

Original Article

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Coincidence of radiation and mechanical isocentre using computed radiography

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Abstract

Background: Verification of the coincidence between the radiation and mechanical isocentres is an essential quality assurance (QA) procedure for linear accelerators (linacs) in radiotherapy. Ensuring this alignment is critical for accurate beam targeting, especially in conformal and intensity-modulated radiotherapy techniques.

Objective: This study aimed to evaluate the feasibility and effectiveness of using computed radiography (CR) with a bare imaging plate (IP) to assess the coincidence between radiation and mechanical isocentres, as a practical QA method, especially applicable in resource-limited settings.

Materials and Methods: The study was conducted on a Precise linac installed at Bac Ninh General Hospital No2. A Fujifilm IP and an FCR Prima T2 reader were used. Mechanical isocentre marking was performed via 1 monitor unit (MU) open-field exposure. Radiation isocentre verification involved multiple exposures with narrow rectangular fields at various gantry, collimator and couch angles. The latent images were processed using FCR View software to analyse displacement diameters between mechanical and radiation centres.

Results: The CR system demonstrated sufficient sensitivity to detect exposures as low as 1 MU. Deviations (diameters) were 0.44–1.04 mm with expanded uncertainty U up to 0.44 mm ($k = 2$). All measurements were within the ± 2 mm tolerance recommended by American Association of Physicists in Medicine (AAPM) for non-stereotactic systems.

Conclusion: The use of a bare IP in CR offers a reliable and low-cost alternative for verifying the coincidence of radiation and mechanical isocentres. This method is suitable for routine QA procedures in clinical environments lacking access to radiochromic film or electronic portal imaging devices.

Introduction

Accurate and reproducible delivery of radiation is a cornerstone of modern radiotherapy. To ensure this precision, regular quality assurance (QA) of linear accelerators (linacs) is mandatory. American Association of Physicists in Medicine (AAPM) task group reports 46, 142 and 198 provide comprehensive guidelines covering various QA aspects, including safety, mechanical integrity and dosimetric performance.^{1–3} Among these, the verification of the spatial coincidence between the mechanical and radiation isocentres is essential, particularly for techniques requiring high geometric accuracy such as Intensity-Modulated Radiation Therapy (IMRT) and stereotactic treatments.

Traditionally, this verification has been performed using radiographic film or radiochromic film (e.g., EDR2, XV2 and EBT3). More recently, the Winston–Lutz test using electronic portal imaging devices (EPIDs) has become the preferred standard due to its efficiency and reproducibility.³ However, such resources are not always available in all clinical settings.

Previous studies have explored the use of computed radiography (CR) systems for isocentre verification. For instance, Irsal et al. demonstrated the feasibility of assessing the radiation isocentre for selected components of the linac using a CR method.⁴ However, a full evaluation of the coincidence between the radiation and mechanical isocentres including collimator, couch and gantry rotations has not been comprehensively addressed.

Recent implementations of the Winston–Lutz test using EPID provide automated feature detection and sub-millimetre localisation accuracy with rapid, fully digital workflows and have become the de facto reference in many centres. Radiochromic film remains a robust alternative with very high spatial fidelity, but it entails film handling, chemical/scan steps and stringent scanner QA. In comparison, the CR approach evaluated here emphasises accessibility and cost-effectiveness: it requires no EPID, uses reusable imaging plates (IPs) and supports low-monitor unit (MU) acquisitions, offering a practical option for routine, non-stereotactic QA in resource-constrained settings.

In this study, we propose a practical and low-cost method using a bare IP and CR reader to visualise and assess isocentre coincidence. The approach was inspired by an incidental observation during a minimal MU exposure, which revealed a central cross-hair imprint on the

latent image. We systematically evaluated this phenomenon to determine its applicability for QA purposes.

Following the AAPM recommendations, the tolerance limits for isocentre deviations are ± 2 mm for standard and IMRT linacs, and ± 1 mm for stereotactic systems. This study aims to assess whether the proposed CR method meets these standards for clinical implementation.

