patients.[2] The errors and the PTV margins for each of the three groups were tabulated and analyzed with F-test for testing statistical significance.

To assess the accuracy of setup errors with EPID, in few random instances, both EPID and CBCT (Cone beam computed tomography) were done on the same patient on the same day. The CBCT was evaluated on XVI (Elekta) software, the images were co-registered by an automatic bone matching tool and the errors were recorded. The 3D systematic and 3D random errors were calculated by each of the two methods of image verification and statistically compared by two-sample F-test for variances.

4. Results

There were 30, 21 and 14 patients in no-immobilization, VBC and aquaplast groups respectively. 78.5% of the patients were females. 61.5% of the overall patients were treated for carcinoma of the uterine cervix. 80% of the patients were treated with 3DCRT (three dimensional conformal radiotherapy) techniques. Total number of EPID images evaluated was 290, 171 and 142 in no-immobilization, VBC and aquaplast arms, respectively (Table 1).

The systematic error (1SD) in the three different axes was the highest in the VBC with 2.55, 1.56 and 4.84 mm (x, y and z axes, respectively) and the lowest in patients treated with no-immobilization with 1.3, 1.39 and 1.41 mm (x, y and z axes, respectively). The systematic rotational errors were also the lowest in no-immobilization arm with pitch and yaw of 0.36 and 0.44 degrees, respectively (Table 2 and Fig. 2).

The random error (1SD) was the highest in the patients treated with aquaplast with 4.01, 4.15 and 2.09 mm (x, y and z axes, respectively) and lowest in those treated with no-immobilization with corresponding values of 1.89, 1.75 and 1.51 mm (x, y and z axes, respectively). This is reflected by more frequent EPID imaging with median number of 10 for aquaplast as compared to 9 and 8 images in no-immobilization and VBC, respectively. The random rotational errors were also the lowest for the patients treated with no-immobilization (Table 3 and Fig. 3). Number of instances where the error was more than 5 mm was 65(38%), 64(45%) and 9(3%) for VBC, aquaplast and no-immobilization respectively.

3D vector systematic and 3D vector random errors were the lowest in patients treated with no immobilization. 3D random error was the highest is patients treated with aquaplast immobilization and 3D systematic error was the highest in patients treated with VBC. There was a statistically significant difference between all the three groups (Table 4).

PTV margin up to 14 mm (z axis) was required for patients treated with VBC. For those treated with aquaplast, the required PTV margin was 9 mm (y axis). PTV margins were the smallest for those in no-immobilization arm with less than 5 mm in all the three axes (Table 5). Fig. 4 graphically summarizes the systematic error, random error, total error and the PTV margins required in the three different techniques of patient positioning.

There were 86 instances, both EPID and CBCT images were taken simultaneously in the same patient on the same day. The systematic and random errors calculated by both the imaging techniques were comparable with less than 1 mm difference between the two. There was no statistically significant difference between the 3D systematic and 3D random errors calculated separately by EPID and CBCT ($p = 0.25$ and 0.50, respectively) (Table 6).

5. Discussion

Setup errors are an integral part of external beam radiotherapy.[2] There can be only measures taken to reduce the setup errors but they cannot be completely removed from the system. Various techniques of positioning and immobilization have been developed for minimizing the errors in pelvic radiotherapy. Our study successfully compared all the three most commonly used techniques in our country with the aim of identifying the best of the three. Our study showed a clear cut advantage of treating patients without any immobilization. PTV margins as small as 5 mm should be sufficient for those patients treated with no-immobilization and hence it is the most reproducible technique of the three. For obvious reasons, treatment of patients with no immobilization with only skin marks is the least time consuming and most economical method.

The patients treated with whole body VBC system had the highest variation in the treatment position in our study. Most of the studies report a similar result.[6,9–12] However, one study by White et al.[5] which used alpha cradle which was chemically formed using two foaming agents, showed a very low systematic and random errors[5] [Table 7]. The alpha cradle used in study by White et al.[5] is likely to be sturdier and less likely to deform during the course of treatment. The vacuum based alpha cradle system, as the one used by our study and the other studies are likely to lose the vacuum over a period of time without a visible change in the shape. The loss of vacuum is probably more in the first few days and slows down as the days progress. Hence, we probably observed a higher systematic error as compared to random error with VBC system. In fact, in our study one of our patients required re-simulation and re-planning due to the loss of vacuum after simulation before starting radiotherapy treatment. We also faced difficulty in making lateral contours in well built patients resulting in thinned out and easily mouldable edges.

