



SITE-SPECIFIC ASSESSMENT OF KILOVOLTAGE IMAGING FOR PATIENT POSITIONING ACCURACY COMPARED WITH CONE-BEAM COMPUTED TOMOGRAPHY IN IMAGE-GUIDED RADIOTHERAPY AT A NIGERIAN TERTIARY HOSPITAL

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ABSTRACT

Cone-beam computed tomography (CBCT) is widely used in image-guided radiotherapy (IGRT) because it provides volumetric verification of patient setup, but routine use may be difficult to sustain in resource-constrained settings. Planar kilovoltage (kV) imaging is faster and simpler, although its positioning accuracy may vary across treatment sites. The research aimed to assess the impact of kV imaging on patient positioning accuracy across different treatment sites compared with CBCT. This prospective within-patient method-comparison study included 39 patient-courses treated at the University of Nigeria Teaching Hospital, comprising breast (n = 9), head and neck (n = 10), spine (n = 10), and pelvis (n = 10). Paired CBCT and orthogonal kV images were acquired on Fractions 1 and 6. Translational couch shifts in the vertical, longitudinal, and lateral directions were analysed using paired t-tests, Bland-Altman analysis, and clinical agreement rates within ± 0.3 cm. Interobserver reliability of kV matching was assessed using intraclass correlation coefficient. Mean three-dimensional differences between kV and CBCT were not significant for breast (0.07 cm; p = 0.158), head and neck (0.04 cm; p = 0.584), and spine (0.095 cm; p = 0.099), but were significant for pelvis (-0.38 cm; p = 0.002). Agreement within ± 0.3 cm was highest in spine (100%), followed by head and neck (80-100%) and breast (66.7–88.9%), while pelvis showed the lowest agreement (50-70%). kV interobserver reliability was good to excellent (ICC = 0.724-0.945). kV imaging can provide clinically acceptable positioning accuracy in relatively rigid treatment sites, especially spine and head and neck, but pelvic cases still require CBCT support.

Keywords: Setup accuracy, Treatment verification, kV imaging, Couch shift

INTRODUCTION

Radiotherapy achieves tumour control only when the prescribed dose is delivered to the intended target volume with adequate geometric precision (Cai *et al.*, 2025). Even small positioning errors may reduce tumour dose and increase irradiation of nearby organs at risk, thereby undermining the therapeutic ratio. For this reason, patient setup verification is a core component of modern radiotherapy rather than a purely technical add-on (Wang and Tepper, 2021).

Image-guided radiotherapy (IGRT) integrates imaging into treatment delivery so that patient anatomy at the treatment couch can be compared with the planning reference immediately before irradiation (Jaffray, 2012). This approach has improved geometric confidence across multiple disease sites and is now central to contemporary external beam radiotherapy practice (Grégoire *et al.*, 2020; Sarma *et al.*, 2024). Among available modalities, Cone-beam computed tomography (CBCT) has become the dominant verification tool because it provides volumetric three-dimensional information and can detect both translational setup error and clinically relevant anatomical change that may not be visible on planar images (Iliopoulos *et al.*, 2023; Wilson *et al.*, 2025). Despite these advantages, CBCT is not cost-free. Repeated acquisitions contribute additional imaging dose, prolong treatment-room occupancy, and may increase maintenance and workflow demands, particularly in low-resource environments where equipment uptime and patient throughput are pressing concerns (Ding *et al.*, 2018; Hope-

Johnson *et al.*, 2025). In Nigeria, where cancer burden remains high and radiotherapy resources are under sustained pressure, a verification strategy that preserves geometric safety while reducing operational burden is of practical importance (FMOH, 2022, Hope-Johnson *et al.*, 2025).

Planar kilovoltage (kV) imaging which is a low dose orthogonal imaging offers that possibility. By matching orthogonal kV radiographs to digitally reconstructed radiographs derived from the planning CT, clinicians can generate translational couch corrections along the vertical, longitudinal, and lateral axes with lower imaging burden than CBCT. Where bony anatomy reliably represents target position, such as in the spine and many head and neck workflows, planar kV imaging may approximate CBCT-derived positioning sufficiently well for routine verification (Çini & Biçakçi, 2023; Grégoire *et al.*, 2020; Wang *et al.*, 2019). However, its performance is expected to be weaker in deformable regions such as the pelvis, where soft-tissue displacement and organ filling limit the usefulness of bony surrogates (Elakshar *et al.*, 2019; Webster *et al.*, 2020).