Materials and methods

Materials

The study was performed on a Precise multi-leaf linac (Elekta, UK), serial number 153193, installed in 2013 at Bac Ninh General Hospital No. 2, Vietnam. The accelerator operates at two photon energy levels: 6 MV and 15 MV, and six electron energy levels: 6 MeV, 9 MeV, 12 MeV, 15 MeV, 18 MeV and 22 MeV. The treatment head is equipped with an MLCi2 multi-leaf collimator, featuring 80 leaves symmetrically distributed across the Y-jaw axis, with each leaf having a nominal width of 1 cm. The accelerator is not equipped with EPID.

For image acquisition, we used a Fujifilm IP cassette, model CC (serial number A53388254C), with dimensions of 24×30 cm. The IP images were processed using the FCR Prima T2 reader, with a reading time of 1 minute and 49 seconds per image. Image analysis was performed using FCR View software. The spatial measurement error of the imaging system was estimated at 1.5%, with a true length of 30 cm corresponding to a measured length of 30.45 cm.

For image acquisition for comparison, we used Kodak EDR2 radiographic films, a sewing needle, a darkroom, film developer, barrel and water. To process the results, we use ballpoint pens, rulers, a diameter gauge (badge gauge) and an X-ray film viewer.

Additional equipment included the SP34 solid phantom, a mechanical front pointer, spirit level, paper, permanent marker and medical adhesive tape.

Experimental set-up

To evaluate the sensitivity of the IP cassette to low-dose exposures, we irradiated it with nominal energies of 6 MV and 15 MV. The IP was placed at a source-to-axis distance (SAD) of 100 cm and covered with a 1 cm or 2 cm phantom layer for 6 MV and 15 MV, respectively. A non-symmetric rectangular field was used ($X1 = 5$ cm, $X2 = 5$ cm, $Y1$ varying from +15 cm to -12 cm, $Y2 = 15$ cm). Irradiation was performed at 1 MU, 2 MU, 5 MU and 10 MU per field. Pixel intensities were extracted and analysed using Microsoft Excel.

The procedure to evaluate the coincidence of radiation and mechanical isocentres using bare IP consisted of four main steps:

Step 1—Tool Preparation: The linac was set to an open field of 34×34 cm² with a beam output of 1 MU. The IP was removed from its cassette and positioned alongside supporting equipment, including the FCR Prima T2 reader, SP34 phantom, front pointer, spirit level, marking tools and couch level verification instruments.

Step 2—Mechanical Isocentre Marking: For collimator and couch evaluation, the IP was placed horizontally on a phantom positioned on the treatment couch. The beam axis was aligned perpendicular to the phantom surface. A mechanical centre mark was created using tape and a permanent marker. For gantry evaluation, the plate was positioned vertically, aligned to the lateral lasers and fixed to the phantom with medical tape before marking (Figure 1). A single exposure of 1 MU was delivered.

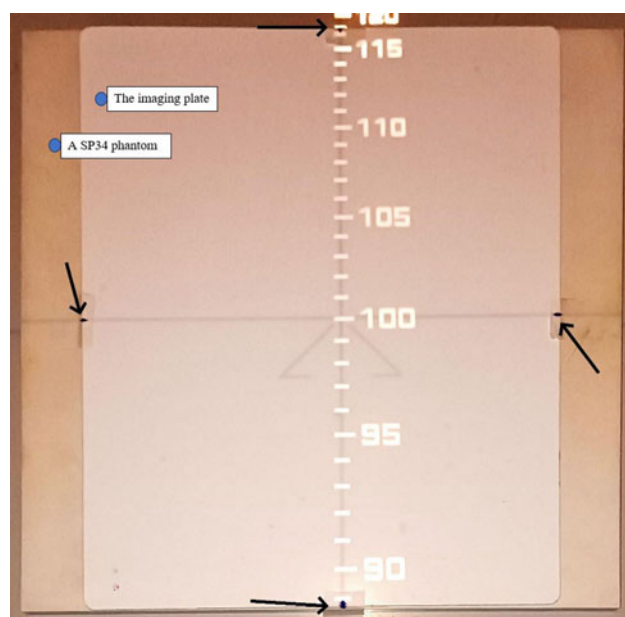


Figure 1. Set up imaging plate on a phantom with isocentre mark.

