Open Access Library Journal
2026, Volume 13, e14723
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Investigation of the Dosimetric Impact from Positional Deviations of a Radioactive Source within a Ring Applicator during Gynaecological Brachytherapy Treatments

Mpho Confidence Mnguni, Nicolas J. Rovetto, Lethukuthula Ntombela, Jane Nubi, Mohau Mashaba

Department of Medical Physics, University of Pretoria, Pretoria, South Africa
Email: mcmphomnguni@gmail.com

How to cite this paper: Mnguni, M.C., Rovetto, N.J., Ntombela, L., Nubi, J. and Mashaba, M. (2026) Investigation of the Dosimetric Impact from Positional Deviations of a Radioactive Source within a Ring Applicator during Gynaecological Brachytherapy Treatments. *Open Access Library Journal*, **13**: e14723.
https://doi.org/10.4236/oalib.1114723

Received: December 9, 2025
Accepted: January 5, 2026
Published: January 8, 2026

Abstract

High-Dose-Rate (HDR) brachytherapy with an Iridium (Ir)-192 source remains a cornerstone in the management of locally advanced cervical cancer. However, the accuracy of dose delivery depends critically on precise source positioning within the applicator geometry. This study aims to investigate the dosimetric impact of small positional deviations of a radioactive source within a 26-mm diameter ring applicator and assess how such deviations influence target coverage and doses to surrounding Organs at Risk (OAR) during gynaecological brachytherapy. A retrospective analysis was performed on twenty previously treated patients using the Elekta Oncentra Treatment Planning System (TPS) at Steve Biko Academic Hospital. Reference treatment plans were generated with ten dwell positions distributed along the ring. Two deviation scenarios, 3 mm clockwise and 3 mm counter-clockwise shifts, were simulated relative to the nominal source path. Dose values were extracted at four reference points: A1 and A2 (prescription points), A3 (bladder), and A4 (rectum), in accordance with the International Commission on Radiation Units and Measurement (ICRU) Report 38 recommendations. The simulated deviations produced observable dosimetric changes. Mean percentage dose differences at A1 and A2 ranged from ±1.7% to ±3.2%, indicating that even minor geometric shifts can alter the target coverage. In terms of OARs, an average dose increase of 2.5% - 3.0% was observed at the bladder and rectum points, with the rectum displaying the highest sensitivity to posterior (counter-clockwise) displacement. These findings confirm that positional deviations of only a few millimetres can lead to clinically significant alterations in dose distribution, particularly in regions adjacent to steep dose gradients. The study underscores the importance of meticulous applicator reconstruction, regular mechanical quality assurance, and an accurate treatment planning system applicator modelling library, which should be established through commissioning of the virtual applicator geometry against physical measurements of the clinical device. Furthermore, incorporating correction factors or applicator-specific calibration during commissioning may further mitigate such uncertainties by enhancing target dose coverage during treatments while ensuring patient safety in HDR brachytherapy.

Subject Areas

Oncology

Keywords

Iridium-192, Ring Applicator, Source Deviation, Dosimetric Impact, Gynaecological Cancer

1. Introduction

HDR brachytherapy using Ir-192 is regarded as the gold-standard treatment modality for a boost treatment in locally advanced cervical cancer, following External Beam Radiotherapy (EBRT) with or without chemotherapy [1]. The technique involves delivering a highly conformal dose to the target volume through a combination of intracavitary applicators, typically a tandem and ring system [1] [2]. The ring component guides the source in a circular path; hence, any reconstruction or physical inaccuracy can shift the actual dwell positions, altering the intended dose distribution [3]. Given the steep dose gradients characteristics of brachytherapy, even millimetre-scale geometric deviations can lead to substantial dosimetric effects [3].

Several studies have reported positional uncertainties arising from catheter reconstruction errors, imaging artefacts, or small differences between applicator models in the treatment planning system and their true physical geometry [3] [4]. These uncertainties can lead to either under- or over-dosage of the clinical target volume or overdosage of critical Organs at Risk (OAR) such as the bladder and rectum. A study by Tanderup *et al.* (2013) provided strong evidence that ring applicators, in particular, are prone to position-dependent source path offsets that can reach up to 3 mm, with the greatest discrepancies occurring in the posterior region adjacent to the rectum. They further showed that these errors can be reduced to below 1 mm when appropriate correction strategies are applied [4]. Their findings helped motivate the current investigation, which examines the dosimetric consequences of applying ±3 mm offsets to the source path.

