Original Article

Rotational Set Up Uncertainly in Non-6D Couch and its Effects in Clinical Target Volume- Planning Target Volume Margin Calculation for Different Sites

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Abstract

Purpose: The purpose of this study was to estimate and incorporate rotational error to translational error for clinical target volume (CTV) to planning target volume (PTV) margin calculations for non-6D couch. **Materials and Methods:** The study involved cone-beam computed tomography (CBCT) images of the patients who already had treatment in Varian Trilogy Clinac. The different sites studied were brain (70 patients, 406 CBCT images), head and neck (72 patients, 356 CBCT images), pelvis (83 patients, 606 CBCT images), and breast (45 patients, 163 CBCT images). Rotational and translational patient shifts were measured with the help of Varian eclipse offline review. The rotational shift introduces translational shift as it resolved along craniocaudal and mediolateral directions. Both rotational and translational error follow normal distribution and their respective errors were used to calculate CTV-PTV margin using van Herk model. **Results:** Rotational effect on CTV-PTV margin contribution increases with increase in size of CTV. It also increases with increase in distance between center of mass of CTV and isocenter. These margins were more pronounce in single isocenter supraclavicular fossa-Tangential Breast plans. **Conclusions:** There is always rotational error in all sites and it causes shift and rotation of the target. Rotational contribution to the CTV-PTV margin depends upon geometric center of CTV and isocenter distance and also on size of CTV. CTV-PTV margins should incorporate rotational error along with transitional error.

Keywords: Clinical target volume-planning target volume margin, rotational uncertainty, set up errors

Received on: 22-08-2022 **Review completed on:** 06-11-2022 **Accepted on:** 05-12-2022 **Published on:** 18-04-2023

Introduction

Patient set-up errors are inherent in radiotherapy and it would be introduced from simulation to treatment delivery. It compromises the objective of radiotherapy which is to give high dose to the target and minimal dose to the surrounding normal tissues. So set up errors or uncertainties management are very important in radiotherapy.[1-4] To take account of this uncertainty, International Commission on Radiation Units and Measurements in its report number 50 recommends margin, usually a uniform margin, around clinical target volume (CTV) to give planning target volume (PTV) so that CTV receives the prescribed dose.[5] Moreover, image guided radiotherapy using on board imager (OBI) have been used to quantify and correct for patient set-up errors in modern radiotherapy.[6-9] Overlaying of the planning computed tomography (CT) and OBI cone-beam CT (CBCT) images could determine translational and rotational errors.[10] The problem with traditional couch is that it could correct only the translational shift. On the other hand the 6D couches, which are installed in few centers, could also correct rotational shift as well as pitch and roll.[11-13] Hence, the objective of this study was to include rotational set-up error in the calculation of CTV-PTV margin for non-couch. Authors like Zhang *et al*. in their study formulated mathematical relation to show the impact of rotation on margin calculation.[14] Miao *et al*. in their work studied the needs for nonuniform CTV to PTV margin expansion to incorporating both rotational and translational uncertainties.[15] Remeijer *et al*. also in their work on CTV-PTV margins for translational and rotational uncertainties which was a probability-based approach studied rotational effects on set up margins.[16] Chang in his studies

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Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_78_22

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How to cite this article: Robert N, Sehgal T, Singh R, Oinam A, Trivedi G, Singh B, *et al*. Rotational set up uncertainly in non-6D couch and its effects in clinical target volume-planning target volume margin calculation for different sites. J Med Phys 2023;48:43-9.

did differently from above all. He emphasized on the effect of single isocenter for multiple targets for CTV-PTV margin calculations.[17] Their studies were well conducted though they did on few selected particular cases. In the present study, we did extensive study on different cases such as brain, head and neck, pelvis cases, and single isocenter tangential breast and supraclavicular fossa (SCF) for non-6D couch.