In contrast to VBC, aquaplast had significantly less setup errors in our study. However aquaplast had significantly more displacements as compared to patients treated with no-immobilization. The systematic and random errors in our study were comparable to other studies in the literature which have evaluated patients treated with aquaplast.[3–5,13,14]

Table 1 – Patient and treatment characteristics.

		No immobilization ($n = 30$)	VBC ($n = 21$)	Aquaplast ($n = 14$)
Gender	Male	6	6	2
	Female	24	15	12
Type of cancer	Cervix	19	11	10
	Endometrium	1	3	0
	Rectum	8	3	4
	Anal canal	1	1	0
	Prostate	1	2	0
	Bladder	0	1	0
Technique of radiotherapy	3DCRT	27	14	11
	IMRT	3	7	3
Number of EPIDs evaluated	Total number	290	171	142
	Mean ± SD	9.67 ± 5.43	8.14 ± 4.03	10.14 ± 2.5
	Median (IQR)	8.5 (7–9.75)	8 (6–9)	10 (9–11)

It was interesting to note that random errors are more compared to systematic errors in patients treated with VBC immobilization. This might be due to the fact that the patients might have lost some weight during the course of the treatment, and, hence, there could be a cranio-caudal displacement of the patient inside the rigid aquaplast. Our observation parallels what exists in the literature (Table 8).[4,5,14]

There are no studies which can be directly compared with our no-immobilization technique of patient

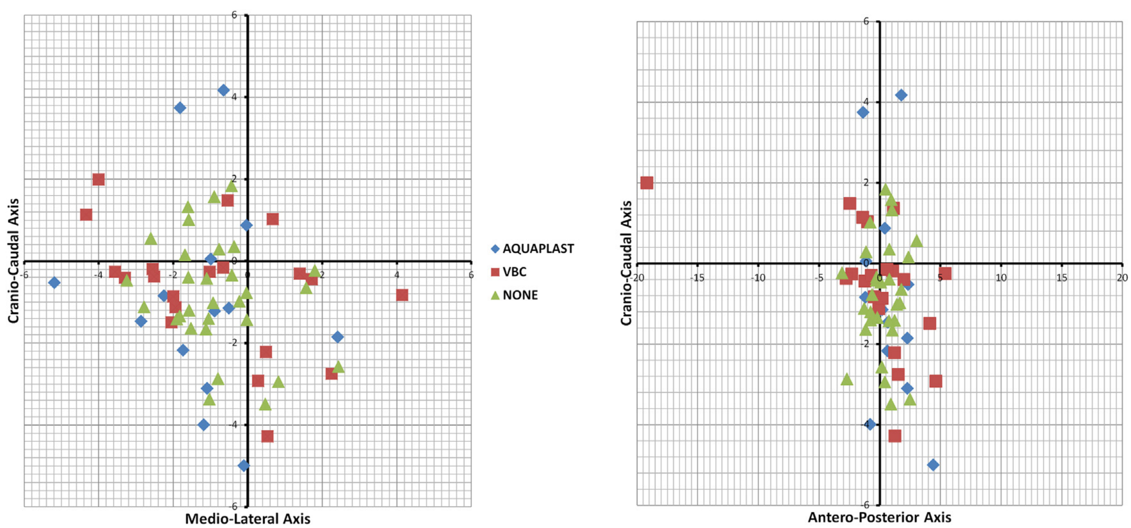

Fig. 2 – Systematic error of three different techniques of Patient positioning represented in the scatter plot.