More recently, Aldrovandi *et al.* (2025) [5] provided one of the most detailed evaluations of these effects to date. Using autoradiographs, kV imaging, and detailed geometric analysis of the Varian PEEK ring applicator, their study showed that dwell position offsets increase quasi-linearly along the ring, ranging from negligible near the tip to nearly 3 mm at the most proximal dwell positions. The study further demonstrated that these deviations arise from mechanical behaviours of the source wire, such as tension, twisting, and non-uniform curvature, which cause the source to follow an effective radius larger than the nominal lumen radius. Crucially, Aldrovandi *et al.* proposed and validated two position-dependent correction methods that reduced residual positioning errors to within ±0.7 mm, satisfying the ±2 mm tolerance required by international guidelines. Their findings reinforce the need for applicator-specific commissioning rather than relying solely on nominal geometric models [5].

This study was directly inspired by the work of Aldrovandi *et al.* [5]. Their demonstration that real ring applicators can exhibit systematic, position-dependent offsets provided strong motivation to investigate the clinical dosimetric implications of such deviations in a patient-specific context. While their study focused on quantifying mechanical and geometric offsets, and developing correction strategies using commissioning, the current work evaluates how similar deviations, when uncorrected, may influence the delivered dose to both target points and OARs in actual brachytherapy treatment. In particular, this study simulates ±3 mm positional shifts along the ring, magnitudes consistent with the offsets observed by Aldrovandi *et al.* [5], and quantifies their effect on prescription points A1 and A2, as well as on bladder and rectal reference points defined by International Commission on Radiation Units and Measurements (ICRU) 38 [6]. By examining these deviations across a cohort of twenty previously treated patients, the study aims to provide clinically relevant insight into the dosimetric sensitivity of standard ring-based plans to source path inaccuracies.

Furthermore, in HDR brachytherapy, the dose decreases inversely with the square of the distance from the source, resulting in a rapid fall-off in dose. Consequently, even small deviations in source position can produce measurable changes in the delivered dose distribution [7] [8]. This underscores the importance of robust applicator reconstruction, accurate applicator modelling within TPS, and stringent quality assurance procedures [9] [10].

2. Materials and Methodology

2.1. Materials

This was a retrospective study that was conducted using the Elekta Oncentra Brachytherapy Treatment Planning System. The study set consisted of the CT images, structure sets, and contours of 20 previously planned and treated brachytherapy patients. To be eligible for the study, patients had to have been planned and treated using the 26 mm-diameter stainless steel ring applicator.

2.2. Methodology

The Clinical Target Volume (CTV) and the organs at risk, namely the bladder and rectum, were copied from each patient's original treatment plan to preserve anatomical accuracy while facilitating consistent dosimetric comparison across cases. Reference treatment plans were generated on the Oncentra Brachytherapy TPS using the Oncentra Applicator Library, which provides accurate geometric representations of clinical applicators. Within the ring applicator, ten dwell positions were activated, five located on the anterior section and five on the posterior section, to represent a typical clinical dwell distribution pattern commonly used for gynaecological brachytherapy. Four reference points were defined in accordance with the ICRU Report 38 recommendations to evaluate dose delivery to both the target volume and OARs. These included two prescription points, A1 and A2, defined at coordinates (2, 2, 0) and (−2, 2, 0), respectively. The origin of the coordinate system was placed at the level of the external cervical os (tandem flange). These coordinates reflect the Manchester System definition of Point A, situated 2 cm superior to the cervical os and 2 cm lateral to the uterine canal. The third reference point, A3, represented the bladder point, defined at the center of the Foley balloon filled with 7 cm^3 of contrast medium, while the fourth reference point, A4, represented the rectal point, defined 5 mm posterior to the posterior vaginal wall. The reference treatment plan was normalized to the prescription points A1 and A2, and this normalization was kept fixed for all simulated shifted plans to ensure consistent dose scaling and comparability across all simulated conditions. These will be considered as interest points. This approach ensured that any observed dose differences that arose were solely dependent on the geometric changes in the source path rather than from re-optimization or renormalization within the TPS.

To simulate the effect of positional deviations of the Iridium-192 source within the ring applicator, two sets of shifts were introduced relative to the reference dwell positions. A shift of 3 mm was applied to all ten dwell positions to represent a potential displacement of the source path toward the anterior or posterior direction within the ring, as seen in Figure 1. Figure 1 illustrates the three source path configurations representing the 3 mm clockwise shift, reference position, and the 3 mm counter-clockwise shift used in this study. The corresponding dose distributions were recalculated, and the dose values at all four reference points (A1, A2, A3, and A4) were recorded. This approach allowed for an assessment of the impact of small, yet clinically relevant, geometric deviations on dose delivery to both the target volume and surrounding critical organs.