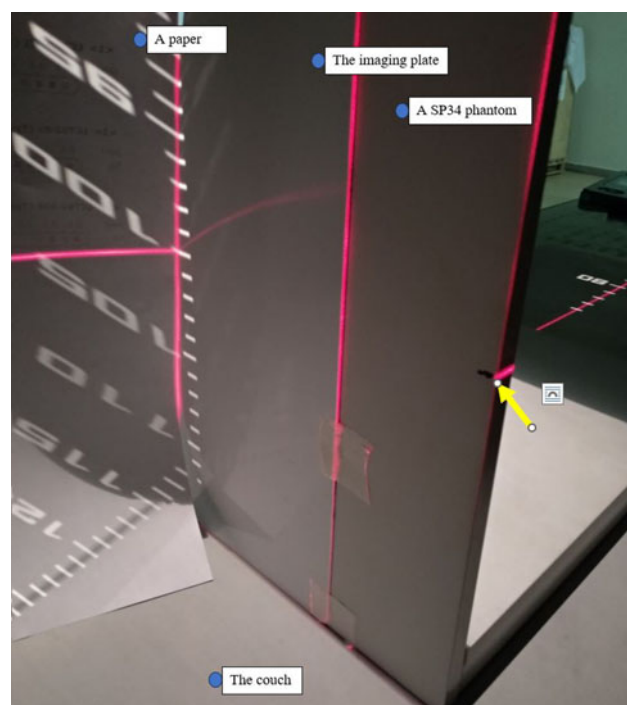


Figure 2. Set up the gantry isocentre with the imaging plate and phantoms on the vertical plane.

Step 3—Radiation Isocentre Creation: To visualise the radiation isocentre, narrow rectangular radiation fields of 0.6×10 cm² were used. The set-up geometry and irradiation angles varied depending on whether the test was performed for the collimator, couch or gantry, as follows:

- **Collimator test:** The IP was placed horizontally on the treatment couch, with a solid phantom positioned directly on top of it. Irradiation was performed with the gantry and couch

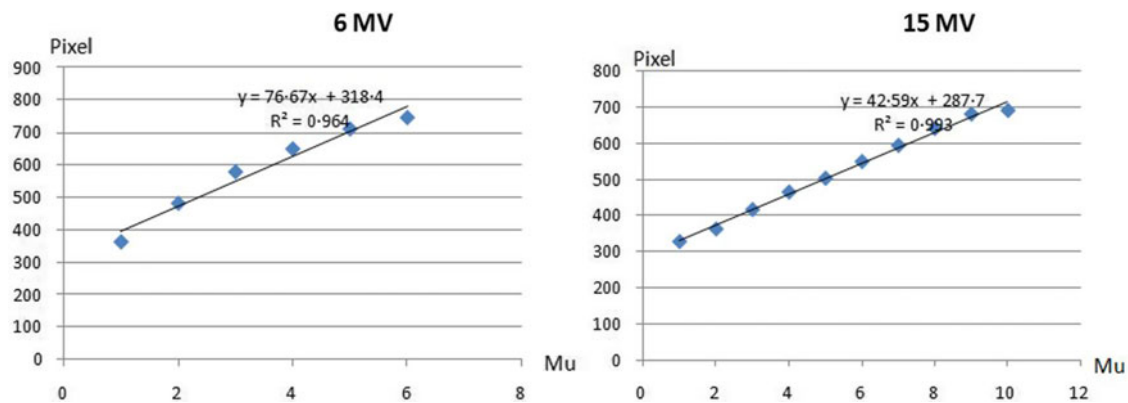


Figure 3. The relationship between the pixel value and MU for 6 MV and 15 MV.

