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ORIGINAL ARTICLE

Dosimetric Comparison of AcurosTM BV with AAPM TG43 Dose Calculation Formalism in Cervix High-Dose-Rate Brachytherapy with Titanium Fletcher Style Tandem and Ovoid Applicator

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OBJECTIVE

The purpose of this study is to compare dosimetric calculations using TG-43 dose formalism and Varian AcurosTM BV (GBBS) dose calculation algorithm for cervix high-dose-rate brachytherapy with a Titanium Fletcher style tandem and ovoid applicator using 192Ir.

METHODS

In this study, 10 cervical cancer patients treated with HDR brachytherapy were included in the study, and the patients' simulation tomography images were used in dose calculation. The high-risk clinical target volume (HR-CTV) was contoured as the primary target volume for all patients. The rectum, bladder, and sigmoid were delineated on each CT slice for the present study. 3D treatment plans were created using TG-43 dose formalism and Varian AcurosTM BV (GBBS) dose calculation algorithm in TPS. Dose volume histograms (DVH) were utilized for analyzing the plans dosimetrically. The values of CTVref, Vref, V150%, and V200% were obtained from DVH, which was used to calculate different quality indices: Coverage Index (CI), Dose homogeneity index (DHI), Overdose index (OI), External volume index (EI), and Conformity Index (COIN). The rectum, bladder, and sigmoid D2cc values were evaluated. The statistical analysis was performed using the Wilcoxon test ($p<0.05$).

RESULTS

In study, it was observed that there was no statistically significant difference between the sigmoid D2cc, bladder D2cc, CTV ref, Vref, V150%, DHI, OI, EI and COIN values ($p=0.386$, $p=0.575$, $p=0.092$, $p=0.445$, $p=0.074$, $p=0.286$, $p=0.306$, $p=0.878$, $p=0.721$ respectively), while significant differences were found in the rectum D2cc, V200% and Coverage Index (CI) values ($p=0.037$, $p=0.05$, $p=0.043$, respectively).

CONCLUSION

The TG-43 algorithm seems not to take into account tissue heterogeneity, attenuation and scatter in the titanium applicator, and the effects of the patient boundary.

Keywords: AcurosBV; brachytherapy; TG-43; titanium Fletcher applicator.

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INTRODUCTION

Cervical cancer remains a significant global health problem and is the fourth most common cancer diagnosed in women worldwide.[1] The standard treatment method for cervical cancer and an integral part of its local control is external beam radiotherapy (EBRT) followed by brachytherapy.[2,3] Due to the its high dose gradient, it allows high radiation doses to be delivered directly to the tumor while protecting surrounding healthy organs. The integration of image-guided brachytherapy (IGBT), particularly when combined with advanced dose calculation techniques, has resulted in significantly improved clinical outcomes in cervical cancer. For decades, the American Association of Medical Physicists (AAPM) Task Group 43 (TG-43) dose calculation formula has served as the gold standard for brachytherapy treatment planning. Developed in the late 1990s and updated in 2004 (TG-43U1), this formalism models dose delivery based on water phantom and radial dose functions, independent of patient-specific anatomy or applicator composition.[4] It is a clinically accepted method with relatively fast calculation times. However, TG-43 assumes that the medium is a homogeneous water equivalent and does not account for heterogeneities such as bone, air, organ boundaries, or application materials. This limitation is particularly important in high-dose rate (HDR) intracavitary brachytherapy for cervical cancer, where titanium Fletcher-type tandem and oval applicators are commonly used. These applicators include high atomic number materials and therefore cause significant attenuation and backscattering effects that the TG43 formalism does not account for.

Consequently, the actual dose delivered to the tumor and nearby organs at risk (OAR), such as the rectum or bladder, may differ significantly from planned values based on TG-43.

To solve these problems, AAPM Task Group 186 (TG-186) has recommended the clinical application of model-based dose calculation algorithms (MBDCA) that solve the linear Boltzmann transport equation (LBTE) to account for tissue heterogeneities and non-water geometries.[5]

Among these, Acuros™ BV, developed by Varian Medical Systems, has emerged as a commercially available deterministic solver that provides accurate and rapid 3D dose calculations by modeling photon transport across various materials and geometries. Acuros™ BV analyzes the patient's CT data and calculates the dose based on the physical properties of the medium, including mass density and atomic composition. Acuros™ BV provides a more physically accurate dose distribution by calculating the dose delivered to the medium.