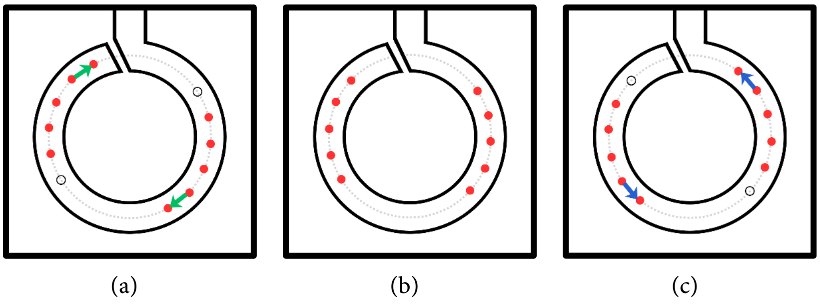
(a) (b) (c)

Figure 1. (a) The 3-mm clockwise shift: (b) The reference position; (c) The 3-mm counter-clockwise shifts.

2.3. Analysis

The percentage differences between the doses obtained from the shifted dwell positions (both clockwise and counter-clockwise) and the reference dwell positions were calculated using the formula:

$$\Delta D\% = \frac{\left(D_{\text{Clock/C.Clock}} - D_{\text{Ref}}\right)}{D_{\text{Ref}}} \times 100\% \tag{1}$$

where $D_{\text{Clock/C.Clock}}$ represents the dose to the interest point after the simulated shift, and D_{Ref} is the dose obtained from the reference dwell configuration.

To analyse the data collected, both positive and negative deviations were considered for the prescription points (A1 and A2) since variations in either direction could lead to potential underdosing or overdosing of the target volume, thereby impacting tumour control probability and treatment effectiveness. In contrast, for the OARs (A3 for the bladder and A4 for the rectum), only positive deviations were taken into account, as an increase in dose to these structures may be clinically significant and directly associated with an increased risk of radiation-induced toxicities.

3. Results

The percentage dose deviations were plotted for each patient across the three configurations. This is summarized in Table 1 and shown in the patient-level line plots for the four measurement points (Figures 2-5). The summary table (Table 1) reports the average percent deviations for each reference point under the two displacement directions and highlights the principal clinical implication for each point. Target prescription points A1 and A2 exhibited both positive and negative deviations depending on the displacement direction (consistent with either increased or reduced coverage), the bladder point (A3) showed relatively modest increases in dose with the displacement, while the rectum point (A4) displayed the largest and most clinically relevant increases when the source path shifted posteriorly, *i.e.*, anticlockwise.

Table 1. Results showing dose deviation at each reference point (A1, A2, A3, A4).

	Clockwise Deviation (Average)	**C. Clockwise Deviation (Average)**	**Clinical Implication**
A1*	1.72%	3.24%	Increased Target Coverage
	−2.61%	−1.93%	Reduced Target Coverage
A2*	2.66%	1.87%	Increased Target Coverage
	−1.63%	−3.25%	Reduced Target Coverage

Continued

A3** (Bladder)	2.51%	2.96%	Increased Dose to Bladder
A4** (Rectum)	2.82%	3.14%	Increased Dose to Rectum

*Positive and negative deviations were considered; **Only positive deviations were considered.