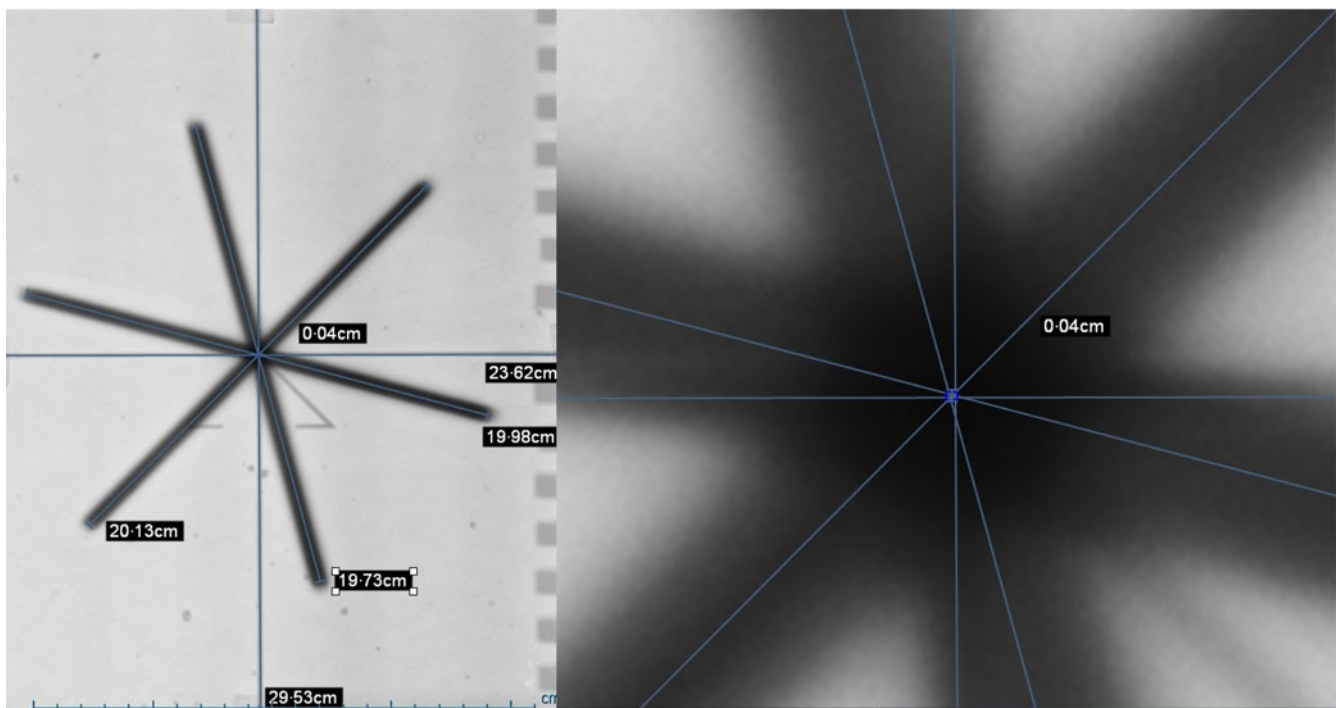


Figure 4. Image of checking the coincidence for the collimator with 6 MV.

fixed at 0°, while the collimator was rotated to 15°, 75° and 135°. One monitor unit (1 MU) was delivered per angle;

- **Couch test:** Similar to the collimator set-up, the IP was positioned on the couch with a solid phantom placed above it. Both the gantry and collimator angles were set to 0°, while the couch was rotated to 15°, 75° and 135°. Each exposure delivered 1 MU;
- **Gantry test:** For gantry evaluation, the IP was positioned vertically, perpendicular to the treatment couch, and sandwiched between two solid phantom plates (Figure 2). The IP was carefully aligned with the lateral room lasers on both sides. The gantry was then rotated to 15°, 75°, 135°, 195°, 255° and 315°, with the collimator and couch angles held at 0°. Each beam was delivered at 1 MU. Particular care was taken to avoid interference with the couch's metal swing arm during rotation.

Step 4—Image Processing: The exposed plate was reinserted into the cassette and processed using the FCR View software. Results were saved as digital image files (PNG or JPG) and archived for further analysis. **For the comparison method**, we used the star shot method with Kodak film.

Uncertainty analysis: For each coincidence check (couch, collimator and gantry) and beam energy (6/15 MV), Type-A uncertainty was estimated from the standard deviations of (i) repeatability within set-up, (ii) inter-operator and (iii) inter-day effects; the components were combined in quadrature. Type-A components (repeatability within set-up, inter-operator and inter-day) were combined in quadrature; Type-B included only the stated 1.5% spatial scale error (no pixel/geometric terms were applied). The combined standard uncertainty was computed as $U_c = \sqrt{u_A^2 + u_B^2}$ and the expanded uncertainty as $U = 2u_c$ (~95% coverage).