This algorithm has been validated through Monte Carlo simulations and phantom studies, demonstrating high dosimetric accuracy across various clinical scenarios.[6] Despite its advantages, Acuros™ BV has not yet been universally adopted in clinical brachytherapy workflows due to factors such as increased commissioning requirements, complexity in interpreting dose-to-medium vs. dose-to-water, and the need for adaptation in treatment planning systems. However, the increasing demand for precise radiation in oncology and the growing use of 3D imaging-guided brachytherapy make this integration both timely and necessary.

The present study was designed to investigate the dosimetric differences between TG-43 and Acuros™ BV in HDR brachytherapy for cervical cancer using titanium Fletcher-style applicators. We aim to quantify these differences using clinically relevant dose-volume histogram (DVH) parameters and quality indices, thereby assessing the clinical importance of transitioning toward model-based algorithms in routine practice. With these study results, it was aimed to contribute to the growing evidence supporting the adoption of MBDCAs and to guide their wider application in gynecological brachytherapy.

MATERIALS AND METHODS

This was a retrospective cohort study including 10 patients diagnosed with locally advanced cervical cancer (FIGO stages IIB–IIIB), who underwent definitive radiotherapy including external beam radiotherapy (EBRT) followed by HDR intracavitary brachytherapy. All patients received EBRT with 45–50.4 Gy in 25–28 fractions to the pelvis, with or without concurrent cisplatin chemotherapy. A titanium Fletcher-style tandem and ovoid applicator was used for HDR intracavitary brachytherapy. After applicator insertion, patients underwent computed tomography (CT) imaging with a 2 mm slice thickness using a Siemens CT scanner. The patients were positioned supine with a flat tabletop, and a Foley catheter was inserted with a 7 cc of contrast-filled balloon to identify the bladder. All contours were created following GEC-ESTRO guidelines for 3D brachytherapy. The high-risk clinical target volume (HR-CTV) included the cervix and any residual parametrial or vaginal involvement. Organs at risk (OARs), including the bladder, rectum, and sigmoid, were delineated on every axial slice (Fig. 1).

Fig. 1. Sagittal views of an example of contours (HR-CTV (red), bladder (yellow), rectum (orange), sigmoid (pink)).

Each patient had two separate treatment plans generated on the same CT dataset using the BrachyVision T PS (Varian Medical Systems, Palo Alto, CA) (Fig. 2).

- -TG-43 Plan: Based on the AAPM TG-43 formalism, assuming a water-equivalent medium. Dose distributions were calculated ignoring heterogeneities and applicator attenuation.

Table 1 Clinical treatment planning objectives for clinical target volume (HRCTV), rectum, bladder, and sigmoid per a fraction

Structure		Planning objectives
HRCTV	≥	90% of prescribed dose
D2cc for rectum	<	3-5 Gy
D2cc for bladder	<	5-7 Gy
D2cc for sigmoid	<	3-5 Gy

- Acuros™ BV Plan: Employed the grid-based Boltzmann solver (GBBS) to model dose distribution based on the actual patient anatomy, accounting for mass density, tissue composition, and the high-Z applicator material. Dose-to-medium reporting was used according to TG-186 recommendations.

The prescribed dose per brachytherapy fraction was 7 Gy to HR-CTV, delivered in 4 fractions. The same plan constraints were used for both planning techniques and independent re-optimization was performed to ensure a fair and clinically relevant comparison.

The optimization was based on 3D DVH constraints, aiming to achieve:

- D90 for HRCTV ≥90% of prescribed dose
- D2cc for rectum <3-5 Gy
- D2cc for bladder <5-7 Gy
- D2cc for sigmoid <3-5 Gy

The same dose objectives were applied for both TG-43 and Acuros™ BV plans (Table 1).

