UNIJERPS
Unizik Journal of Educational Research and Policy Studies VOL.21 (2);
January-June, 2026 https://unijerps.org
2023 Impact Factor: **6.834;** 2022 ***Impact Factor***: 5.156; ***2021 Impact Factor: 5.641;***
2020 Impact Factor: 5.355. *Indexing and Impact Factor URL: http://sjifactor.com/passport.php?id=21363*

AGREEMENT OF KV PLANAR IMAGING AND CBCT FOR PATIENT POSITIONING IN IMAGE-GUIDED RADIOTHERAPY: A MULTI-SITE ASSESSMENT OF SETUP ACCURACY, CLINICAL AGREEMENT, AND BIAS CORRECTION

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ABSTRACT

Background*: Highly conformal radiotherapy requires precise daily patient positioning to prevent target underdosing or normal tissue toxicity. While CBCT provides comprehensive 3D volumetric data that accounts for soft tissue variations, planar kV imaging is faster and more efficient, making it crucial to evaluate where 2D bony landmarks serve as an acceptable surrogate for 3D localization. Aim: To assess the impact of kV imaging on patient positioning accuracy across diverse treatment sites compared to CBCT, and to evaluate axis-specific setup agreement utilizing 3D displacement magnitudes and clinical tolerance thresholds. Methods:*

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Using a prospective within-patient design at the University of Nigeria Teaching Hospital, 39 patients were evaluated across breast (N=9), head and neck (N=10), pelvis (N=10), and spine (N=10) cohorts. A total of 392 measurements (77 CBCT and 315 kV) were captured. Same-session paired kV and CBCT scans were taken at fractions 1 and 6 to assess translational couch shifts (vertical, longitudinal, lateral) and 3D vector magnitudes. Analysis was executed via paired t-tests, Bland-Altman limits of agreement, interobserver reliability statistics, and clinical pass rates within a strict ±3{mm} tolerance. Results: Treatment fractional distributions matched perfectly (1:1) between verification imaging and delivered dose fractions. The spine demonstrated perfect pre-calibration agreement (100.00) across all axes with compressed CBCT standard deviations (SD =0.05 {cm} vertical, & 0.07 {cm} longitudinal). Head and neck setups showed excellent agreement (100.00 vertical/lateral), except for a significant longitudinal discrepancy where kV over-shifted by 0.201 {cm} & p=0.002). Breast setups showed moderate agreement but a dropped lateral pass rate (66.67, p=0.011) reflecting tissue compliance. The pelvis exhibited severe disagreement; planar kV heavily understated misalignments compared to CBCT, which revealed large mean shifts (vertical: 0.24 {cm}, lateral: 0.20 {cm} and massive volatile SDs (0.37 - 0.39 {cm}), collapsing pre-calibration vertical and longitudinal clinical agreement to a coin-flip 50.00. Conclusion: Positional agreement between modalities is heavily site-dependent. Planar kV imaging achieves clinically acceptable setup accuracy within a ± 3{mm} tolerance for rigid bony anatomy (spine and head/neck). Conversely, planar imaging possesses critical blind spots regarding internal organ motion and soft-tissue deformation in the pelvis, meaning CBCT remains clinically indispensable in this region to prevent geographical target misses.

Keywords: Image-Guided Radiotherapy (IGRT); Patient Positioning; Setup Accuracy; Planar kV Imaging; Cone Beam Computed Tomography (CBCT); Interfraction Variation; Clinical Tolerance Pass Rate.

Introduction

Image-guided radiotherapy (IGRT) has become central to modern radiation oncology because accurate daily patient positioning is necessary to ensure that the prescribed dose is delivered to the target while sparing surrounding normal tissues. Even when treatment planning is highly conformal, the delivered dose can be undermined by setup variation, organ filling, respiratory motion, and anatomical change across fractions (Liang et al, 2021; Kuo et al, 2021). CBCT provides three-dimensional verification and is especially useful when soft tissue anatomy or internal organ motion is important, but it is more time-consuming and adds imaging dose compared with planar kV imaging (Baskar, 2012). The clinical challenge is therefore not simply whether imaging should be used, but which imaging modality gives sufficient geometric accuracy at the lowest reasonable burden. In rigid anatomical sites such as spine and parts of head and neck, planar kV imaging may be adequate because bony anatomy is a stable surrogate for target position (Opele & Adepoju, 2024). In more variable regions such as the pelvis, however, bony alignment may not fully represent internal target position because bladder and rectal filling can change the true location of the target from day to day. This study was designed to test that site dependence directly using paired comparisons of kV and CBCT couch shifts.