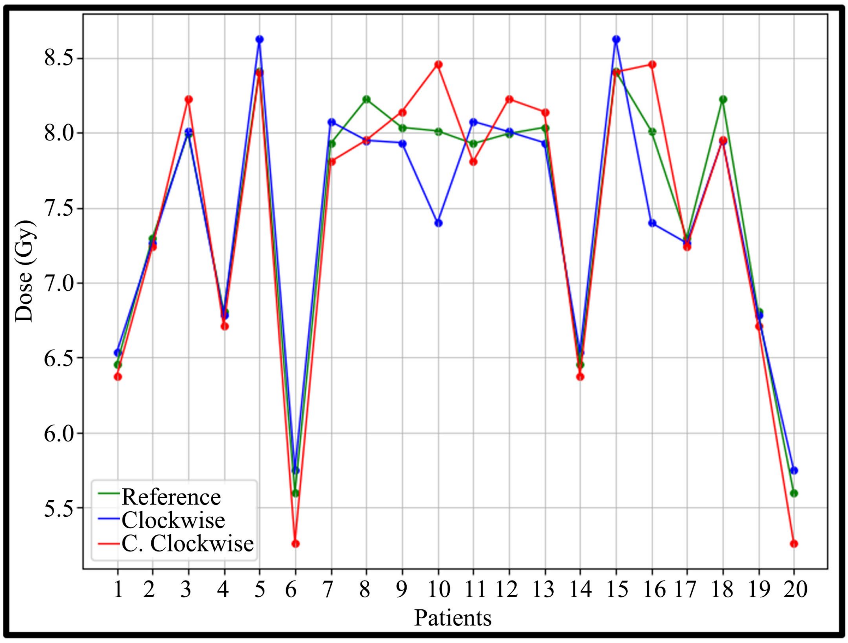

Figure 2. Dose at point A1 for simulated configuration.

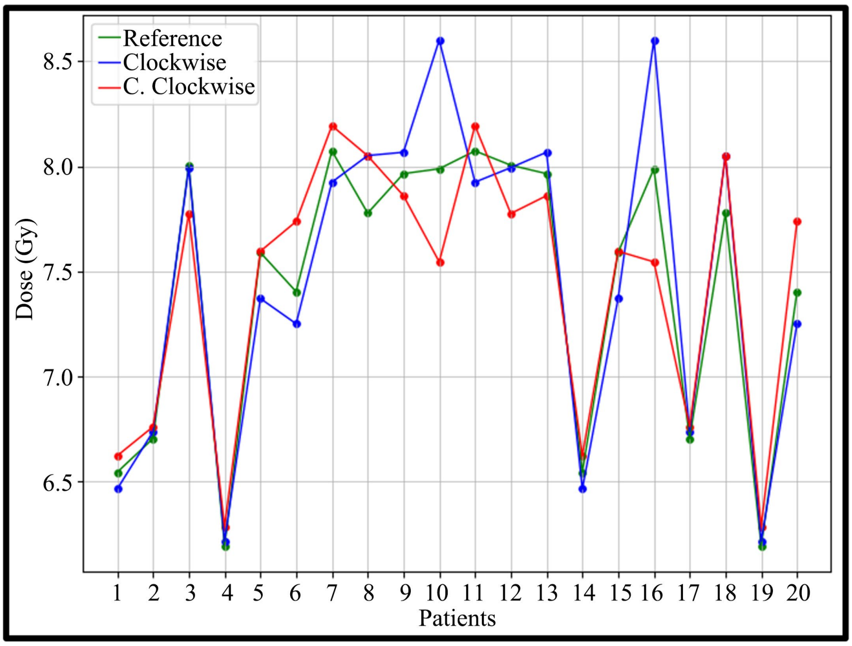

Figure 3. Dose at point A2 for simulated configuration.

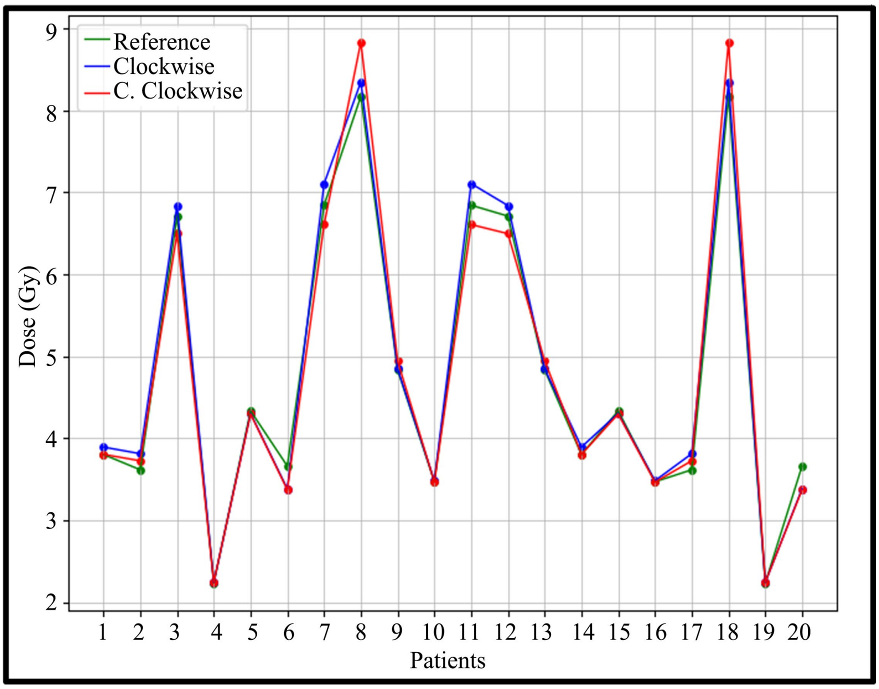

Figure 4. Dose at point A3 for simulated configuration.

