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Authors: Shraddha Srivastava, Ajay Kannathuparambil Venugopal, Moirangthem Nara Singh

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Effect of mModel-based dose-calculation algorithms in high dose rate brachytherapy of cervical carcinoma

Shraddha Srivastava[a], Ajay Kannathuparambil Venugopal[b], Moirangthem Nara Singh[c],

[a]Department of Radiotherapy, King George's Medical University, Lucknow, India

[b]Department of Radiotherapy, Fortis Hospital, New Delhi, India

[c]Department of Radiation Oncology, Regional Institute of Medical Sciences, Manipur, India

Corresponding author
Dr. Shraddha Srivastava
Department of Radiotherapy
King George's Medical University
Lucknow
India
E-mail:shraddha686@gmail.com
Ph.no.+91-9936933854

Abstract:

Background: TG-43 formalism does not consider the tissue and applicator heterogeneities. This study is to compare the effect of model-based dose calculation algorithms, like Advanced Collapsed Cone Engine (ACE), on dose calculation with the TG-43 dose calculation formalism in patients with cervical carcinoma.

Materials and methods: 20 patients of cervical carcinoma treated with a high dose rate of intracavitary brachytherapy were prospectively studied. The target volume and organs at risk (OARs) were contoured in the Oncentra treatment planning system (Elekta, Veenendaal, The Netherlands). All patients were planned with Co-60 and Ir-192 sources with doses of 21 Gy in 3 fractions. These plans were calculated with TG-43 formalism and a model-based dose calculation algorithm ACE. The dosimetric parameters of TG-43 and ACE-based plans were compared in terms of target coverage and OAR doses.

Results: For Co-60-based plans, the percentage differences in the D90 and V100 values for HR-CTV were 0.36±0.43% and 0.17±0.31%, respectively. For the bladder, rectum and sigmoid, the percentage differences for D2cc volumes were -0.50±0.51%, -0.16±0.53% and -0.37±1.21%, respectively. For Ir-192-based plans, the percentage difference in the D90 for HR-CTV was 0.54±0.79%, while V100 was 0.24±0.29%. For the bladder, rectum and sigmoid, the doses to 2cc volume were 0.35±1.06%, 0.99±0.74% and 0.74±1.92%, respectively. No significant differences were found in the dosimetric parameters calculated with ACE and TG-43.

Conclusion: The ACE algorithm reduced doses to OARs and targets. However, ACE and TG-43 did not show significant differences in the dosimetric parameters of the target and OARs with both sources.

Keywords: Algorithms, Brachytherapy, Cervical cancer, Iridium-192, Monte Carlo Method, Organs at Risk

1. Introduction

The dose calculation in brachytherapy relies on the gold standard of the American Association of Physicists in Medicine (AAPM) Task Group 43 (TG-43) [1]. In the TG-43 formalism, the absorbed dose is calculated by superimposing the precalculated dose distribution for a single source in a homogeneous water medium. This method, however, does not consider the impact of heterogeneities like tissues, applicators, patient anatomy, and dimensions [2]. These heterogeneities can thus complicate the prediction of dose distribution. Therefore, the absorbed dose delivered to all irradiated tissues in the presence of such inhomogeneities must be predicted accurately.

For this purpose, a dose algorithm that includes the heterogeneities inside the medium while calculating the dose has been developed. It is known as a model-based dose-calculation algorithm~~s~~ (MBDCA) [3]. MBDCAs help calculate~~s~~ the dose in non-homogenous media (tissues, air-tissue interfaces), considering all the scattering sources for computation, leading to a more accurate dose distribution [2,4]. These algorithms have been introduced in the brachytherapy treatment planning system to consider the heterogeneities like tissues and applicators. The recommendations by AAPM on the clinical implementation of these algorithms in brachytherapy have been discussed in its TG-186 report [2].

TG-186 describes three MBDCAs viz. Collapsed cone convolution (CCC), grid-based Boltzmann solver [5,6] and Monte Carlo [7–10] have been used for brachytherapy treatment planning. Commercially available MBDCA collapsed cone convolution (CCC) has been integrated into the Oncentra Brachy treatment planning system (TPS) (Elekta, Veenendaal, The Netherlands) as Oncentra-ACE (Advanced Collapsed cone Engine) [11]. The algorithm is essentially based on the data from CT images of patients and the types of applicators and shields used in brachytherapy [2]. ACE models the radiation transport in actual media and sums up the dose separately deposited by primary and scattered photons [12]. Very few studies [12,13] have explored the impact of ACE on treatment planning of cervix patients.