Objectives

1. To assess the impact of kV imaging on patient positioning accuracy across different treatment sites compared with CBCT.
2. To evaluate kV-CBCT setup agreement using axis-specific tolerances and three-dimensional displacement magnitude.

Methods

The study used a prospective within-patient method-comparison design at the University of Nigeria Teaching Hospital, Enugu. Thirty-nine patients were recruited across four treatment sites: breast, head and neck, spine, and pelvis. A total of 392 measurements were recorded, comprising 77 CBCT measurements and 315 kV measurements. Paired same-session CBCT and orthogonal kV acquisitions were obtained on Fractions 1 and 6, while other fractions were verified with kV only. Patients were immobilized with site-specific devices, and setup verification data were extracted from the oncology information system. CBCT images were registered to the planning CT, while orthogonal kV images were matched to planning DRRs (AAPM, 2018). Translational couch shifts were recorded in the vertical, longitudinal, and lateral directions, and 3D displacement magnitude was computed as X2+Y2+Z2\sqrt{X^2 + Y^2 + Z^2}X2+Y2+Z2. The main comparisons used paired t-tests, Bland-Altman analysis, tolerance-based agreement rates, and interobserver reliability statistics

Results

Table 1. Patient treatment course distribution by site

Site	N	Median kV fractions	Max kV fractions	Median dose fractions	Max dose fractions
Breast	9	10.0	10	10.0	10
Head & Neck	10	5.5	8	5.5	8
Pelvis	10	7.0	8	7.0	8
Spine	10	8.0	8	8.0	8

Table 1 shows that the treatment courses were not identical across sites, which is important because the number of verification fractions affects how much positional variability can be observed. This table outlines the patient cohort and treatment course distribution across four distinct anatomical sites, detailing the sample size (n), the number of localization imaging fractions (Median and Max kV fractions), and the corresponding delivered radiation fractions (Median and Max dose fractions). A fundamental takeaway from this dataset is the exact mathematical matching between the number of kV imaging fractions and the total dose fractions across all cohorts (e.g., a median of 10.0 kV fractions corresponds to exactly 10.0 dose fractions for the breast). This perfect pairing indicates a rigorous clinical protocol where every single treatment fraction is preceded by planar verification imaging, ensuring a 1:1 ratio of setup validation to radiation delivery throughout the entire course of therapy.

The Breast cohort consists of 9 patients who underwent a highly uniform treatment regimen. Both the median and maximum

values for kV fractions and dose fractions are identical at 10. This lack of variation indicates that every single patient in this group received exactly 10 fractions of radiation, and each fraction was paired with daily imaging. Clinically, a 10-fraction regimen is characteristic of an accelerated, hypofractionated course of breast irradiation (such as a boost or a short-course whole breast protocol), where scheduling uniformity is strictly maintained across the patient volume.

The remaining three cohorts Head & Neck, Pelvis, and Spine, each consist of 10 patients and follow a highly structured, shorter hypofractionated treatment paradigm, capped at a maximum of 8 fractions. For the Spine group, the median and maximum fractions are perfectly aligned at 8.0, showing that all 10 patients completed an identical 8-fraction treatment course with daily imaging. This uniformity is common in palliative spinal regimens or specialized stereotactic courses designed to maximize local tumor control while sparing the adjacent spinal cord.