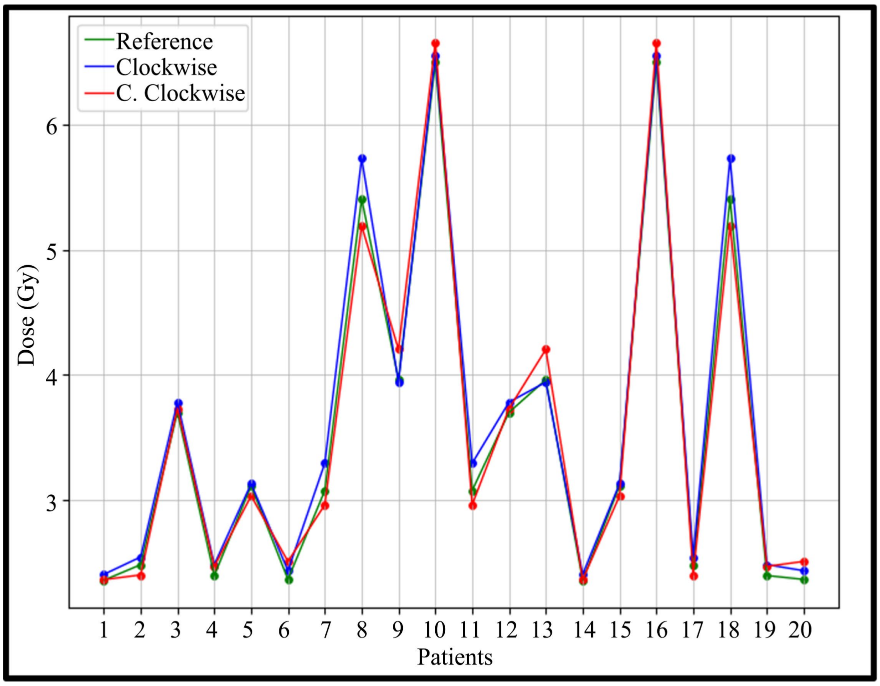

Figure 5. Dose at point A4 for simulated configuration.

Quantitatively, the average percentage changes for A1 and A2, as seen in Table 1, where up to ≈3%, with individual patient variability. These percentage changes are significant given the steep dose gradient produced by a HDR source, which implies that a small spatial change can translate into a non-negligible change in the dose delivered to the target.

In this study, the plans were deliberately normalized to A1 and A2 in every case; therefore, the observed changes at those points reflect only geometric effects due to the changed source path and not planner remediation by optimization. In practice, this demonstrates that if the applicator reconstruction or assumed source path in the TPS does not match the true source trajectory, target coverage may be consistently compromised across all delivered fractions unless recognized and corrected.

The results presented in Table 1 show a clear and direction-dependent relationship between the applied geometric deviation and the resulting dose variation at the four reference points. For the prescription points A1 and A2, both clockwise and counter-clockwise shifts produced measurable percentage changes, with average deviations ranging from ~±1.7% to ±3.2%. Although these values appear modest, they are consistent with the dose variations expected from small positional changes of only a few millimetres within the steep dose gradients inherent to HDR brachytherapy. The presence of both positive and negative deviations also confirms that geometric shifts can either increase or decrease target coverage depending on the direction of the displacement. Importantly, the fact that these variations arise despite consistent normalization to the prescription A-points across all plans. This indicates that they stem directly from altered dwell-point distances rather than from any optimization-based compensatory effect within the TPS. It highlights the inherent sensitivity of prescription point doses to the true source trajectory within the applicator.

For the OARs, the trends in Table 1 demonstrate that even a simplified, uniform 3 mm deviation can induce systematic increases in dose, within the bladder (A3), showing average increases of 2.5% - 3.0% and the rectum (A4), showing the highest sensitivity, with mean increases of 2.8% - 3.1%. These findings reinforce the well-established observation that the rectum lies within a region of a very steep dose gradient posterior to the ring, implying that even small reductions in the source-to-rectum distances may amplify the delivered dose disproportionately. The variation in magnitude across patients arises because, although the same geometric displacement was applied to every case, the underlying pelvic anatomy differs. As a result, the displaced source position affects the distance to each reference point differently for each patient. Collectively, the patterns in Table 1 illustrate that even minor positional inaccuracies can propagate into clinically meaningful dose variations for both target points and OARs, underscoring the importance of precise applicator reconstruction and mechanical accuracy of the dwell positions.