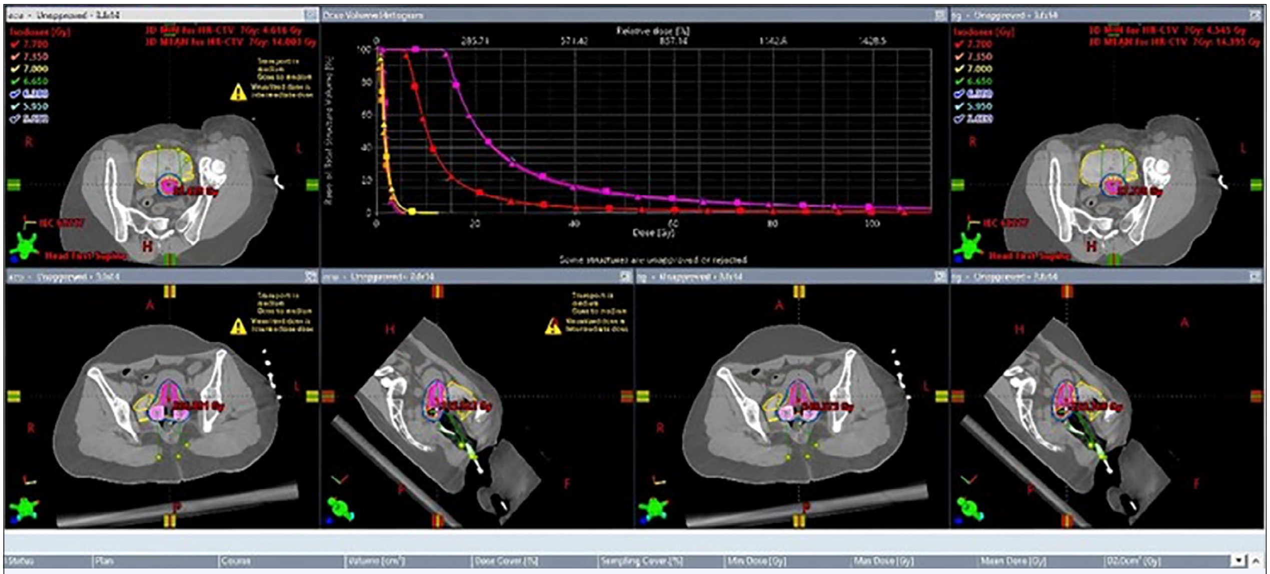

Fig. 2. The TG-43 Plan and Acuros™ BV Plan.

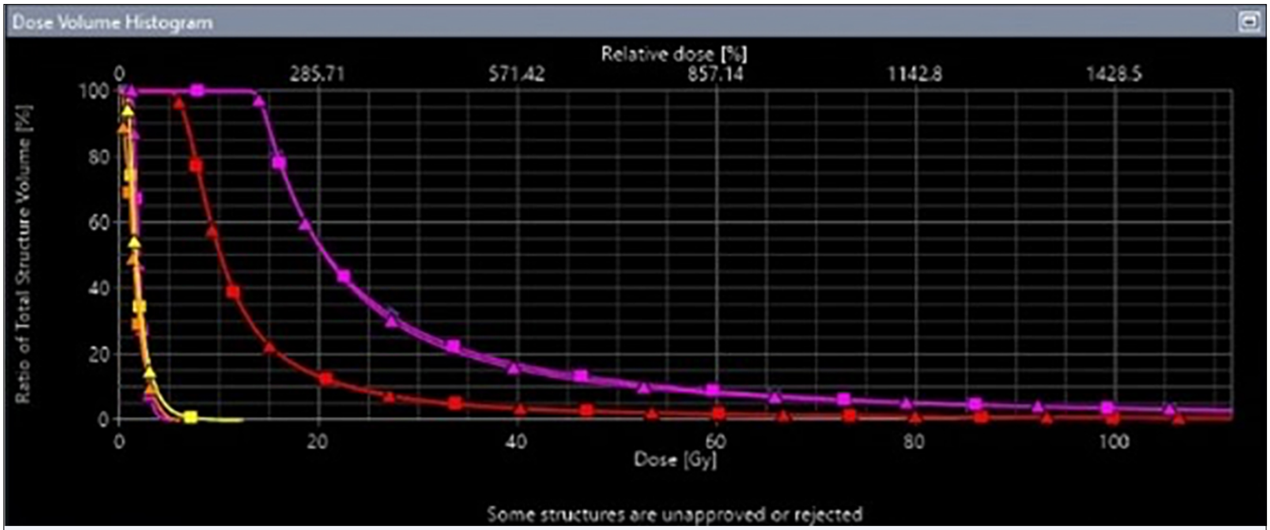

Fig. 3. The dose volume histogram of target volumes, bladder, rectum, and sigmoid. (HR- CTV (red), rectum (orange), bladder (yellow), sigmoid (pink).