We conducted this prospective study on 20 cervical cancer patients to study the impact of ACE on dosimetric treatment planning parameters and compare it with the dose-volume indices of plans done with the TG-43 method. Another objective was to compare the dose-volume parameters of Co-60- and Ir-192-based plans calculated with an ACE algorithm.

2. Materials and methods

20 patients with cervical carcinoma (FIGO stage IIB-IIIB) treated with a Co-60-based high dose rate intracavitary brachytherapy between 2021 to 2022 were prospectively studied. This study was approved by the Institutional Ethics Committee (Reference no. 116th ECM IIA/P27). Intracavitary brachytherapy (ICBT) was performed with Fletcher CT/MR applicator. The Foley balloon was inflated inside the bladder during the applicator placement, followed by vaginal gauze packing. All patients underwent CT scans on a CT simulator (Brilliance CT simulator, Philips). These images were exported to Oncentra brachytherapy treatment planning system version 4.6.0 (Elekta, Veenendaal, The Netherlands). Contouring of the high-risk clinical target volume (HR-CTV) and organs at risks (OARs), such as bladder, rectum and sigmoid, was performed using GYN GEC-ESTRO guidelines [14–16].

A dose of 21 Gy in 3 fractions was prescribed. Dose calculation as per routine clinical practice was performed using the TG-43 method. Dosimetric parameters for HR-CTV, such as D90, D100 and V100 and OARs including D2cc, D1cc and D0.1cc, were compared with TG-43 and ACE algorithm. For statistical analysis, SPSS Statistics 20.0 (IBM Corp., Armonk, NY, USA) was used. Dosimetric parameters between TG-43 and ACE for both ~~the~~ sources were statistically compared using a paired t-test at 5% level of significance.

2.1 Calculation of Co-60-based plans with the ACE algorithm

All the patients were replanned with the ACE algorithm. The applicator library (loaded with information such as mass density, material composition and dimensions of applicator) was used to reconstruct the applicator. Material composition and mass density values were assigned for each contoured structure as per the material definitions given in the TG-186 report. The patient's external contour was assigned material as soft tissue, while the HR-CTV was assigned ~~the~~ material as mean skin. In OARs, the bladder material was defined as water, while the rectum and sigmoid material were defined as soft tissue. In addition, the rectal retractor was modelled as polyphenylsulfone (PPSU). The mass densities of each structure were automatically assigned from the Hounsfield units (HU) (Table 1). The dose prescription and dwell positions were kept the same as the TG-43-based plans. The dose was then computed with the ACE algorithm.

Table 1. Mass density of the different structures

Structure	Material	Mass density (g/cm^3)
HR-CTV	Mean skin	1.09
Bladder	Water	1.00
Rectum	Female soft tissue	1.02
Sigmoid	Female soft tissue	1.02
Rectal retractor	PPSU	1.3

2.2 Treatment planning with Ir-192 source

Patients treated with Co-60-based brachytherapy and calculated with the ACE algorithm were replanned with Ir-192 source in Oncentra TPS version 4.6.0 (Elekta, Veenendaal, The Netherlands) using TG-186 the ACE algorithm for comparison purposes. The dose prescription and dwell positions were kept the same as in Co-60-based plans. We compared the dosimetric parameters of plans treated with a Co-60 source to those planned with an Ir-192 source.

3. Results

3.1 Co-60-based ICBT plans

The dosimetric parameters calculated using TG-43 and ACE algorithm in Co-60-based plans have been depicted in Table 2. The mean percentage difference in the D90 and V100 values for HR-CTV were 0.36±0.43% and 0.17±0.31%, respectively. Fig. 1a illustrates the mean D90 and V200 values of patients planned with the ACE algorithm and the TG-43 formalism using Co-60. For the bladder, the percentage differences between the ACE algorithm and the TG-43 formalism for 2cc, 1 cc and 0.1cc volumes were -0.50±0.51%, -0.52±0.50% and -0.51±0.53%, respectively. For the rectum, the percentage differences for 2cc, 1 cc and 0.1cc volumes were -0.16±0.53%, -0.22±0.67% and -0.28±0.89% respectively. Similarly, for the sigmoid, the percentage differences for these volumes were -0.37±1.21%, -0.37±1.05% and -0.40±0.86%, respectively. The doses received by 2cc, 1cc and 0.1cc volumes of the bladder, rectum and sigmoid have been demonstrated in Fig. 2a, 3a and 4a, respectively. No significant difference was found between the target coverage and OAR doses with the T-43 and ACE algorithms.