4. Discussion

The graphical representation of the results and the comparative dose data provided a clear visualization of the relationship between positional source deviations within the ring applicator and the corresponding effects on dose distribution patterns to both the target volume and the OARs.

4.1. Target Coverage (A1 and A2)

Figure 2 and **Figure 3** show the doses per patient at prescription points A1 and A2 for the reference, clockwise and counter-clockwise dwell paths. The green (reference), blue (clockwise) and red (counter-clockwise) curves are largely in agreement with one another, however, with clear, direction-dependent separations for a subset of patients. In particular, patients such as Patient 10 and Patient 16 demonstrate the clearest departure from the reference: one displacement direction produced a measurable increase in dose to the A-points while the opposite direction produced a comparable decrease. This behaviour is expected from the geometry of a curved ring applicator: shifting the effective source path toward the anterior side moves the dwell positions closer to the anterior prescription points and away from the posterior points (or vice versa), producing opposing deviations in localized dose.

4.2. Bladder Dose (A3)

Figure 4 shows the bladder point (A3) doses for each patient. Compared with the target points, the bladder exhibited smaller and less variable dose increases with the simulated ±3 mm displacements. The summary table (**Table 1**) recorded a modest mean percentage increase in the order of 1% - 3% for A3 under both displacement directions. Patient 8 and Patient 18 (**Figure 4**) show clear upward deviations, indicating that anatomy and relative geometry determine whether the bladder receives a measurable incremental dose for a given source shift. The bladder point is often anterior and somewhat further from the posterior rim of the ring; therefore, small posterior shifts tend to affect the rectum more strongly than the bladder. However, the bladder dose increase observed is not negligible: repeated fractionation could accumulate measurable increased dose.

4.3. Rectum Dose (A4)

The rectum point (A4) demonstrated the largest sensitivity to source path deviations. **Figure 5** and **Table 1** both show that posterior-directed deviations (counter-clockwise in the chosen sign convention) produced the greatest increased dose changes to A4, with Patients 8 and 13 showing a significant increase. This finding aligns closely with earlier characterisations of ring applicator behaviour: Tanderup *et al*. first emphasised the positional dependence of source offsets and their disproportionate effect on posterior structures adjacent to the ring, and the work of Aldrovandi & Bulling documents similar offset patterns and proposed correction strategies. The mean A4 deviation reached the largest percent among the OARs (≈3% on average, with some individual patients reaching higher doses), indicating that minute mechanical deviations that move the source path posteriorly can potentially increase the rectal exposure.

This observation is amplified when fractions are considered collectively: an increase of ~0.3 - 0.4 Gy per fraction (which is consistent with the per-fraction magnitude implied by the percentage deviations observed) can accumulate over 3 - 5

HDR fractions to produce a cumulative increase in EQD_2 that may be clinically relevant with respect to rectal toxicity limits (EMBRACE-II recommends conservative rectal D_{2cc} objectives). Such cumulative dose escalation may translate into an increased risk of late rectal toxicities, including radiation proctitis, rectal bleeding, ulceration, and fibrosis, which are known to be strongly correlated with total delivered dose and high-dose exposure to rectal tissue. Even modest per-fraction increases arising from uncorrected source-path deviations can therefore have meaningful implications for long-term patient morbidity and quality of life, particularly when accumulated over multiple HDR fractions. Therefore, even if a single fraction's increase appears minute, the aggregate effect motivates attention to applicator QA and reconstruction accuracy.

4.4. General Discussion

The uniform systematic shifts simulated in this study are most representative of mechanical effects inherent to the source-applicator system, including source wire tension, internal friction, and non-uniform curvature of the source channel within the ring applicator. During source transit and dwell positioning, the flexible drive cable may experience elastic deformation, torsion, and resistance against the inner lumen of the applicator, particularly in curved geometries, causing the radioactive source to follow an effective trajectory with a larger radius than the nominal applicator path. These mechanical behaviours result in position-dependent offsets that are systematic in nature and most pronounced in posterior regions of the ring, as experimentally demonstrated by Aldrovandi *et al.*, and are therefore well represented by the controlled, directional shifts applied in this study.