In contrast, the Head & Neck and Pelvis cohorts display fractional variation within their patient pools. The Pelvis group features a maximum course length of 8 fractions but a lower median of 7.0 fractions, revealing that a portion of the cohort completed their radiation course early or were prescribed a slightly shorter regimen. The Head & Neck cohort demonstrates the lowest median course length at 5.5 fractions, despite possessing a maximum cap of 8 fractions. This split indicates an uneven distribution of treatment lengths among the 10 patients (for example, an equal split between patients receiving 5 fractions and those receiving 6 or 8 fractions). Such variation in the head, neck, and pelvic regions is typically reflective of individualized clinical decision-making, where fractional volume and prescription lengths are tailored to specific staging, palliative intent, or patient tolerance.

Table 2. Mean setup shifts by site and modality

Site	Axis	kV Mean ± SD (cm)	CBCT Mean ± SD (cm)
Breast	Vertical	0.18 ± 0.09	0.05 ± 0.11
Breast	Longitudinal	0.13 ± 0.14	0.07 ± 0.06
Breast	Lateral	0.13 ± 0.16	-0.09 ± 0.23
Breast	3D magnitude	0.33 ± 0.07	0.25 ± 0.12
Head & Neck	Vertical	-0.03 ± 0.14	-0.03 ± 0.11
Head & Neck	Longitudinal	0.16 ± 0.20	-0.04 ± 0.12
Head & Neck	Lateral	0.08 ± 0.11	0.02 ± 0.25
Head & Neck	3D magnitude	0.29 ± 0.13	0.25 ± 0.15
Spine	Vertical	0.03 ± 0.19	-0.01 ± 0.05
Spine	Longitudinal	0.08 ± 0.10	0.00 ± 0.07
Spine	Lateral	-0.04 ± 0.12	-0.04 ± 0.16
Spine	3D magnitude	0.24 ± 0.09	0.14 ± 0.10
Pelvis	Vertical	0.01 ± 0.14	0.24 ± 0.37
Pelvis	Longitudinal	-0.03 ± 0.18	-0.08 ± 0.39
Pelvis	Lateral	0.07 ± 0.11	0.20 ± 0.28
Pelvis	3D magnitude	0.24 ± 0.10	0.16 ± 0.25

Table 2 suggests that the pelvic site showed larger variability in CBCT than in kV, which is consistent with internal anatomy changes being better captured by volumetric imaging. The table details the mean setup shifts and standard deviations (SD) across four anatomical treatment sites, comparing planar kilo-voltage (kV) imaging with three-dimensional Cone Beam Computed Tomography (CBCT). The mean values reflect the average directional trends of patient misalignments, where positive or negative values dictate the spatial orientation of the shift. Meanwhile, the standard deviations are a critical clinical metric representing setup variability and precision; higher standard deviations signal unreliability and erratic day-to-day patient positioning, directly expanding the required margins to avoid missing the intended target. Overall, the data illustrates that 3D volumetric imaging consistently reveals complex spatial variations that 2D planar images oversimplify or completely obscure.

For Breast treatments, planar kV imaging generally registers larger mean shifts than CBCT, yielding an overall 3D vector magnitude of 0.33{cm}compared to CBCT's 0.25{cm}. This inflation is especially pronounced in the Vertical axis (0.18{ cm} vs. 0.05{ cm}). However, the standard deviation for CBCT in the Lateral axis (0.23{ cm} is significantly larger than its kV counterpart (0.16{ cm}. This broader spread indicates that while planar imaging tracks stable, superficial bony anatomy or skin markers, 3D volumetric imaging is actively capturing the irregular, non-rigid deformation and swelling of soft breast tissue, which introduces substantial day-to-day spatial dispersion.

In the Head & Neck cohort, the two modalities display comparable overall 3D shift magnitudes (0.29{cm} for kV vs. 0.25 {cm} for CBCT) and mirror each other perfectly in the Vertical axis (both at -0.03 {cm}. A notable divergence occurs in the Longitudinal axis, where kV registers a clear forward shift of 0.16{cm} while CBCT shows a slight negative shift of -0.04 {cm}. Furthermore, the standard deviation for the CBCT Lateral axis (0.25 {cm} is more than double that of the kV axis (0.11 {cm}. This tells us that while a thermoplastic mask provides rigid, visible alignment boundaries on a 2D radiograph, a 3D volumetric scan exposes subtle lateral head rotations and variations in soft tissue anatomy inside the mask that planar imaging overlooks.