Materials and Methods

The study involved CBCT images of the patients who already had image-guided radiotherapy in Varian Trilogy Clinac. This study was performed in four different sites which were brain (70 patients, 406 CBCT images), head and neck (72 patients, 356 CBCT images), pelvis (83 patients, 606 CBCT images), and breast (45 patients, 163 CBCT images). For brain, head and neck, and pelvis cases, the isocenter of the plans were keep at the geometrical center of the CTV/PTV. Moreover, for breast cases, the plans were of single isocenter for both SCF half beam and tangential breast half-beam. All these patients have completed the treatment schedule with CBCT image-guided radiotherapy. In this retrospective study, these CBCT images and planning CT images were overlaid and the translational and rotational patient shifts were measured with the help of Varian Eclipse offline review (Offline Review 11.0). The translational shifts were along vertical (anterior-posterior), longitudinal (superior-inferior [SI]) and lateral (left-right [LR]) directions measure in millimeters and the rotational shifts were only along the frontal plane of the treatment couch (as the study is only in non-6D couch) in degree. From the translational shifts [Table 1], population systematic and random errors were calculated and were used to find the CTV-PTV margin due to transitional error using van Herk model [Tables 3 and 4]. His model provided a simple formula that satisfied the requirement that 90% of the chance the tumor will be covered by 95% of the prescription dose. Furthermore, the patient rotational shifts in frontal plane have components along patients SI and LR and this introduces additional translational shift as it resolved along SI and LR directions [Figure 1]. The population systematic and random error due this rotational effect was independently calculated and then effective systematic and random error was calculated using error propagation method [Table 3]. In Table 4, the CTV-PTV margin with and without taking account of rotational effects were shown.

Statistical analysis

The frequency distribution and normality test of set up error (shifts) were analyzed with IBM SPSS Statistics (Release 20.0.0) software (IBM Corp., Armonk, New York, USA). Results as per many authors' studies show that for large sample size like in this present study, z-score and absolute

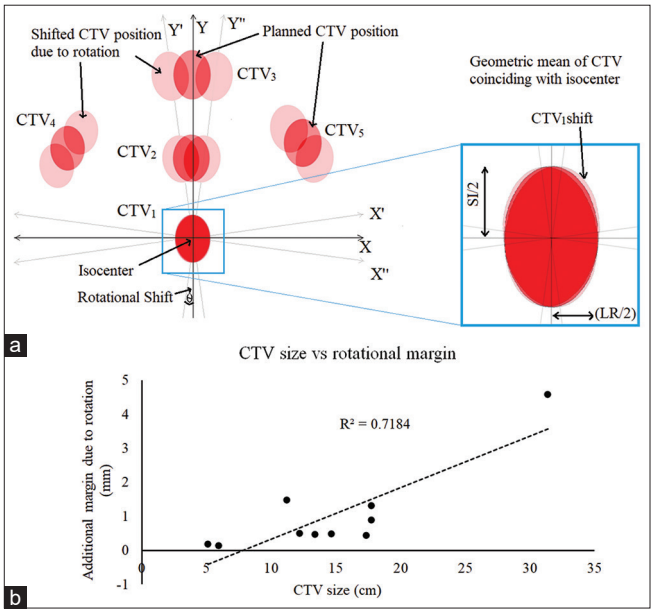

Figure 1: Schematic diagram showing the effects of rotational set up error and need for additional margin due to it for different CTVs located at different distances from isocenter (a). CTV size and its effect on additional margin due to rotational error (b) using table 4. CTV: Clinical target volume

Table 1: Skewness, kurtosis, standard error of skewness and kurtosis and *Z*-score for different sites

Site and sample size (*n*)	VRT			LNG			LAT			ROT		
	Calculated value	SE	*Z*-score	Calculated value	SE	*Z*-score	Calculated value	SE	*Z*-score	Calculated value	SE	*Z*-score
Brain (406)												
Skewness	1.350	0.121	11.148	1.887	0.121	15.576	−0.633	0.121	−5.224	−0.423	0.121	−3.493
Kurtosis	10.287	0.242	42.570	7.866	0.242	32.552	3.499	0.242	14.480	7.755	0.242	32.090
Head and neck (356)												
Skewness	0.721	0.130	5.560	−0.146	0.130	−1.125	0.568	0.130	4.379	−1.020	0.130	−7.871
Kurtosis	10.601	0.259	40.999	8.591	0.259	33.227	5.972	0.259	23.096	15.162	0.259	58.637
Pelvis (606)												
Skewness	−0.911	0.099	−9.167	0.554	0.099	5.574	0.598	0.099	6.015	0.330	0.099	3.319
Kurtosis	1.879	0.199	9.466	7.711	0.199	38.843	3.358	0.199	16.913	6.018	0.199	30.316
Breast (163)												
Skewness	−0.086	0.191	−0.448	0.964	0.191	5.041	−0.122	0.191	−0.636	0.668	0.191	3.490
Kurtosis	0.377	0.380	0.991	3.354	0.380	8.818	2.674	0.380	7.031	3.858	0.380	10.150