From each plan, the following dosimetric and volumetric parameters were extracted from the dose-volume histograms (DVHs) (Fig. 3).

Target Coverage

- CTVref: The reference isodose enclosing the clinical target volume
- Vref (%): The reference isodose covering the volume (Volume of HR-CTV receiving 90% of the prescribed dose)
- V150%, V200%: Volumes of HR-CTV receiving 150% and 200% of the prescribed dose

Organs at Risk

- D2cc for bladder, rectum, and sigmoid (Gy)

Quality Indices

- Coverage Index (CI) = CTVref / CTV (ideal CI=1)
- Dose Homogeneity Index (DHI) = (1 - V150% / CTVref) ideal DHI=1)
- Overdose Volume Index (OI) = V200% / CTVref (ideal OI=0)
- External Volume Index (EI) = 1-CTVref / Vref (ideal EI=0)
- Conformity Index (COIN) = C1X C2

Where C1 = CTVref/CTV volume and C2 = CTVref/Vref (ideal COIN=1)

All parameters were calculated within BrachyVision using DVH analysis tools.

The axial view of the dose distribution of the plan was showed in Figure 4.

The Wilcoxon signed-rank test was used for pairwise comparison of TG-43 and Acuros™ BV results. A p-value of <0.05 was considered statistically significant. All analyses were performed using IBM SPSS Statistics version 26.

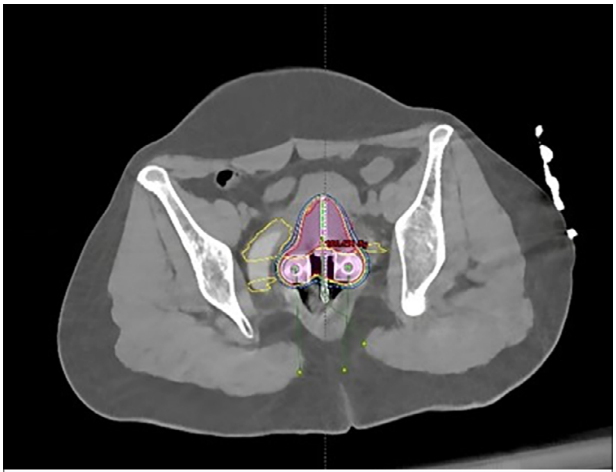

Fig. 4. The axial view of the dose distribution of the plan.

Statistical analysis focused on:

- Dosimetric differences in target volumes and OAR doses,
- Evaluation of how each algorithm affected clinical quality metrics.

RESULTS

Dosimetric comparisons were performed between the TG-43 and Acuros™ BV dose calculation algorithms for all 10 cervical cancer patients (Table 2).

Table 2 TG-43 and Acuros BV with p-value for dosimetric parameters of HR-CTV and OARs

Parameters	**192Ir TG-43**		**192 Ir ACUROS BV**		**p**
	Mean	**SD**	**Mean**	**SD**	
CTVref (cc)	30.807	0.685	30.516	0.799	0.092
Vref (cc)	45.183	4.984	45.305	4.224	0.445
V150% (cc)	16.443	1.211	16.273	1.060	0.074
V200% (cc)	9.361	0.711	9.078	0.663	**<0.05**
Coverage index (CI)	0.905	0.020	0.895	0.012	**<0.05**
Dose homogeneity index (DHI)	0.498	0.068	0.469	0.054	0.286
Overdose volume index (OI)	0.299	0.023	0.296	0.025	0.306
External volume index (EI)	0.307	0.098	0.319	0.084	0.878
Conformity index (COIN)	0.625	0.094	0.611	0.079	0.721
Rectum D2 (cc)	4.275	0.155	4.340	4.340	**<0.05**
Bladder D2 (cc)	6.523	0.231	6.531	0.241	0.575
Sigmoid D2(cc)	3.413	0.381	3.415	0.295	0.386

The analysis of high-risk clinical target volume (HR-CTV) dosimetry showed notable differences in the volumetric coverage metrics:

- CTVref and Vref showed no statistically significant differences (p=0.092 and p=0.445, respectively), although slight decreases were observed with Acuros™ BV (Figs. 5, 6).
- V150% demonstrated a decreasing trend with Acuros™ BV (p=0.074), but did not reach statistical significance (Fig. 7).
- V200%, however, showed a statistically significant reduction with Acuros™ BV compared to TG-43 (p=0.050), indicating a lower volume receiving excessively high doses when heterogeneity was considered (Fig. 8).