The Spine displays the highest level of setup precision in the dataset, particularly when evaluated via CBCT. Volumetric imaging brings the mean shifts down to nearly zero across all three primary axes (Vertical: -0.01{cm}, Longitudinal: 0.00{cm}, Lateral: -0.04\text{cm}. Crucially, CBCT demonstrates remarkably narrow standard deviations in the Vertical (0.05 {cm} and Longitudinal (0.07 {cm} directions compared to the wider spreads seen in kV imaging (0.19{cm} and 0.10 {cm}, respectively). This compression of variance underscores the superior accuracy of CBCT for spine tracking; by visualizing the bony vertebrae in three dimensions, it eliminates the parallax errors and landmark ambiguities inherent to 2D planar views, confirming highly reproducible setups.

Conversely, the Pelvis results demonstrate a severe increase in both shift magnitude and variability when moving from planar to volumetric imaging. Planar kV imaging heavily underestimates pelvic

misalignments, capturing almost zero mean shift in the Vertical (0.01 {cm} and Longitudinal (-0.03\text{cm} axes. However, CBCT reveals substantial mean shifts of 0.24 {cm} vertically and 0.20 {cm}laterally. Most alarmingly, the standard deviations for CBCT skyrocket to 0.37 {cm} longitudinally and 0.39 {cm} vertically, dwarfing the tighter kV spreads. This massive volatility highlights the blind spots of planar imaging in the pelvic region. While 2D radiographs falsely suggest a stable setup by aligning to the rigid pelvic girdle, 3D CBCT exposes massive internal variations caused by unpredictable bladder and rectal filling, proving that relying solely on planar kV imaging leaves pelvic targets highly vulnerable to geographical miss.

Table 3. Paired t-test comparison of kV and CBCT

Site	Axis	Mean Difference (kV - CBCT) cm	p-value
Breast	Vertical	0.131	0.047
Breast	Longitudinal	0.060	0.355
Breast	Lateral	0.223	0.011
Breast	3D magnitude	0.072	0.158
Head & Neck	Vertical	-0.001	0.980
Head & Neck	Longitudinal	0.201	0.002
Head & Neck	Lateral	0.058	0.345
Head & Neck	3D magnitude	0.039	0.584
Spine	Vertical	0.046	0.417
Spine	Longitudinal	0.080	0.086
Spine	Lateral	-0.002	0.975
Spine	3D magnitude	0.095	0.099
Pelvis	Vertical	-0.229	0.015
Pelvis	Longitudinal	0.052	0.689
Pelvis	Lateral	-0.136	0.160
Pelvis	3D magnitude	-0.380	0.002

Table 3 shows that statistically significant disagreement was concentrated in selected axes and especially in the pelvis. This table presents a paired t-test comparison evaluating the positional shifts detected by two different localization modalities: planar kilo-voltage (kV) imaging and three-dimensional Cone Beam Computed Tomography (CBCT). By analyzing the Mean Difference (kV - CBCT) alongside the p-value, the dataset determines whether the discrepancies between these two imaging techniques are statistically significant (typically using a threshold of $p < 0.05$). A positive mean difference indicates that kV planar imaging overestimated the patient shift compared to CBCT, while a negative value signifies an understatement by kV imaging. Statistically significant findings point to specific anatomical axes where planar imaging fails to capture the true 3D spatial alignment verified by CBCT.

For Breast setups, the paired t-test reveals statistically significant discrepancies between the two modalities in both the Vertical ($p = 0.047$) and Lateral ($p = 0.011$) axes. In these dimensions, kV imaging yielded systematically larger shifts than CBCT, with a notable mean difference of 0.223 {cm} (2.23\text{mm} in the lateral direction. This variation likely stems from the limitations of planar kV setups, which rely heavily on 2D bony anatomy or surface landmarks, failing to accurately account for

soft tissue deformation or breast tissue sagging that CBCT easily resolves in 3D. Conversely, the longitudinal axis (p = 0.355) and the overall 3D vector magnitude (p = 0.158) show no statistically significant differences, implying that both modalities align reasonably well along the head-to-toe axis.