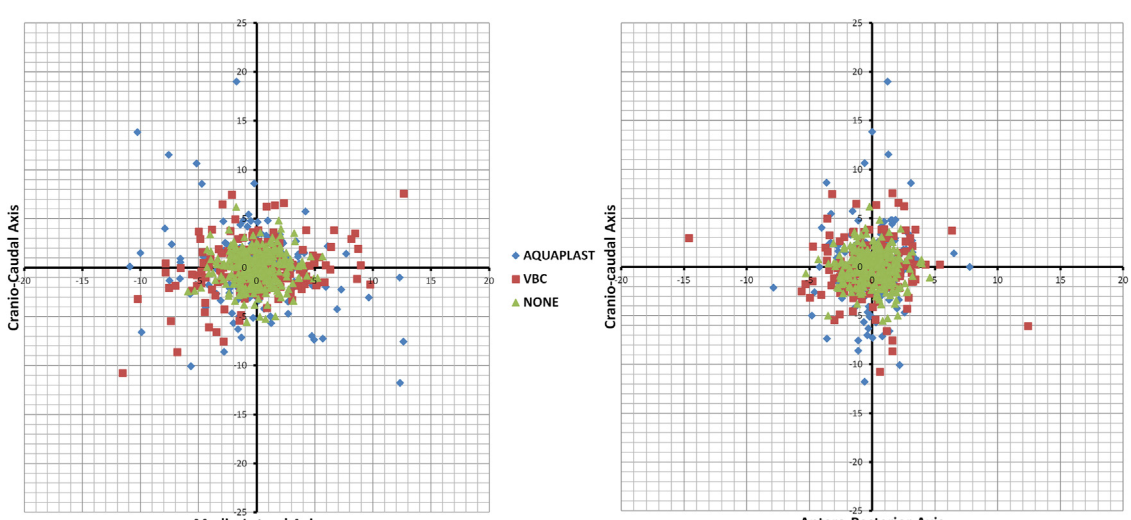

Fig. 3 – Random error of three different techniques of Patient positioning represented in the scatter plot.

Table 2 – The systematic error in patients treated with different positioning techniques.

Systematic error	x (mm)	y (mm)	z (mm)	Yaw (deg)	Pitch (deg)
VBC (N/n; 21/171)	2.55	1.56	4.84	0.68	1.06
Aquaplast (N/n; 14/142)	1.69	2.57	1.69	0.59	1.49
No-immobilization (N/n; 30/290)	1.30	1.39	1.41	0.36	0.44

N = number of patients, n = number of EPID images evaluated.

Table 3 – The random error in patients treated with different positioning techniques.

Random error	x (mm)	y (mm)	z (mm)	Yaw (deg)	Pitch (deg)
VBC (N/n; 21/171)	3.92	2.73	2.57	0.83	1.14
Aquaplast (N/n; 14/142)	4.01	4.15	2.09	1.26	1.29
No-immobilization (N/n; 30/290)	1.89	1.75	1.51	0.59	0.67

N = number of patients, n = number of EPID images evaluated.

Table 4 – Systematic 3D and random 3D error for different positioning techniques.

Type		Systematic 3D error (mean ± 1SD, mm)	Random 3D error (1SD, mm)
VBC (A) (N/n; 21/171)		4.31 ± 3.84	2.96
Aquaplast (B) (N/n; 14/142)		3.39 ± 1.71	3.59
No-immobilization (C) (N/n; 30/290)		2.42 ± 0.97	1.39
Statistical F-test for variance (p value)	(A) vs (B)	0.002	0.007
	(B) vs (C)	0.006	<0.0001
	(A) vs (C)	<0.0001	<0.0001

N = number of patients, n = number of EPID images evaluated.

Table 5 – PTV margins calculated for each of positioning techniques based on the formula by van Herk[2] PTV = 2.5SE + 0.7RE.

Type	x (mm)	y (mm)	z (mm)
VBC	9.108314	5.814478	13.90422
Aquaplast	7.026505	9.324423	5.682745
No-immobilization	4.558218	4.686849	4.588979

Table 6 – Comparison of systematic and random errors calculated from EPID and CBCT respectively.

n/N = 18/86	Systematic error		Random error	
	EPID	CBCT	EPID	CBCT
x (mm)	2.80	3.17	3.19	3.52
y (mm)	4.25	3.99	2.15	2.31
z (mm)	2.27	2.74	2.94	3.06
Yaw (deg)	0.73	0.80	0.72	0.76
Roll (deg)	n/a	0.96	n/a	0.76
Pitch (deg)	1.49	1.16	1.01	1.17
3D error	4.44 ± 3.68	4.95 ± 3.11	2.78 (1SD)	2.77 (1SD)
Statistical F-test for variance	p = 0.25		p = 0.50	

N = number of patients, n = number of EPID/CBCT images evaluated.