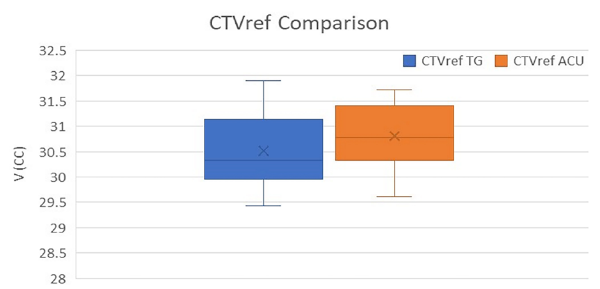

Fig. 5. Comparison of the CTVref for TG-43 and Acuros™ BV plans.

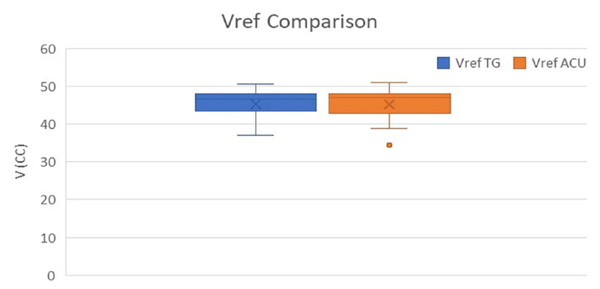

Fig. 6. Comparison of the Vref for TG-43 and Acuros™ BV plans.

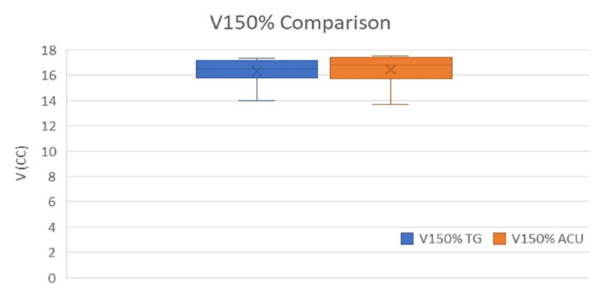

Fig. 7. Comparison of the V150% for TG-43 and Acuros™ BV plans.

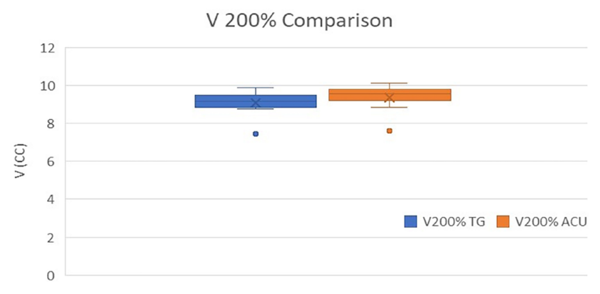

Fig. 8. Comparison of the V200% for TG-43 and Acuros™ BV plans.

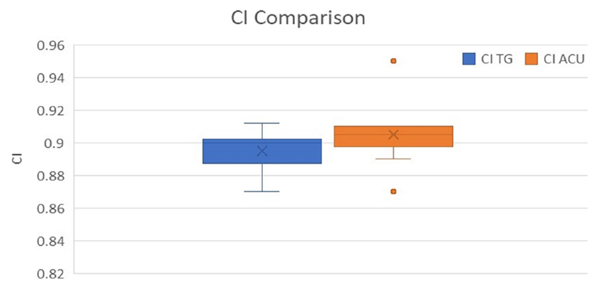

Fig. 9. Comparison of the CI for TG-43 and Acuros™ BV plans.

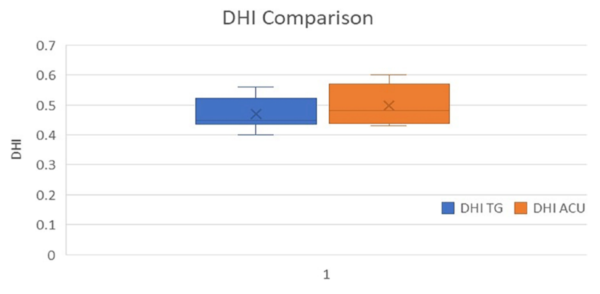

Fig. 10. Comparison of the DHI for TG-43 and Acuros™ BV plans.