The available literature is still fragmented because many studies focus on a single anatomical site or use different agreement metrics, making cross-site interpretation difficult. There is also limited prospective evidence from sub-Saharan African radiotherapy centres, where kV-dominant workflows may be especially relevant. The present study therefore assessed, at patient-course level, how closely kV-derived couch shift corrections agreed with CBCT-derived

corrections across breast, head and neck, spine, and pelvis treatments at the University of Nigeria Teaching Hospital. The contribution to knowledge lies in providing a multi-site Nigerian dataset analysed with complementary agreement metrics that reflect not only average difference, but also bias, variability, and clinical tolerance performance. The study therefore offers practical evidence on when planar kV imaging may be acceptable for routine patient positioning and when CBCT should remain the preferred verification modality.

MATERIALS AND METHODS

This was a prospective within-patient method-comparison study conducted at the Radiotherapy Department of the University of Nigeria Teaching Hospital, Ituku-Ozalla, Enugu State, Nigeria. The study included 39 patient-courses recruited between September and December 2025 across four treatment sites: breast (n = 9), head and neck (n = 10), spine (n = 10), and pelvis (n = 10). The study population comprised patients undergoing Image guided radiation therapy (IGRT) who met the inclusion criteria for these anatomical sites. Ethical approval was obtained from the hospital ethics committee before commencement of data collection.

Patients were immobilised using site-appropriate devices, and treatment setup followed the department's routine IGRT workflow. For each patient-course, paired CBCT and orthogonal kV images were obtained on Fraction 1 and Fraction 6, permitting direct same-session comparison of the two modalities. Fractions between and after those paired sessions were verified with kV imaging only, but the primary modality-comparison analysis for this paper was restricted to the paired imaging sessions in order to preserve direct comparability. For each paired session, translational couch shifts in the vertical (X), longitudinal (Y), and lateral (Z)

directions were recorded from both modalities. Patient-course means were then derived from the two paired fractions for each modality.

The main outcome measure was patient positioning accuracy of kV imaging relative to CBCT across treatment sites. Agreement was assessed using paired t-tests for mean differences, Bland-Altman bias and limits of agreement, and clinical agreement rates within ± 0.3 cm per axis, with supplementary interpretation at stricter thresholds. Overall translational discrepancy was also summarised using 3D displacement magnitude. To evaluate the reproducibility of kV matching, two independent reviewers performed the kV registrations, and interobserver reliability was calculated using the intraclass correlation coefficient (ICC). Statistical significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

Within-course assessment showed that early and late kV-derived three-dimensional shifts did not differ significantly for breast, head and neck, pelvis, or spine, indicating that kV positioning behaviour remained stable across the treatment course and that the paired-session comparison on Fractions 1 and 6 was representative of routine kV performance.

Table 1 shows the descriptive setup shifts for both modalities. For breast, head and neck, and spine, mean axis-level shifts were small and generally similar between kV and CBCT. Pelvis showed the clearest divergence, with substantially larger CBCT-derived vertical shifts and larger three-dimensional displacement magnitude than kV. This pattern is consistent with the known influence of bladder filling, rectal volume change, and soft-tissue displacement in pelvic radiotherapy, which cannot be adequately represented by planar bony matching alone (Elakshar *et al.*, 2019; Webster *et al.*, 2020).