positioning. Fiorino et al.[9] reported that the immobilizing only leg is more reproducible than using a pelvic alpha cradle.[9] The immobilization in the legs can be closely comparable to placing a leg separator and maintaining a stable abduction of legs in no-immobilization arm of our study.[9] Song et al.[6] compared four different patient immobilization techniques and suggested that patients treated with different immobilizations did not have significant difference as compared to no-immobilization.[6] On contrary to Song et al.,[6] another study by Bentel et al.[15] reported custom immobilization with hemibody foam cast had better reproducibility than no-immobilization.[6,15] It must be noted that no-immobilization in our study is different and cannot be compared directly to these studies. Catton et al. later reported that simple immobilization of lower limbs below knees significantly improves reproducibility.[16] In our study, the use of a homemade leg separator to maintain a stable abduction in the lower limbs helped in maintaining a more reproducible setup. However, it is worth mentioning that some commercially available devices for lower limb immobilization such as Kneefix TM® may provide a better reproducibility than our home made leg separator. But there is no data comparing the two in the literature.

It is a well established fact that there is subjective variation of manual interpretation of EPID images.[17] Hence, we

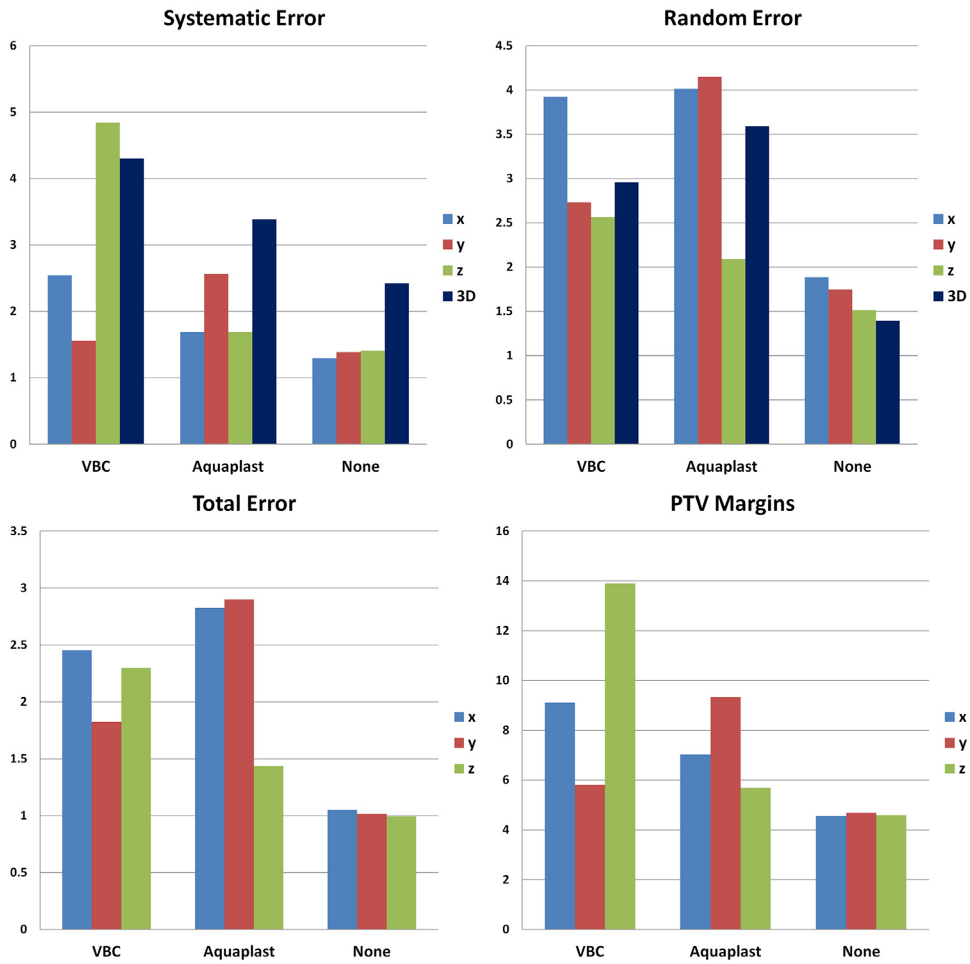

Fig. 4 – Graphical representation of systematic error, random error, total error and PTV margins in the present study. *x*, *y* and *z* represent deviation in medio-lateral, cranio-caudal and antero-posterior axes respectively. 3D represents the 3D vector error for systematic and random deviations.