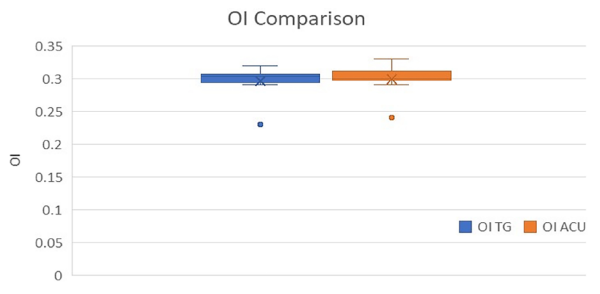

Fig. 11. Comparison of the OI for TG-43 and Acuros™ BV plans.

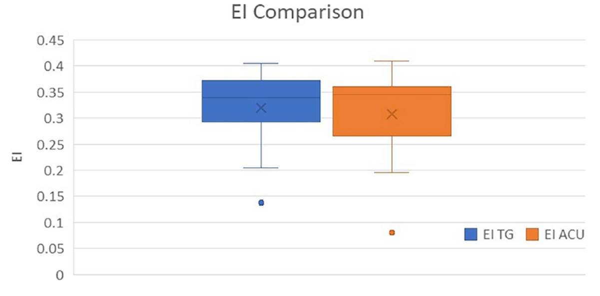

Fig. 12. Comparison of the EI for TG-43 and Acuros™ BV plans.

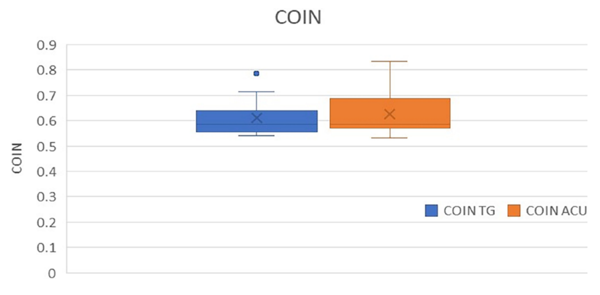

Fig. 13. Comparison of the COIN for TG-43 and Acuros™ BV plans.

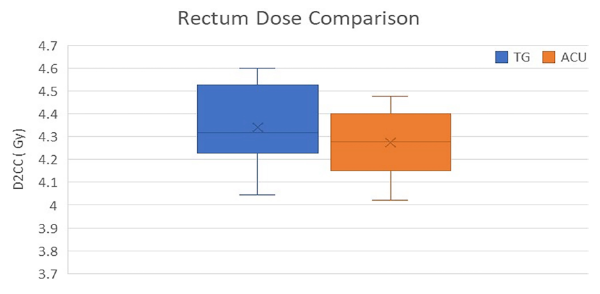

Fig. 14. Comparison of the Rectum D2 (cc) for TG-43 and Acuros™ BV plans.

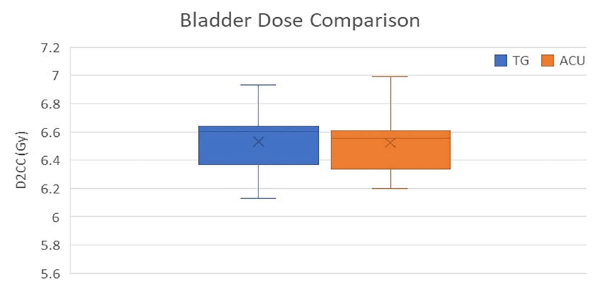

Fig. 15. Comparison of the Bladder D2 (cc) for TG-43 and Acuros™ BV plans.

Fig. 16. Comparison of the Sigmoid D2 (cc) for TG-43 and Acuros™ BV plans.

- The Coverage Index (CI) was significantly lower in Acuros™ BV (p=0.043), reflecting the algorithm's more realistic modeling of attenuation and reduced target over-coverage (Fig. 9).
- DHI, OI, EI, and COIN values were not statistically different between the two algorithms (p>0.05), although COIN values trended slightly lower in Acuros™ BV plans (Figs. 10-13).
- Rectum D2cc was significantly higher with Acuros™ BV (p=0.037), reflecting more accurate modeling of the dose near the titanium applicator (Fig. 14).
- Bladder D2cc and Sigmoid D2cc did not show statistically significant differences (p=0.575 and p=0.386, respectively), but inter-patient variability was noted (Figs. 15, 16).