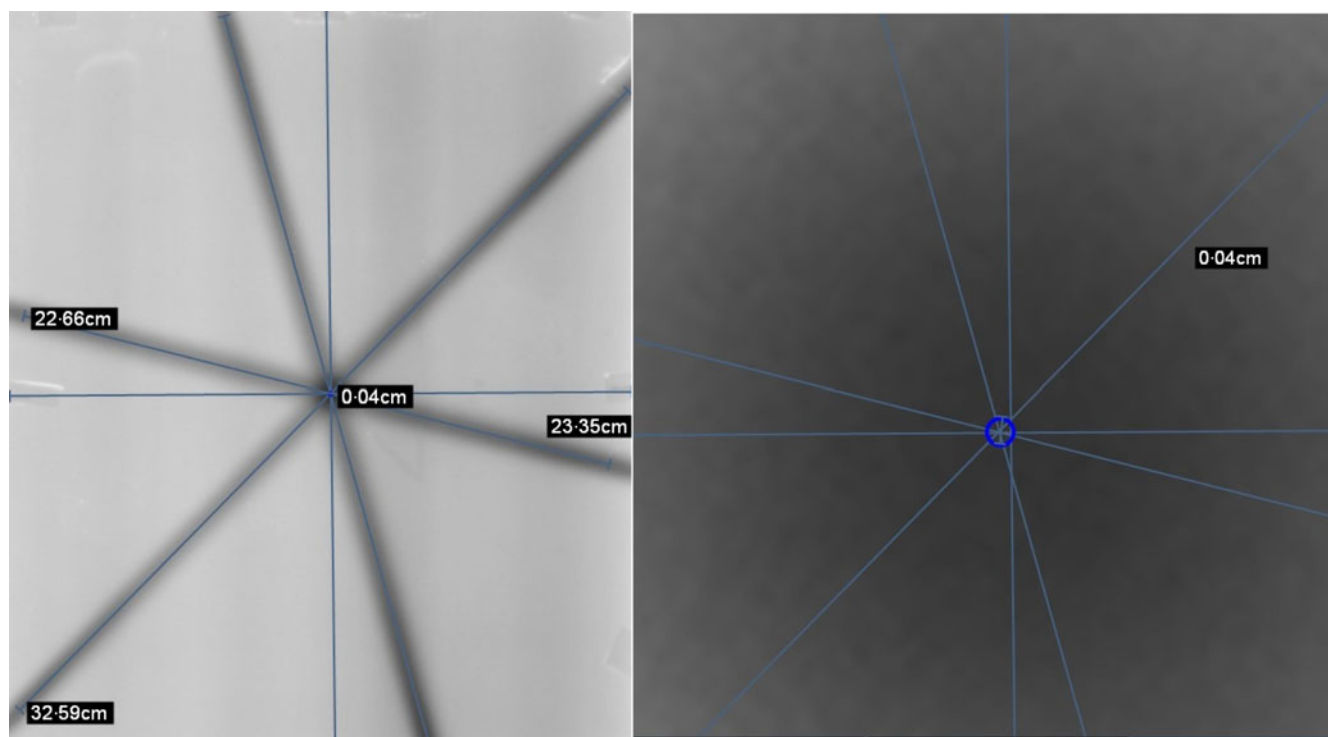


Figure 5. Image of checking the coincidence for the gantry with 6 MV.