SE: Standard error, VRT: Vertical, LNG: Longitudinal, LAT: Lateral, ROT: Rotational

skewness and kurtosis derived from skewness and kurtosis and its standard errors (SE) is a good way to check normality of a distribution.[18-21] The z-scores were calculated with 95% confidence level from skewness and kurtosis using IBM SPSS Statistics. The relation to calculate z-score is given below:

$$Z_{Skewness} = \frac{Skewness - 0}{SE_{Skewness}} \text{ and } Z_{Kurtosis} = \frac{Kurtosis - 0}{SE_{Kurtosis}}$$

Results

The histogram of rotational and translational errors is illustrated in Figures 2-5 and their respective errors were used to calculate CTV-PTV margin using van Herk model.[22] From Figures 2-5, the mean set up errors with standard deviation along vertical, longitudinal, lateral and rotation for brain, head and neck, pelvis, and breast cases are shown in Tables 1and 2. Similarly, Table 3 shows the population systematic and random error due to translational and rotational error and their effective population systematic and random error for the brain, head and neck, pelvis, and breast cases. In Table 4, CTV to PTV margin due to translational set up error only and effective margin after inclusion of rotational effects were shown. From which it was observed that CTV-PTV effective margin for brain increases from 1.53 mm to 1.71 mm for along SI and 1.60 mm to 1.74 mm along LR. For head and neck, it was 2.00 mm to 2.46 mm along SI and 1.99 mm to 2.49 mm along LR. Similarly, for pelvis, it was 2.67 mm to 3.10 mm along SI and 2.70 mm to 3.18 mm along LR. Moreover, for breast (tangential), it increases from 9.32 mm to 13.90 mm along SI and 5.84 mm to 6.72 mm along LR. For breast (SCF), it was 9.32 mm to 10.79 mm along SI and 5.84 mm to 7.14 mm along LR.

Table 2: Mean set up errors with standard deviation along vertical, longitudinal, lateral and rotation for different sites

	Mean set up error			
	VRT (mm)	LNG (mm)	LAT (mm)	ROT (°)
Brain	0.16±1.18	0.10±0.81	0.12±0.79	0.03±0.89
Head and neck	0.20±1.33	0.05±1.01	0.11±0.99	0.07±0.74
Pelvis	0.74±2.42	0.13±1.27	0.21±1.1	0.01±0.67
Breast	0.45±2.41	0.04±3.85	0.39±2.43	0.14±1.93

VRT: Vertical, LNG: Longitudinal, LAT: Lateral, ROT: Rotational

Discussion

Table 1 shows the normality test using z-score, skewness, and kurtosis. From this table, it showed that all distribution follows normal distribution except a moderate departure from normality in breast case along LNG direction. The possible reason could be outliers. For normality test, there are different methods available. All of them are sample size dependent. Shapiro–Wilk test and Kolmogorov–Smirnov test are used for small to medium sized samples (e.g., n <300) but are not accurate for large samples.[18] Visual inspection like boxplot, P-P plot (probability-probability plot), and Q-Q plot (quantile-quantile plot) are used for checking normality visually. This approach is usually unreliable and does not guarantee that the distributions are normal.[19-21] For small samples (n <50), if absolute z-scores for either skewness or kurtosis lie within ± 1.96, then the distribution is normal with alpha level 0.05. For medium-sized samples (50 < n <300), if the absolute z-value is within ± 3.29, then the distribution is

Table 3: Population (translational, rotational and effective) systematic and random error of anterior-posterior, superior-inferior and left-right direction for different treatment sites