Table 1: Descriptive Summary of Mean Setup Shifts (Cm) For Kv and CBCT by Site and Axis

Site	Axis	N	kV Mean \pm SD (cm)	kV Range (cm)	CBCT Mean \pm SD (cm)	CBCT Range (cm)
Breast	Vertical (X)	9	0.18 \pm 0.09	-0.01-0.30	0.05 \pm 0.11	-0.16-0.17
Breast	Longitudinal (Y)	9	0.13 \pm 0.14	-0.08-0.33	0.07 \pm 0.06	-0.01-0.18
Breast	Lateral (Z)	9	0.13 \pm 0.16	-0.17-0.29	-0.09 \pm 0.23	-0.46-0.19
Breast	3D magnitude	9	0.33 \pm 0.07	0.23-0.46	0.25 \pm 0.12	0.06-0.50
Head and neck	Vertical (X)	10	-0.03 \pm 0.14	-0.26-0.21	-0.03 \pm 0.11	-0.16-0.17
Head and neck	Longitudinal (Y)	10	0.16 \pm 0.20	-0.15-0.50	-0.04 \pm 0.12	-0.24-0.16
Head and neck	Lateral (Z)	10	0.08 \pm 0.11	-0.05-0.26	0.02 \pm 0.25	-0.19-0.54
Head and neck	3D magnitude	10	0.29 \pm 0.13	0.10-0.56	0.25 \pm 0.15	0.05-0.57
Spine	Vertical (X)	10	0.03 \pm 0.19	-0.35-0.26	-0.01 \pm 0.05	-0.08-0.07
Spine	Longitudinal (Y)	10	0.08 \pm 0.10	-0.14 -0.19	0.00 \pm 0.07	-0.14-0.07
Spine	Lateral (Z)	10	-0.04 \pm 0.12	-0.17-0.18	-0.04 \pm 0.16	-0.41-0.10
Spine	3D magnitude	10	0.24 \pm 0.09	0.15 -0.42	0.14 \pm 0.10	0.05-0.42
Pelvis	Vertical (X)	10	0.01 \pm 0.14	-0.21-0.16	0.24 \pm 0.37	-0.51-0.62
Pelvis	Longitudinal (Y)	10	-0.03 \pm 0.18	-0.29- 0.28	-0.08 \pm 0.39	-0.56-0.61
Pelvis	Lateral (Z)	10	0.07 \pm 0.11	-0.03-0.34	0.20 \pm 0.28	-0.19-0.63
Pelvis	3D magnitude	10	0.24 \pm 0.10	0.13-0.46	0.62 \pm 0.25	0.26-0.99

Note. 3D magnitude = $\sqrt{(X^2 + Y^2 + Z^2)}$. Values are patient-course means averaged across Fractions 1 and 6.

The paired modality analysis confirmed that mean three-dimensional differences between kV and CBCT were not statistically significant for breast, head and neck, or spine, but were significant for pelvis. Specifically, the mean three-dimensional difference was 0.07 cm for breast ($p = .158$), 0.04 cm for head and neck ($p = .584$), and 0.10 cm for spine ($p = .099$), whereas pelvis recorded a mean difference of -0.38 cm ($p = .002$). These findings suggest that, on average, planar kV imaging can approximate CBCT-derived translational

corrections in relatively rigid treatment sites, but not in pelvic treatments where internal anatomy is more variable (Grégoire *et al.*, 2020; Webster *et al.*, 2020).

Axis-level analysis revealed important directional effects that would have been obscured by three-dimensional summary alone. Significant differences were observed in breast vertical and lateral shifts, head and neck longitudinal shifts, and pelvic vertical shifts, while no axis-level difference reached significance in spine. In breast radiotherapy, this likely

reflects sensitivity of lateral matching to arm position, chest wall geometry, and breathing state, which has also been reported in previous comparisons of planar imaging and volumetric guidance (Topolnjak *et al.*, 2010; Wang *et al.*,

2019). In head and neck, the longitudinal discrepancy is plausibly related to shoulder position and mask fit, as described in earlier image-guidance studies (Kang *et al.*, 2010).

Table 2: Paired T-Test Comparison of Kv versus CBCT Couch Shifts (Cm) By Site and Axis