Table 7 – The studies which have reported systematic error, random error and PTV margins in patients treated with whole body alpha cradle or vaccum bag cushion (VBC).

		Fiorino et al. (1998)[9]	Santanam et al. (2008)[11]	Cheng et al. (2013)[12]	White et al. (2014)[5]	Present study
Systematic error (mm)	x (ML)	2.8	3.7	2.1	0.92	2.55
	y (CC)	1.9	3.6	1.9	0.48	1.56
	z (AP)	3.5	2.4	3.1	0.42	4.84
Random error (mm)	x (ML)	2.4	3.3	1.6	1.5	3.92
	y (CC)	2.5	3.8	1.6	1.2	2.73
	z (AP)	3.1	3.8	2.1	1.0	2.57
PTV (mm) (van Herk method)[2]	x (ML)	8.68	11.56	6.37	3.4	9.11
	y (CC)	6.43	11.66	5.87	2.1	5.82
	z (AP)	10.92	8.66	9.22	1.8	13.90

ML = medio-lateral, CC = cranio-caudal, AP = antero-posterior.

compared the errors measured by CBCT (automatic bone fusion mode) and EPID in a small subset of patients, which showed that both techniques are comparable with less than 1 mm difference. This proves the observations made by us via EPID to be reliable and results valid.

Positioning of the patient receiving pelvic radiotherapy poses distinct challenges as compared to sites like the head and neck. Firstly, there is a lack of skeletal frame work with abundance of soft tissue in the pelvis and lower abdomen, hence, the soft tissues can stretch and deform in an unpredictable manner even inside a rigid immobilization system. Secondly, long legs can significantly displace the hip joints and an equally long and heavy upper segment can deviate, bend and alter the position of the lower abdomen.

Table 8 – Studies which have calculated systematic error, random error and PTV margins in patients treated with aquaplast immobilization system as compared to present study.

		Saini et al. (2014)[4]	Thasanthan et al. (2014)[13]	White et al. (2014)[5]	Yao et al. (2015)[14]	Patni et al. (2017)[3]	Present study
Systematic error (mm)	x (ML)	1.9	2.568	0.44	2.4	1.9	1.69
	y (CC)	2.9	3.284	2.13	2.5	3.5	2.57
	z (AP)	2.0	2.698	0.58	1.6	2.0	1.69
Random error (mm)	x (ML)	4.5	1.628	1.1	2.3	1.3	4.01
	y (CC)	10.9	1.603	4.2	3.1	2.3	4.15
	z (AP)	6.9	2.339	1.2	2.5	1.3	2.09
PTV (mm) (VanHerk method)[2]	x (ML)	7.9	7.56	1.9	7.6	5.66	7.03
	y (CC)	14.88	9.33	8.3	8.3	10.36	9.32
	z (AP)	9.83	8.38	2.3	5.6	5.84	5.68

ML = medio-lateral, CC = cranio-caudal, AP = antero-posterior.

To ensure adequate radiation doses to the clinical target volume (CTV), a geometric expansion called PTV is given.[2,18] It is well documented that there is higher dose to the organs at risk and higher normal tissue complication probability with increased PTV margins.[19,20] It was noted in our study that deviations of more than 5 mm were noted in only 3% of the patients treated with no-immobilization and thus calculated PTV margins were less than 5 mm in all the three dimensions.

In developing countries like India, most of the radiotherapy centres treat 60–80 patients a day.[21] This gives a very short time for each patient on the treatment table. High case load limits the use of frequent image verification and mandates the use of the most reproducible technique. Hence, based on our study we recommend using the no-immobilization technique during pelvic radiotherapy. Also, the no-immobilization technique reduces the treatment cost and is, therefore, more viable economically.

The present study is not without limitations, firstly due to a retrospective study design. Secondly, although CBCT was done on a small subset of patients, only the skeletal displacements were taken into account, internal organ motion or rotational errors cannot be studied adequately with EPID and, finally, we were not able to study the correlation with patient specific factors and technique due to small sample size .

6. Conclusions

No-immobilization technique with a leg separator is the most reproducible technique of patient positioning in the treatment of pelvic malignancies. The use of six point aquaplast system is comparatively more reproducible than the VBC system. In either case they require more frequent on-board image verification compared to no-immobilization technique. No-immobilization technique requires the smallest PTV margins (<5 mm) as compared to the other two techniques.

Conflict of interest

None declared.

Financial disclosure

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