The magnitude and direction-dependent deviations observed are consistent with prior observations of ring applicator behaviour in both phantom-based and patient-specific investigations. Tanderup *et al.* (2013) demonstrated that even small systematic offsets in digitisation or mechanical source path position can yield clinically relevant changes in delivered dose because of the non-linear interplay between radial distance and the inverse-square fall-off. The present results reinforce this observation by showing that the relationship between the displacement direction and dose deviation is not uniform, but it is governed by the relative anatomy at each reference point. For example, posterior shifts consistently amplified rectal dose due to reduced radial distance, whereas the bladder, which is more anterior and often at a slightly greater average distance from the majority of ring dwell positions, exhibited more modest changes. This direction-dependent sensitivity highlights that the same magnitude of geometric deviation can have markedly different clinical implications depending on the proximity of steep gradients to nearby organs.

Furthermore, the patient-specific patterns observed in the A-point curves (Figure 2 and Figure 3) illustrate the dependence of target-point sensitivity on both applicator geometry and individual pelvic anatomy. Some patients displayed nearly symmetrical changes in A1 and A2 under opposite shifts, while other patients showed asymmetrical behaviour, suggesting that even small anatomical asymmetries around the applicator can influence how deviations propagate into the dose distribution. This reinforces the argument made by Hellebust *et al.* (2007) [2], who noted that applicator reconstruction inaccuracies do not manifest uniformly across patients and that CT-based geometric distortions can amplify these inconsistencies. These findings justify the use of patient-specific reconstruction checks, especially for applicators where curvature introduces additional geometric complexity.

Accurate brachytherapy TPS applicator modelling libraries are essential to minimise dosimetric uncertainties arising from source path inaccuracies. In clinical practice, this requires commissioning the virtual applicator model against the physical applicator geometry rather than relying solely on manufacturer-provided nominal dimensions. International recommendations from GEC-ESTRO and the AAPM state that applicator commissioning should include verification of dwell position accuracy using autoradiography, radiochromic film, or imaging-based techniques, with systematic offsets incorporated into the TPS model where necessary [7]. Such applicator-specific commissioning has been shown to reduce residual source positioning errors to sub-millimetre levels, thereby improving agreement between planned and delivered dose distributions [9].

The most clinically relevant finding from this study is the consistent increase in rectal dose with posterior deviations, averaging just over 3% and reaching higher values of about 7.1% in some patients. While they might seem small per fraction, these changes may accumulate across multiple HDR fractions and raise the rectal EQD_2 toward or beyond recommended limits as suggested by the EMBRACE-II protocol, given the strong dose-volume dependence of late rectal toxicity. This highlights the importance of applying correction strategies, such as the position-dependent offset methods proposed by Aldrovandi *et al.* (2025) [5], which can reduce geometric errors to below 1 mm, and which reinforces the need for robust mechanical QA, accurate digitisation, and reliable applicator modelling. By demonstrating the clinical implications of uncorrected source-path deviations in a real patient cohort, the study emphasizes that even small geometric uncertainties warrant careful attention in routine brachytherapy practice.

5. Study Limitations

The analysis included only 20 patient datasets, primarily due to limited applicator availability during the study period. Only one ring applicator size (26 mm diameter) was evaluated, as it was the only size routinely used in the department at the time. Another limitation is that the study was simulation-based, using planned geometric shifts rather than measured or *in vivo* source positions. This approach allowed for controlled analysis but does not fully account for mechanical tolerances, applicator wear, or patient-specific variations that may occur during actual treatment delivery. The assumption of a uniform 3 mm shift in either direction also represents a simplified model of potential deviations, as true displacements are likely to vary along the ring curvature. Additionally, the use of point doses (A1, A2, A3, and A4) provided a focused geometric assessment but did not include volumetric dose metrics such as D_{2cc} or D_{90}, which could better capture the overall dosimetric effect on target and organ volumes. Volumetric dose metrics such as D_{2cc} are now the standard for OAR assessment because they better reflect the dose delivered to clinically relevant tissue volumes and have been shown to correlate more strongly with late toxicity risk than point-dose measurements, particularly in regions of steep dose gradients; this approach is explicitly recommended in the EMBRACE II protocol for cervical cancer brachytherapy. Lastly, as this was a single-institution study, the findings are specific to the equipment and clinical practices of the hospital involved.

Despite these limitations, the results provide a valuable baseline for future departmental and multi-institutional studies. Expanding the dataset to include more patients and ring applicator sizes, and determining an average percentage error or correction factor, could strengthen quality assurance protocols and enhance both target coverage and organ-at-risk protection in routine clinical practice.