Sites and average CTV dimension along SI and LR	Direction	Translational systematic error (Σ_T) (mm)	Translational random error (σ_T) (mm)	Translational systematic error due to rotation error (Σ_R) (mm)	Translational systematic error due to rotation error (σ_R) (mm)	Effective systematic error $\Sigma_E = \sqrt{\Sigma_T^2 + \Sigma_R^2}$ (mm)	Effective random error $\sigma_E = \sqrt{\sigma_T^2 + \sigma_R^2}$ (mm)
Brain	AP	0.67	1.04	DNA	DNA	DNA	DNA
(5.13 cm)	SI	0.40	0.74	0.21	0.34	0.45	0.81
(5.93 cm)	LR	0.42	0.78	0.19	0.31	1.00	0.84
Head and neck	AP	0.80	1.22	DNA	DNA	DNA	DNA
(13.40 cm)	SI	0.54	0.94	0.41	0.60	0.68	1.12
(12.22 cm)	LR	0.52	0.97	0.42	0.63	0.67	2.62
Pelvis	AP	1.43	2.16	DNA	DNA	DNA	DNA
(17.36 cm)	SI	0.70	1.31	0.45	0.63	0.83	1.45
(14.67 cm)	LR	0.71	1.31	0.47	0.71	0.85	1.49
Breast (Tang)	AP	1.55	2.31	DNA	DNA	DNA	DNA
(15.74 cm)	SI	2.85	3.14	3.03	3.90	4.16	5.01
(17.74 cm)	LR	1.70	2.29	0.97	1.29	1.96	2.63
Breast (SCF)	AP	1.55	2.31	DNA	DNA	DNA	DNA
(5.60 cm)	SI	2.85	3.14	1.57	2.13	2.31	3.13
(17.74 cm)	LR	1.70	2.29	0.91	2.43	2.86	3.20

AP: Anterior-posterior, SI: Superior-inferior, LR: Left-right, CTV: Clinical target volume, SCF: Supraclavicular fossa, DNA: Data not available

Table 4: Differences of clinical target volume to planning target volume margin along anterior-posterior, superior-inferior and left-right with and without rotational set up error in margin calculation using van Herk recipe

Sites and average CTV dimension along SI and LR	Direction	CTV-PTV margin due to translational error (van Herk) $2.5\Sigma_T+0.7\sigma_T$ (mm)	CTV-PTV margin due to translational and rotational error (van Herk) $2.5\Sigma_E+0.7\sigma_E$ (mm)	Extra CTV-PTV margin due to inclusion of rotational error (mm)
Brain	AP	3.56	3.56 (DNA for rotation)	DNA
(5.13 cm)	SI	1.53	1.71	0.18
(5.93 cm)	LR	1.60	1.74	0.14
Head and neck	AP	2.85	2.85 (DNA for rotation)	DNA
(13.40 cm)	SI	2.00	2.46	0.46
(12.22 cm)	LR	1.99	2.49	0.50
Pelvis	AP	5.09	5.09 (DNA for rotation)	DNA
(17.36 cm)	SI	2.67	3.10	0.43
(14.67 cm)	LR	2.70	3.18	0.48
Breast (Tang)	AP	5.48	5.48 (DNA for rotation)	DNA
(15.74 cm)	SI	9.32	13.90	4.58
(17.74 cm)	LR	5.84	6.72	0.88
Breast (SCF)	AP	5.48	5.48 (DNA for rotation)	DNA
(5.60 cm)	SI	9.32	10.79	1.47
(17.74 cm)	LR	5.84	7.14	1.30

AP: Anterior-posterior, SI: Superior-inferior, LR: Left-right, CTV: Clinical target volume, SCF: Supraclavicular fossa, DNA: Data not available, PTV: Planning target volume