Table 1. Diameter value of coincidence between mechanical and radiation isocentres in each repeated measurement

Nominal energy	Moving parts	Repeatability (within set-up)					Inter-operator		Inter-day	
		1	2	3	4	5	Quân	Minh	Day 1	Day 2
6 MV	Collimator (diameter—mm)	0.4	0.6	0.4	0.5	0.4	0.4	0.5	0.4	0.4
6 MV	Couch (diameter—mm)	0.4	0.4	0.5	0.4	0.5	0.4	0.4	0.4	0.4
6 MV	Gantry (diameter—mm)	0.4	0.5	0.4	0.4	0.5	0.4	0.5	0.4	0.6
15 MV	Collimator (diameter—mm)	1.0	1.0	1.1	1.0	1.1	1.0	1.1	1.0	1.1
15 MV	Couch (diameter—mm)	0.8	0.8	1.0	0.9	0.8	0.8	1.0	0.8	0.8
15 MV	Gantry (diameter—mm)	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.3

Results and discussion

Sensitivity of the IP

The Fujifilm IP cassette was tested for its response to low-dose irradiation at 6 MV and 15 MV photon energies. Exposures of 1, 2, 5 and 10 MUs were delivered. At 5 MU and 10 MU, the images exhibited excessive darkening, indicating saturation. With repeated 2-MU exposures on the same plate without erasure, pixel values reached the upper limit at ≥ 3 exposures (cumulative ≥ 6 MU), indicating saturation. However, 1 MU exposures produced clearly distinguishable images with a consistent response in the linear range (Figure 3). These findings indicate that the cassette is suitable for use in QA procedures involving low-dose imaging.

Coincidence of radiation and mechanical isocentre

The coincidence between mechanical and radiation isocentres was evaluated for the collimator, couch and gantry using the proposed CR method. Representative images acquired at 6 MV for the collimator and gantry are shown in Figures 4 and 5, respectively.

We quantified the measurement uncertainty of the CR checks for the couch, collimator and gantry at 6 MV and 15 MV. We obtained the following data: repeatability within set-up, inter-operator and inter-day (Table 1).

Uncertainty analysis:

- 6 MV: collimator 0.46 ± 0.23 mm, couch 0.44 ± 0.11 mm, gantry 0.44 ± 0.34 mm (values are mean $\pm$ U, $k=2$);

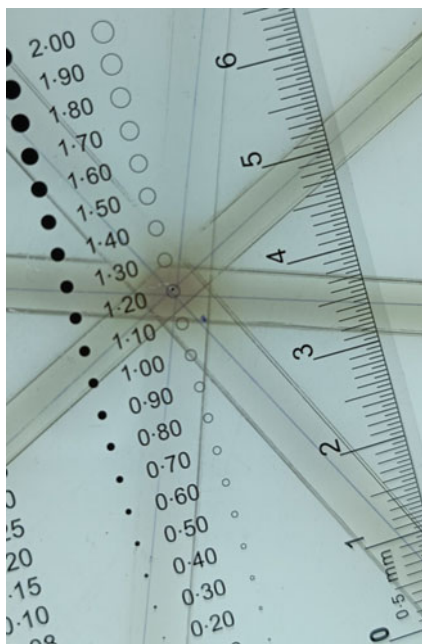


Figure 6. Image of checking the coincidence for the gantry with 6 MV using Kodak film.

- 15 MV: collimator 1.02 ± 0.22 mm, couch 0.86 ± 0.34 mm, gantry 1.04 ± 0.44 mm.

For the comparison method, measurement results using Kodak EBR2 film representative images acquired at 15 MV for the gantry are shown in Figure 6.

The results of the comparison between the two methods are given in Table 2.

CR (mean $\pm$ UUU) versus EDR2 (mean): 6 MV—collimator 0.46 ± 0.23 versus 0.60 mm; couch 0.44 ± 0.11 versus 0.60 mm; gantry 0.44 ± 0.34 versus 0.80 mm. 15 MV—collimator 1.02 ± 0.22 versus 1.00 mm; couch 0.86 ± 0.34 versus 1.00 mm; gantry 1.04 ± 0.44 versus 1.20 mm. All within ± 2 mm. Across 6 and 15 MV beams, the CR-based diameters agreed closely with the EDR2 film reference and remained within the ± 2 mm tolerance. The film benchmarks were 0.56 – 1.24 mm across the same checks. These results indicate good concordance between CR and film while explicitly accounting for measurement uncertainty in the CR workflow. CR and film showed close agreement across all components and energies, and all values met the ± 2 mm tolerance for routine (non-SRS) QA.

These results demonstrate that the CR-based method is capable of detecting submillimeter deviations in isocentre alignment. The couch measurements exhibited slightly smaller deviations, suggesting higher mechanical stability. The method provides a viable solution for facilities lacking access to EPID systems or radiochromic film.