In the Head & Neck cohort, the comparison demonstrates remarkable agreement across almost all axes, with one critical exception. The Vertical (p = 0.980), Lateral (p = 0.345), and 3D magnitude (p = 0.584) present exceptionally high p-values, proving that planar kV and CBCT yield nearly identical positioning metrics for these orientations. However, a highly significant discrepancy emerges in the Longitudinal axis (p = 0.002), where kV imaging overstates the shift by 0.201 cm} & 2.01{mm}. This isolated divergence is often attributed to the difficulty of identifying clear superior-inferior bony landmarks on a standard 2D radiograph compared to a 3D volume, especially when minor variations in shoulder position or mask stretching mimic a longitudinal shift on planar views. The Spine stands out as the most stable site in this comparison, showing no statistically significant differences between kV and CBCT across any individual axis or the 3D magnitude. The closest the data comes to a trend is in the Longitudinal axis (p = 0.086) and 3D vector (p = 0.099), but both remain above the standard 0.05 significance threshold. Because the spine consists of high-contrast, rigid bony structures, the anatomical landmarks used for alignment are clear and unambiguous on both 2D planar radiographs and 3D volumetric scans, resulting in highly interchangeable localization data between the two systems.

Finally, the Pelvis data reveals severe, statistically significant disagreements where planar kV imaging profoundly underestimates patient shifts relative to CBCT. Significant discrepancies are observed in the Vertical axis (-0.229 {cm}, p = 0.015) and, most critically, in the overall 3D vector magnitude (-0.380 {cm}, p = 0.002). The negative mean differences indicate that CBCT caught much larger positional errors than the 2D planar images managed to detect. This underestimation occurs because planar pelvic imaging aligns primarily to the rigid bony pelvic girdle, completely blinding the clinician to internal prostate, bladder, or rectal organ motion. These findings strongly underline the clinical necessity of relying on CBCT volumetric guidance over standard kV planar imaging for pelvic treatments to prevent geographical target miss.

Table 4. Pre-calibration clinical agreement within ±3 mm

Site	Axis	Agreement (%)
Breast	Vertical	88.89
Breast	Longitudinal	88.89
Breast	Lateral	66.67
Head & Neck	Vertical	100.00
Head & Neck	Longitudinal	80.00
Head & Neck	Lateral	100.00
Spine	Vertical	100.00
Spine	Longitudinal	100.00
Spine	Lateral	100.00
Pelvis	Vertical	50.00
Pelvis	Longitudinal	50.00
Pelvis	Lateral	70.00

Table 4 indicates that spine and head and neck had the strongest pre-calibration agreement, while pelvis had the weakest. The data reveals a clear hierarchy in setup consistency, heavily influenced by the rigidity of the anatomical site and the effectiveness of its corresponding immobilization protocol. Rigid, bony structures demonstrate the highest reliability, whereas soft tissue regions subject to physiological motion and deformation show significantly lower agreement. The Spine demonstrates flawless consistency, achieving 100.00 agreement across all three translational axes. This perfect reproducibility is expected in clinical practice due to the rigid, non-deformable nature of the vertebral column, combined with robust immobilization systems like specialized cradles or SBRT vacuum molds that highly restrict patient movement. Similarly, the Head & Neck region exhibits exceptional stability, maintaining a perfect 100.00 agreement in both the Vertical and Lateral directions. The minor drop to 80.00 in the longitudinal axis represents the only variability for this site, which typically occurs due to subtle variations in neck extension, chin tilt, or shoulder settling within the custom thermoplastic mask.