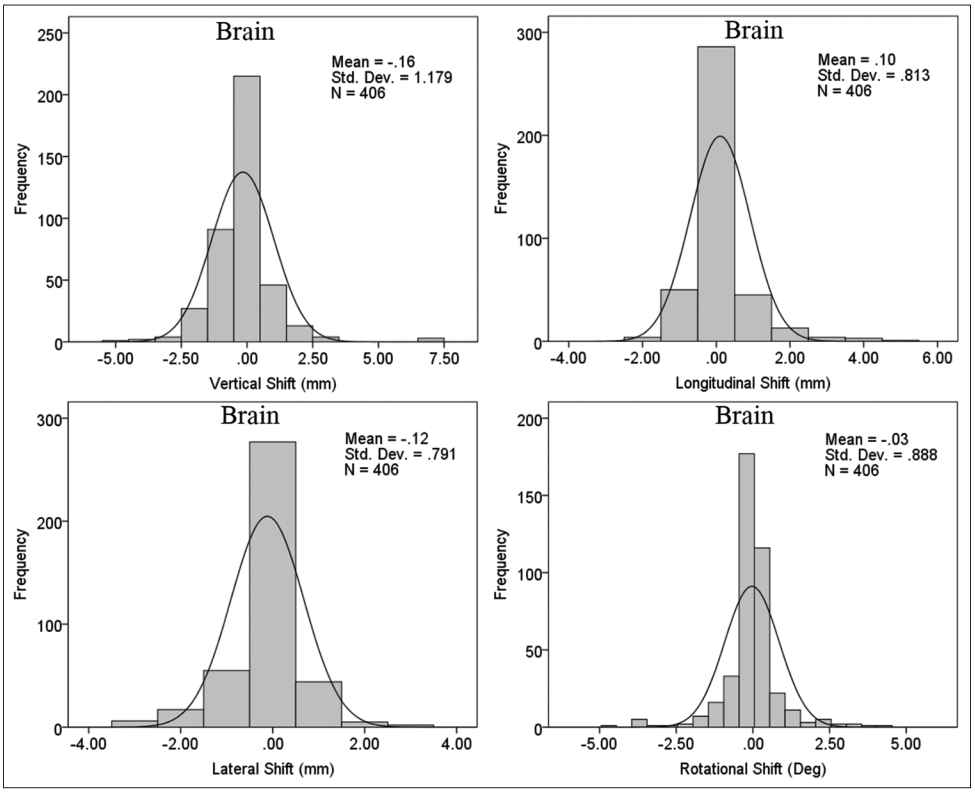

Figure 2: The histogram of translational and rotational shift with mean and standard deviation for brain cases

normal with alpha level 0.05. For sample sizes >300, depend on the histograms and the absolute values of skewness and kurtosis without considering z-values. Either an absolute skewness value smaller than 2 or an absolute kurtosis (proper) smaller than 7 may be used as reference values for determining substantial normality.[18]

From the Table 4, it shows that additional margins are required over and above the margins due to translational effect alone if rotational effects are to be included in CTV-PTV margin calculations. The rotational effects were calculated for SI and LR directions as data were not available (DNA) for vertical direction (pitch-roll information) since the study was done on