FCR View is a general imaging tool and not purpose-built for QA; our workflow therefore required manual Region of Interest (ROI) selection and centroiding, which introduces subjectivity. This is a limitation of this method. To mitigate operator dependence when dedicated QA software is unavailable, we used fixed window/level, template ROIs.

This CR method was validated for routine (non-SRS) QA (± 2 mm). It has not been evaluated for stereotactic workflows and should not be used for Stereotactic Radiosurgery (SRS)/Stereotactic

Table 2. Verification of coincidence of radiation and mechanical isocentre on linac

Nominal energy	Moving parts (metric)	CR method (mean $\pm$ U, $k=2$)	EDR2 film (mean)	Tolerance
6 MV	Collimator (diameter)	0.46 ± 0.23 mm	0.58 mm	± 2 mm
6 MV	Couch (diameter)	0.44 ± 0.11 mm	0.56 mm	± 2 mm
6 MV	Gantry (diameter)	0.44 ± 0.34 mm	0.66 mm	± 2 mm
15 MV	Collimator (diameter)	1.02 ± 0.22 mm	1.08 mm	± 2 mm
15 MV	Couch (diameter)	0.86 ± 0.34 mm	1.06 mm	± 2 mm
15 MV	Gantry (diameter)	1.04 ± 0.44 mm	1.24 mm	± 2 mm

Table 3. Comparison of method by technical attributes

Attribute	EPID–Winston–Lutz	Radiochromic film (EBT2/EBT3)	CR with bare imaging plate (this study)
Typical accuracy	~ 0.06 – 0.3 mm versus film/standards	Very high, scanner-limited (≤ 0.1 mm feasible)	Set by reader pixel size and geometric scale; here < 1 mm for non-SRS
Pixel/resolution at isocentre	~ 0.2 – 0.3 mm (panel pitch, SDD dependent)	150–300 dpi scans (0.17 – 0.085 mm/pixel)	Reader-dependent (e.g., FCR); requires scale calibration
Workflow	Fast, automated, no film processing	Time-consuming scan/analysis	Fast, low-cost; manual plate handling/readout
Recommended use	SRS/SBRT and routine QA	Reference measurements, independent verification	Routine non-SRS QA in resource-limited settings

Body Radiation Therapy (SBRT) without further refinement and site-specific validation against a sub-millimetre reference method. In our programme, it is performed annually and post-service/alignment updates.

The following table compares the technical properties of this study with current methods (Table 3).

Among current method, EPID-based methods provide automated feature detection and sub-millimetre localisation driven by panel pixel pitch and Source-to-Detector Distance (SDD), making them well suited to high-throughput and stereotactic use.^{5,6} Radiochromic film (EBT2/EBT3) remains a robust reference thanks to very high spatial fidelity and low energy dependence but requires scanner QA and added handling time.⁷ Within this landscape, the CR approach evaluated here emphasises accessibility and cost-effectiveness: it avoids EPID hardware, uses reusable plates and enables low-MU imaging; however, achievable accuracy

is bounded by reader pixel size and geometric scale calibration, so we position it for routine non-SRS QA (± 2 mm per TG-142), while stereotactic programmes should rely on validated EPID/film workflows.^{2,3} This framing is consistent with the historical origins of Winston–Lutz and modern practice.^{5,6,8}

In summary, the use of CR with a bare IP presents a practical and cost-effective approach for routine verification of radiation and mechanical isocentre coincidence in radiotherapy QA programmes.

Conclusions

This study demonstrated the feasibility of using CR with a bare IP to verify the coincidence between mechanical and radiation isocentres on a linac. All measured deviations were within the tolerance limits recommended by the AAPM, confirming the reliability of the proposed method. The technique is simple, reproducible and cost-effective, making it especially suitable for clinical settings particularly in low- and middle-income countries with limited access to high-end QA tools such as EPIDs or radiochromic films.

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T.-M. Nguyen: data acquisition, formal analysis and draft writing.

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Ethical approval. This study did not involve any human or animal subjects and therefore did not require ethical approval.

Informed consent. Not applicable.

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