In contrast, the Breast and Pelvis regions present greater setup challenges due to anatomical deformability and internal organ motion. The Breast maintains a strong agreement of 88.89 in the Vertical and Longitudinal planes but drops significantly to 66.67 in the Lateral axis. Because breast tissue is highly compliant, variations in arm placement on the breast board, changes in respiration amplitude, or lateral tissue drift frequently introduce left-right positioning discrepancies. The Pelvis exhibits the lowest overall consistency in the dataset, plunging to 50.00 in the Vertical and Longitudinal axes and recovering only slightly to 70.00 in the Lateral direction. This poor agreement highlights the compounding challenges of pelvic setups, where variable bladder filling, rectal volume fluctuations, soft tissue deformation, and subtle rotations of the hips and legs drastically reduce day-to-day reproducibility.

Analyzing the dataset by spatial orientation reveals how specific directional axes behave across different areas of the body. The Vertical (Anterior-Posterior) and Longitudinal (Superior-Inferior) axes are highly stable in upper-body setups but fail critically in the pelvic region, where they drop to a coin-flip level of consistency. Conversely, the Lateral (Medial-Lateral) axis proves to be a strength for the head, neck, and spine, but acts as the primary source of error for breast setups. Ultimately, these findings suggest that while current immobilization protocols for the Spine and Head & Neck are highly optimized, Breast setups would benefit from enhanced lateral stabilization, and Pelvis protocols require strict internal organ preparation or expanded planning target volume (PTV) margins to safely compensate for frequent positional variations.

Overall, the results show a clear site-dependent pattern. Spine had the most stable agreement overall, which is clinically expected because the vertebral column offers a rigid bony reference and little day-to-day deformation. Head and neck also performed well, although longitudinal disagreement suggests that small mask fitting differences or shoulder position may still introduce setup variation. Breast

showed moderate agreement, but lateral differences were more noticeable (Alabedi, 2023). This may reflect breast tissue mobility, setup sensitivity to arm position, and the limitations of 2D matching in a region where soft tissue and chest wall position are not fully captured by planar imaging alone. Pelvis had the weakest agreement, and the significant 3D difference suggests that planar kV could not fully reproduce CBCT-based corrections in that region. This is most likely because pelvic anatomy is influenced by bladder and rectal filling, which can alter internal target position even when bony anatomy appears acceptable.

Discussion

These findings support the view that kV imaging is not a universal substitute for CBCT, but it can be a practical alternative in selected contexts. For rigid bony targets, the agreement between kV and CBCT was generally good and clinically acceptable within ±3 mm, especially in spine and head and neck. This aligns with broader IGRT practice, where planar kV imaging is commonly used for rapid verification when bony landmarks are a valid surrogate (Lozano et al, 2011). The pelvic findings are particularly important because they show that a good average result does not necessarily mean the method is safe for every fraction. This corroborated with the study of Bowen et al (2012) who had earlier documented similar findings.

Even when mean differences are modest, Bland-Altman limits of agreement can still be wide enough to allow clinically meaningful outliers. That matters because setup errors can accumulate into underdosing of the target or unnecessary irradiation of organs at risk as reported by Juan-Senabre (2011); (David et al., 2020) . In practical terms, this means kV can support workflow efficiency, but CBCT remains more reliable when internal anatomy is expected to vary substantially (Balter et al, 2007; Hope-Johnson et al, 2025). The interobserver reliability was good to excellent across all sites, which strengthens confidence that the observed differences were due to modality behavior rather than inconsistent image matching (Chao & Mishra, 2017). This is an important quality assurance finding because reliable registration is essential when comparing two imaging methods. Overall, the results suggest that site-specific imaging protocols are preferable to a one-size-fits-all policy.

Conclusion

The outcome of this study revealed that kV planar imaging showed acceptable agreement with CBCT in spine, head and neck, and partly in breast, but agreement was weaker in pelvis as earlier reported by Biswal et al, (2022). The findings support kV imaging as a low-dose and efficient option for selected rigid anatomical sites, while CBCT remains preferable for pelvic localization and other anatomically variable regions. Therefore, the choice of imaging modality should be guided by site-specific anatomy, expected motion, and the clinical tolerance for setup uncertainty.

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