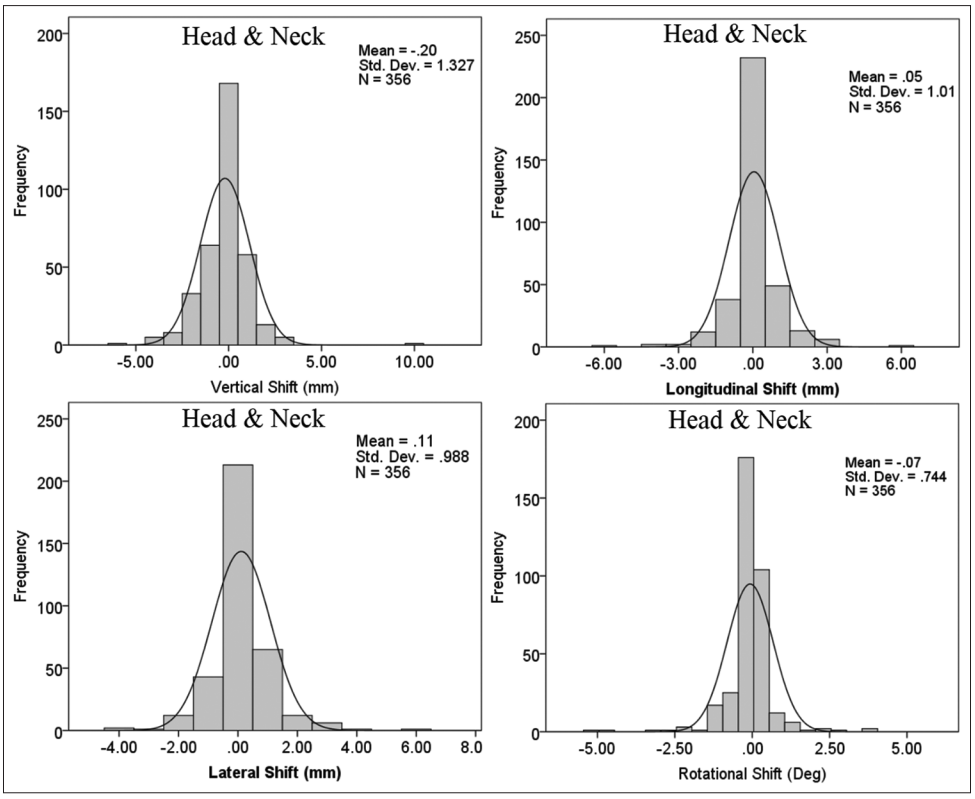

Figure 3: The histogram of translational and rotational shift with mean and standard deviation for head and neck cases

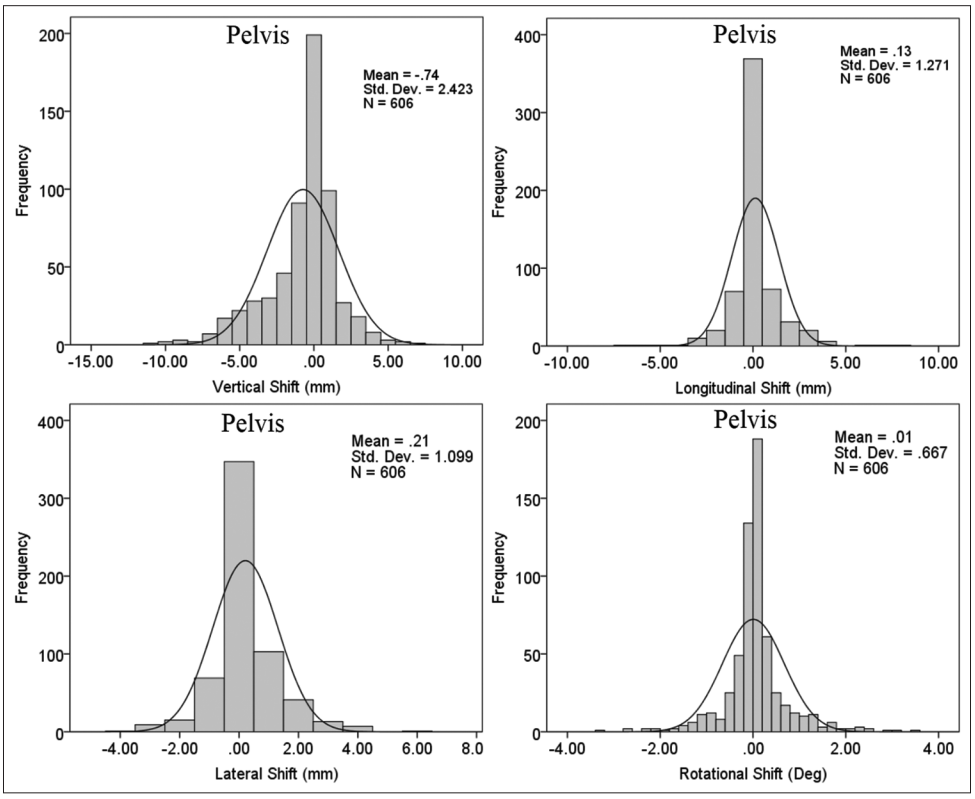

Figure 4: The histogram of translational and rotational shift with mean and standard deviation for pelvis cases

non-6D [Table 4]. The effects of rotational error in patient set up in CTV-PTV margin calculation are observed to increases with increase in size of CTV. This can be observed from the results in Table 3 and 4. Larger is the size of CTV, more will