These results show that the TG-43 and Acuros™ BV plans are generally comparable and provides more conservative and realistic dose estimates, particularly around sensitive structures.

DISCUSSION

This study shows that model-based dose calculation algorithms (MBDCAs), such as Acuros™ BV, can generate clinically significant improvements in dosimetric outcomes, particularly in anatomically heterogeneous mediums such as HDR brachytherapy for cervical cancer performed using titanium applicators, compared to the TG-43 formalism. The TG-43 formalism, althoug long considered the gold standard in brachytherapy planning, can no longer meet the demands of modern precision radiotherapy. Specifically, TG-43 assumes the environment to be an infinite, homogeneous medium, entirely equivalent to water. It does not take into account the patient anatomy, air cavities, bone, or applicator materials. Dose deposition is calculated assuming dose-to-water regardless of tissue characteristics.

These limitations have been well-documented in the literature. Rivard et al.[4] emphasize that TG-43 cannot accurately calculate the dose in heterogeneous mediums and recommend caution.

Similarly, Tedgren et al.[5] showed through Monte Carlo simulations that titanium applicators create attenuation effects of up to 10%, which TG-43 does not account for.

Acuros™ BV, a grid-based Boltzmann solver (GBBS), addresses TG-43's deficiencies by solving the linear Boltzmann transport equation (LBTE) in 3D voxelized space. It uses CT-derived density and material segmentation to calculate dose-to-medium, thereby modeling photon interactions with tissue and applicator materials more realistically.

Sinnatamby et al.[7] indicated that comparison of GBBS and TG-43 formalism on interstitial metal catheters shows a difference in dose prescribed to CTV and other OARs. While the estimated dose to CTV was only marginally different between the two systems, there was a significant difference in estimated doses, ranging from 4 to 53% in the mean value of all parameters analyzed.

Shajid et al.[8] showed that compared with ACE (TG-186) plans, TG-43 plans predicted higher doses for point A, point B, D90, D100, V100, V150, V200, and V300 for HR-CTV (p<0.05) .TG-43 plans indicated higher doses for bladder point, rectum point, D0.1cm3, D10 cm3, and D2cm3 for bladder, rectum, and sigmoid (p<0.05).

Similarly, studies evaluating dose–volume indices and DVH-based parameters in cervix brachytherapy emphasize the importance of accurate dose calculation for both target and organs at risk (OARs). Poddar et al.[9] reported that indices such as coverage index (CI), dose homogeneity index (DHI), and overdose volume index (OVI) are sensitive to variations in dose distribution and directly influence plan quality and clinical outcomes. While their analysis was performed within a TG-43 framework, our results suggest that the use of Acuros™ BV may systematically modify these indices by reducing artificial dose escalation in high-density regions, potentially leading to more reliable plan evaluation.

Radiobiological implications of dosimetric variations have also been discussed in the literature. Kaur et al.[10] demonstrated significant correlations between DVH-derived quality indices and tumor control probability (TCP) as well as normal tissue complication probability (NTCP) in HDR intracavitary brachytherapy for cervical cancer. In the context of our study, the observed differences in high-dose regions and OAR dose metrics when using Acuros™ BV may translate into more accurate estimations of TCP and NTCP, particularly for organs such as the rectum and bladder where air cavities and tissue heterogeneities are common.

There are so many studies that Acuros BV produce lower estimates for target coverage metrics compared with TG-43 in cervical cancer brachytherapy. In the study by Bi et al.[11] Acuros BV plans exhibited significantly lower D90%, V100%, and V150% values for CTV-HR relative to TG-43 across different applicator types, with the largest discrepancies observed for tandem-and-ovoid applicators (~10%) and smaller differences for tandem-and-ring and cylinder applicators (~1–5%).These findings mirror our observation of reduced high-dose volumes (e.g., V200%) with Acuros BV, suggesting that TG-43 may systematically overestimate dose in regions of high heterogeneity near metal or air interfaces.

A retrospective clinical analysis similarly reported consistent reductions in D90% for both high-risk and intermediate-risk CTVs when using Acuros BV compared with TG-43, with mean percentage decreases of ~4.1–4.3% across target metrics.