Site	Axis	N	Mean kV (cm)	Mean CBCT (cm)	Mean difference (cm)	t	p	95% CI (cm)
Breast	Vertical (X)	9	0.180	0.049	0.131	2.34	.047	0.00-0.26
Breast	Longitudinal (Y)	9	0.127	0.067	0.060	0.98	.355	-0.08 -0.20
Breast	Lateral (Z)	9	0.129	-0.094	0.223	3.29	.011	0.07- 0.38
Breast	3D magnitude	9	0.327	0.255	0.072	1.56	.158	-0.03-0.18
Head and neck	Vertical (X)	10	-0.026	-0.025	-0.001	-0.03	.980	-0.11-0.11
Head and neck	Longitudinal (Y)	10	0.164	-0.036	0.201	4.25	.002	0.09-0.31
Head and neck	Lateral (Z)	10	0.080	0.022	0.058	1.00	.345	-0.07-0.19
Head and neck	3D magnitude	10	0.288	0.249	0.039	0.57	.584	-0.12-0.19
Spine	Vertical (X)	10	0.034	-0.012	0.046	0.85	.417	-0.08-0.17
Spine	Longitudinal (Y)	10	0.084	0.004	0.080	1.93	.086	-0.01-0.17
Spine	Lateral (Z)	10	-0.040	-0.038	-0.002	-0.03	.975	-0.13-0.12
Spine	3D magnitude	10	0.238	0.142	0.095	1.84	.099	-0.02- 0.21
Pelvis	Vertical (X)	10	0.014	0.243	-0.229	-2.99	.015	-0.40 -0.06
Pelvis	Longitudinal (Y)	10	-0.030	-0.082	0.052	0.41	.689	-0.23-0.34
Pelvis	Lateral (Z)	10	0.068	0.204	-0.136	-1.53	.160	-0.34-0.07
Pelvis	3D magnitude	10	0.237	0.617	-0.380	-4.46	.002	-0.57-(-0.19)

Note. Mean difference = kV-CBCT.

Bland-Altman analysis further clarified the difference between statistical similarity and clinical interchangeability. Even in spine, where paired t-tests were non-significant, the lateral axis limits of agreement extended from -0.35 cm to 0.34 cm, indicating that some individual patient-courses still showed differences approaching 3.5 mm between modalities. In head and neck, the longitudinal axis showed asymmetric limits of agreement (-0.09 cm to 0.49 cm), suggesting a tendency for kV to underestimate corrections that CBCT would prescribe in that direction. Thus, non-significant mean difference should not be interpreted as perfect equivalence when treatment margins are tight (van Herk *et al.*, 2000).

Pelvis again showed the poorest agreement, especially in the longitudinal direction where limits of agreement spanned from -0.73 cm to 0.83 cm. This very wide range indicates poor interchangeability, even though the mean bias itself was modest. In practical terms, the two methods may agree on average while diverging substantially for individual patients, which makes kV-only positioning unsafe when soft-tissue displacement is clinically important. Similar concerns have been reported in pelvic image-guided radiotherapy studies comparing planar and volumetric verification methods (Elakshar *et al.*, 2019; Eren *et al.*, 2020; Webster *et al.*, 2020).

Table 3: Bland-Altman Bias And 95% Limits Of Agreement (Cm) For Kv versus CBCT by Site and Axis

Site	Axis	N	Bias (cm)	SD of difference (cm)	95% limits of agreement (cm)
Breast	Vertical (X)	9	0.131	0.168	-0.20-0.46
Breast	Longitudinal (Y)	9	0.060	0.182	-0.30-0.42
Breast	Lateral (Z)	9	0.223	0.204	-0.18-0.62
Head and neck	Vertical (X)	10	-0.001	0.151	-0.30-0.29
Head and neck	Longitudinal (Y)	10	0.201	0.149	-0.09-0.49
Head and neck	Lateral (Z)	10	0.058	0.183	-0.30-0.42
Spine	Vertical (X)	10	0.046	0.172	-0.29- 0.38
Spine	Longitudinal (Y)	10	0.080	0.132	-0.18-0.34
Spine	Lateral (Z)	10	-0.002	0.176	-0.35-0.34
Pelvis	Vertical (X)	10	-0.229	0.242	-0.70-0.24
Pelvis	Longitudinal (Y)	10	0.052	0.399	-0.73- 0.83
Pelvis	Lateral (Z)	10	-0.136	0.282	-0.69-0.42

Note. Bias = mean difference (kV - CBCT). Limits of agreement = bias \pm 1.96 \times SD.

Note. Bias = mean difference (kV - CBCT). Limits of agreement = bias \pm 1.96 \times SD of the paired difference.