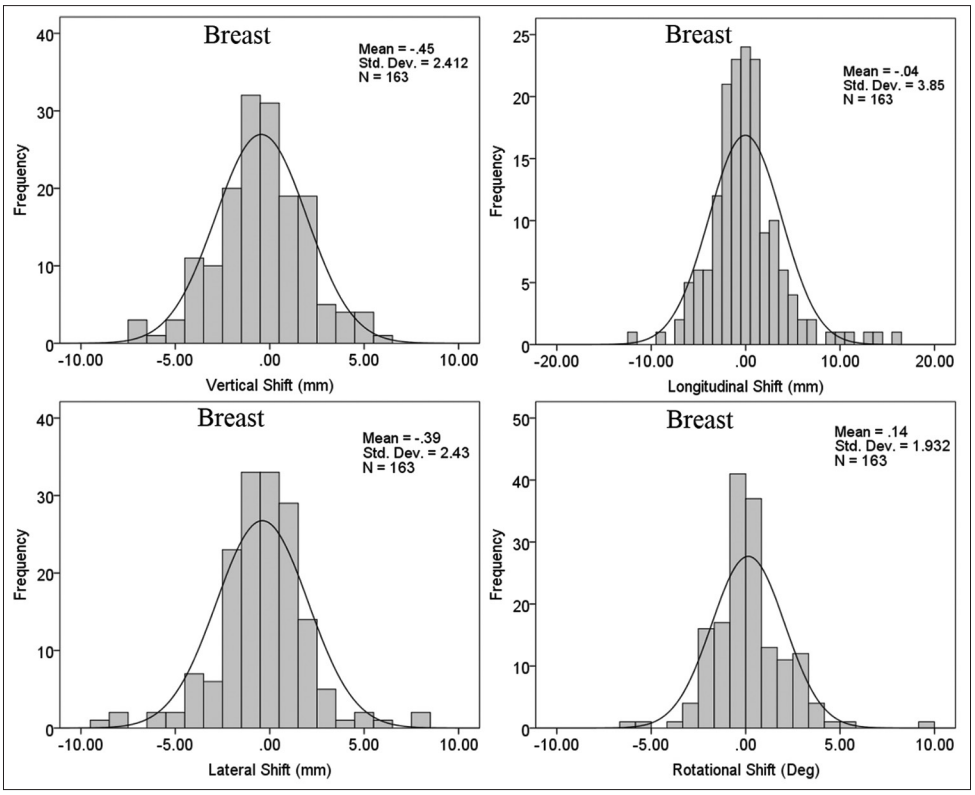

Figure 5: The histogram of translational and rotational shift with mean and standard deviation for breast cases

be the margin to create PTV and vice versa. Figure 1b shows the correlation between size of CTV and additional margin due to rotation. It has good correlation as $R^2 = 0.7184$, $P = 0.002$ and was statistically significant ($P < 0.05$). The average size of CTV along SI and LR for brain cases was 5.13 cm and 5.93 cm, respectively. For head and neck, it was 13.40 cm (along SI) and 12.22 cm (along LR). For pelvis cases, it was 17.36 cm (along SI) and 14.67 cm (along LR). For breast SCF cases, it was 5.6 cm (along SI), 17.74 cm (along LR), and for tangential breast, it was 15.74 cm (along SI) and 17.74 cm (along LR). For brain, head and neck, and pelvis cases, the isocenter of the plans was keep at the geometrical center of the CTV/PTV, whereas for breast cases, the plans were of single isocenter for both SCF half beam and tangential breast half beam. Hence, the size of the breast and SCF measured along SI needs to be double in plotting Figure 1b. Similarly, this effect is also observed to increases with increase in distance between center of mass of CTV and isocenter. Hence, CTV-PTV effective margin for brain increases from 1.53 mm to 1.71 mm for along SI and 1.60 mm to 1.74 mm along LR. For head and neck, it was 2.00 mm to 2.46 mm along SI and 1.99 mm to 2.49 mm along LR. Similarly, for pelvis, it was 2.67 mm to 3.10 mm along SI and 2.70 mm to 3.18 mm along LR. Moreover, for breast (tangential), it was 9.32 mm to 13.90 mm along SI and 5.84 mm to 6.72 mm along LR. For breast (SCF), it was 9.32 mm to 10.79 mm along SI and 5.84 mm to 7.14 mm along LR. Hence, the additional margin due to rotational effects was more pronounce in single isocenter SCF-Tangential Breast plans. This will also have huge impact in multi-target single isocenter SRS plans where the isocenter do not coincide with the center of mass of the CTV, as shown in Figure 1a.

Conclusions

There is always rotational error in all sites and it causes shift and rotation of the target. Rotational contribution to the CTV-PTV margin depends upon geometric center of CTV and isocenter distance and also on size of CTV. CTV-PTV margins should incorporate rotational error along with transitional error.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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