The comparison of Monte Carlo, TG-43 and Acuros BV by Dagli et al.[12] theoretically supports the above trends. They reported that for a simulated patient geometry, Acuros BV and Monte Carlo calculations were in close agreement across most of the dose distribution. However, TG-43 showed significant differences for both in heterogeneous scenarios, particularly at material interfaces and near OARs.

The observed differences between TG-43 and Acuros BV can be attributed to fundamental differences in dose reporting methodology and underlying physical modeling. TG-43 formalism assumes a homogeneous water medium under full scatter conditions and reports dose-to-water, thereby neglecting tissue heterogeneities, applicator effects, and interseed attenuation. In contrast, Acuros BV is a model-based dose calculation algorithm that solves the linear Boltzmann transport equation and accounts for patient-specific heterogeneities, reporting dose-to-medium.

Previous studies have consistently shown that TG-43 tends to overestimate dose compared to model-based algorithms, particularly in situations lacking full scatter or involving complex geometries. For example, Boman et al.[13] demonstrated up to 15% dose overestimation with TG-43 in superficial treatments, while Acuros showed strong agreement with measurements. Similarly, recent investigations reported systematically lower target doses with Acuros due to heterogeneity corrections, especially in the presence of air cavities.

These findings highlight that discrepancies between TG-43 and Acuros are not merely numerical but arise from fundamental physical modeling differences, emphasizing the clinical importance of model-based dose calculation algorithms.

In summary, our dosimetric findings and supporting literature indicate that while Acuros BV delivers accurate dose results in all mediums, TG-43 maintains its performance only under homogeneous conditions.

The main advantage of Acuros™ BV over the TG-43 formalism is its ability to account for tissue heterogeneities and applicator material composition, which are often ignored in TG-43 dose calculations.

TG-43 assumes an infinite water medium and therefore neglects attenuation and scatter effects arising from high-density materials such as titanium applicators and from non-water tissues commonly encountered in the pelvic anatomy.

In the present study, Acuros™ BV consistently produced different dose-volume parameters compared to TG-43, particularly in high-dose regions and in organs at risk located near tissue–air or tissue–applicator interfaces. These findings are in agreement with previously published studies in cervix HDR brachytherapy.

For the tumor coverage, TG-43 may provide falsely reassuring results. This can lead to plans that appear conformal and homogeneous but underdeliver dose near applicator-tissue interfaces.

Moreover, TG-186 Task Group specifically highlighted the limitations of TG-43 for “non-water equivalent” clinical setups and strongly recommended the use of MBDCAs like Acuros™ BV in clinical protocols that involve applicator shielding or significant tissue heterogeneity.[5]

This study has limitations. The patient number was limited to 10 patients, which may reduce the statistical power of some comparisons. Additionally, clinical outcomes such as local control, recurrence, and toxicity were not included and would be essential in future prospective validation studies.

Multicenter studies with standardized implementation protocols, paired with toxicity data, are needed to solidify Acuros™ BV’s role in treatment decision-making. In the future, these systems could become the new reference standard in brachytherapy dosimetry.

CONCLUSION

This study highlights the dosimetric discrepancies between the traditional TG-43 dose calculation formalism and the more advanced model-based algorithm, Acuros™ BV, in the context of HDR intracavitary brachytherapy for cervical cancer using titanium Fletcher-style applicators.

Our findings demonstrate that while TG-43 remains a clinically accepted standard, it significantly underestimates dose to organs at risk—particularly the rectum—and overestimates target volume coverage due to its simplifying assumptions. In contrast, Acuros™ BV provides a more realistic and conservative assessment of dose distribution by accounting for heterogeneities such as high-Z applicator materials and varying tissue densities.

The statistically significant increase in rectal dose and the reduction in high-dose subvolumes (V200%) observed with Acuros™ BV suggest that model-based algorithms may improve both treatment safety and accuracy. Furthermore, differences in the Coverage Index (CI) reinforce the need for precise modeling in dose evaluation, especially in anatomically complex treatment sites.

Despite the added complexity in implementation and interpretation, the clinical benefits of enhanced dosimetric accuracy—particularly in minimizing toxicity and improving tumor coverage—justify their integration into standard brachytherapy workflows.

Future work should aim to validate these dosimetric improvements with clinical outcome data and expand the evidence base through larger, multicenter prospective studies.

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