6. Conclusions

This study successfully evaluated the dosimetric impact of source positional deviations within a ring applicator during HDR Ir-192 brachytherapy for gynaecological cancers. By systematically shifting the dwell path by ±3 mm from the reference trajectory, it was possible to quantify the resulting dose variations to both target points (A1 and A2) and organs at risk (bladder-A3, and rectum-A4). The results demonstrated that even small positional deviations can lead to clinically meaningful changes in dose distribution, particularly to the rectum, which showed the highest sensitivity to geometric displacement. These findings highlight the steep dose gradients inherent in brachytherapy and the precision required in applicator positioning, reconstruction, and source path modelling.

The observed trends are consistent with those reported by Tanderup *et al.* (2013) [4] and Aldrovandi *et al.* (2025) [5], who emphasized that ring applicators are prone to position-dependent offsets due to their curvature and the mechanical characteristics of the source wire. The present study reinforces this evidence by demonstrating that posterior deviations can substantially increase rectal dose exposure, underscoring the importance of precise applicator alignment and robust quality assurance procedures.

Clinically, these results underline the necessity for accurate digitization, applicator verification, and continuous TPS model refinement to ensure that the delivered dose closely matches the planned dose. Incorporating improved geometric modelling and offset correction tools within the TPS, or developing standardized departmental correction factors, could further minimize dosimetric uncertainties.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Lim, Y.K. and Kim, D. (2021) Brachytherapy: A Comprehensive Review. *Progress in Medical Physics*, **32**, 25-39. https://doi.org/10.14316/pmp.2021.32.2.25

[2] Hellebust, T.P., Tanderup, K., Bergstrand, E.S., Knutsen, B.H., Røislien, J. and Olsen, D.R. (2007) Reconstruction of a Ring Applicator Using CT Imaging: Impact of the Reconstruction Method and Applicator Orientation. *Physics in Medicine and Biology*, **52**, 4893-4904. https://doi.org/10.1088/0031-9155/52/16/012

[3] Jamema, S.V. (2014) Dosimetric Studies in Image Guided Adaptive Brachytherapy in Gynaecological Cancers. Doctoral Dissertation, Homi Bhabha National Institute.

[4] Tanderup, K., Nesvacil, N., Pötter, R. and Kirisits, C. (2013) Uncertainties in Image Guided Adaptive Cervix Cancer Brachytherapy: Impact on Planning and Prescription. *Radiotherapy and Oncology*, **107**, 1-5. https://doi.org/10.1016/j.radonc.2013.02.014

[5] Aldrovandi, L.G., Dessein, M.E.T., Pearson, S.M. and Bulling, S.M. (2025) Position-dependent Offset Corrections for Ring Applicator Reconstruction in Cervical Cancer Brachytherapy. *Journal of Applied Clinical Medical Physics*, **26**, e70079. https://doi.org/10.1002/acm2.70079

[6] International Commission on Radiation Units and Measurements (ICRU) (1985) ICRU Report 38, Dose Volume Specification for Reporting Intracavitary Therapy in Gynaecology. ICRU.

[7] Rivard, M.J., Coursey, B.M., DeWerd, L.A., Hanson, W.F., Saiful Huq, M., Ibbott, G.S., *et al.* (2004) Update of AAPM Task Group No. 43 Report: A Revised AAPM Protocol for Brachytherapy Dose Calculations. *Medical Physics*, **31**, 633-674. https://doi.org/10.1118/1.1646040

[8] Williamson, J.F. and Li, Z. (1995) Monte Carlo Aided Dosimetry of the Microselectron Pulsed and High Dose-Rate ^{192}Ir Sources. *Medical Physics*, **22**, 809-819. https://doi.org/10.1118/1.597483

[9] Kirisits, C., Rivard, M.J., Baltas, D., Ballester, F., De Brabandere, M., van der Laarse, R., *et al.* (2014) Review of Clinical Brachytherapy Uncertainties: Analysis Guidelines of GEC-ESTRO and the Aapm. *Radiotherapy and Oncology*, **110**, 199-212. https://doi.org/10.1016/j.radonc.2013.11.002

[10] Petrič, P., Pötter, R., Van Limbergen, E. and Haie-Meder, C. (2010) Adaptive Contouring of the Target Volume and Organs at Risk. In: Viswanathan, A.N., *et al.*, Eds., *Gynecologic Radiation Therapy: Novel Approaches to Image-Guidance and Management*, Springer, 99-118. https://doi.org/10.1007/978-3-540-68958-4_9