Clinical tolerance pass rates translated the statistical findings into treatment-room relevance. Spine achieved 100% agreement within 0.3 cm across all axes, indicating that every spine patient-course had kV and CBCT corrections within 3 mm of each other. Head and neck also performed strongly, with pass rates of 80% to 100%, while breast showed acceptable but less consistent agreement, especially in the lateral axis where only 66.7% of patient-courses met the 3 mm

threshold. These findings suggest that planar kV imaging may be a reasonable routine verification option for rigid sites, but that caution is needed in breast treatments where lateral mismatch may persist (Topolnjak *et al.*, 2010; Wang *et al.*, 2019).

Pelvis performed substantially worse, with only 50% of patient-courses meeting the 0.3 cm threshold in the vertical and longitudinal axes. At stricter thresholds, agreement

declined further across all sites, but the rank order remained unchanged, with spine best and pelvis worst. This pattern is clinically relevant because systematic modality-dependent differences increase the margin required to maintain adequate

target coverage, and van Herk's margin framework highlights the particularly strong impact of systematic error on population dose delivery (van Herk *et al.*, 2000).

Table 4: Clinical Agreement Rates between Kv and CBCT within Tolerance Thresholds by Site and Axis

Site	Axis	N	≤ 0.3 cm, n (%)	≤ 0.2 cm (%)	≤ 0.1 cm (%)
Breast	Vertical (X)	9	8 (88.9)	66.7	22.2
Breast	Longitudinal (Y)	9	8 (88.9)	77.8	44.4
Breast	Lateral (Z)	9	6 (66.7)	55.6	33.3
Head and neck	Vertical (X)	10	10 (100.0)	90.0	20.0
Head and neck	Longitudinal (Y)	10	8 (80.0)	60.0	30.0
Head and neck	Lateral (Z)	10	10 (100.0)	70.0	30.0
Spine	Vertical (X)	10	10 (100.0)	100.0	40.0
Spine	Longitudinal (Y)	10	10 (100.0)	80.0	50.0
Spine	Lateral (Z)	10	10 (100.0)	80.0	30.0
Pelvis	Vertical (X)	10	5 (50.0)	40.0	10.0
Pelvis	Longitudinal (Y)	10	5 (50.0)	40.0	20.0
Pelvis	Lateral (Z)	10	7 (70.0)	50.0	10.0

Note. Tolerances were applied axis-wise to the absolute kV - CBCT difference per patient-course.

Interobserver reliability of kV-based registrations was good to excellent across all sites and axes, with ICC values from 0.724 to 0.945. Mean differences between observers were small, and limits of agreement were narrow, indicating that the kV registration process was reproducible and that the observed differences between kV and CBCT were not simply due to inconsistent matching by different reviewers. This finding supports the suitability of kV imaging for routine clinical workflows where multiple staff may perform image registration on different treatment days (Koo and Li, 2016; Quinn *et al.*, 2023).

Taken together, the results point to a site-selective strategy for image guidance. Spine showed the strongest case for kV-based setup verification because the vertebral column provides a rigid and radio graphically conspicuous surrogate for treatment position. Head and neck also showed generally acceptable agreement, although longitudinal uncertainty deserves attention where margins are tight. Breast was broadly acceptable but less robust in the lateral direction. Pelvis remained the clear exception because the dominant uncertainty is internal soft-tissue motion rather than bony alignment. In that setting, CBCT should remain the preferred setup verification modality because it provides the volumetric information required to detect clinically important anatomical change (Grégoire *et al.*, 2020; Webster *et al.*, 2020; Wilson *et al.*, 2025).

CONCLUSION

Planar kV imaging demonstrated clinically acceptable patient positioning accuracy relative to CBCT in breast, head and neck, and especially spine treatment sites, where overall 3D differences were small and non-significant and agreement within ± 0.3 cm was high. However, pelvic treatments showed significantly poorer agreement, indicating that kV imaging is less reliable in anatomically variable regions where soft-tissue motion and organ filling contribute substantially to setup uncertainty. These findings suggest that kV imaging can support efficient routine setup verification in relatively rigid sites, but CBCT should remain the preferred modality when internal anatomical variability is likely to compromise planar matching accuracy.

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