Fig. 5 (a & b) shows the isodose distribution of an ICBT patient in axial sections calculated with the TG-43 and ACE (TG-186) algorithms respectively. The figure shows distortion in lower isodoses of 50%, 30% and 20% in ACE calculated plans, while no such distortion is observed in the TG-43 calculated plans.

The average volumes of the 50%, 30%, and 20% isodose curves were determined to be 267.38±31.49 cc, 490.66±45.68 cc, and 616.33±45.44 cc, respectively, in plans based on TG-43 calculations. However, in plans calculated using TG-186, materials were assigned to contoured structures according to the material definitions and mass densities outlined in the TG-186 report, making it impossible to assign materials to the isodose volumes in such plans.

Additionally, the planning system automatically reverted the calculations back to TG-43 for plans based on TG-186 as soon as the isodose structures of 50-%, 30-%, and 20% isodose lines were created. Consequently, the volumes of these isodose lines could not be quantified in TG-186 calculated plans.

3.2 Ir-192-based ICBT plans

The dosimetric parameters calculated using TG-43 and ACE algorithm in Ir-192-based plans have been depicted in Table 2. For HR-CTV, the mean percentage difference in the D90 was 0.54±0.79-%, while for V100, it was 0.24±0.29-%. Fig. 1b illustrates the mean D90 and V200 values of patients planned with the ACE algorithm and the TG-43 formalism using Ir-192. For the bladder, rectum and sigmoid, the percentage differences of doses to 2cc volume were 0.35±1.06%, 0.99±0.74% and 0.74±1.92%, respectively. The mean doses received by the bladder, rectum and sigmoid have been demonstrated in Fig. 2b, Fig. 3b and Fig. 4b, respectively. No significant differences were found in both calculation methods' dosimetric parameters of target and OARs. Fig. 5 (c & d) shows the isodose distribution of an ICBT patient in axial sections calculated with the TG-43 and ACE (TG-186) algorithms respectively. A distortion in lower isodose lines of 50%, 30%, and 20% was observed in the ACE calculated plans. The average volumes of 50%, 30% and 20% isodose curves in the TG-43-based plans was found to be 260.96±26.40 cc, 508.62±63.63 cc and 622.53±36.30 cc, respectively. As explained earlier, the volumes of these isodose lines could not be quantified in the TG-186 calculated plans.

Fig. 1 Comparison of D90 and V200 values calculated with ACE algorithm and TG-43 formalism using (a) Co-60 source and (b) Ir-192 source

Fig. 2 Comparison of D2cc, D1cc and D0.1cc values of bladder calculated with ACE algorithm and TG-43 formalism using (a) Co-60 source and (b) Ir-192 source

Fig. 3 Comparison of D2cc, D1cc and D0.1cc values of rectum calculated with ACE algorithm and TG-43 formalism using (a) Co-60 source and (b) Ir-192 source

Fig. 4 Comparison of D2cc, D1cc and D0.1cc values of sigmoid calculated with ACE algorithm and TG-43 formalism using (a) Co-60 source and (b) Ir-192 source

Fig. 5 Isodose distribution of an ICBT plan with Co-60 source in axial section calculated with (a) TG-43 and (b) ACE (TG-186) algorithm. Isodose distribution of an ICBT plan with Ir-192 source in axial section calculated with (c) TG-43 and (d) ACE (TG-186) algorithm

Table 2. Dosimetric parameters for target and OARs calculated with TG-43 and ACE algorithm in patients with cervical cancer treated with Co-60- and Ir-192-based ICBT

Source	ROI	Dosimetric parameters	TG-43	ACE	Percentage difference	p-value
Co-60	HR-CTV	D90 (Gy)	7.16±1.84	7.13±1.84	0.36±0.43	0.944
		D100 (Gy)	4.51±1.51	4.50±1.51	0.26±1.33	0.965
		V100 (%)	88.82±12.04	88.68±12.09	0.17±0.31	0.949
		V150 (%)	63.48±16.24	63.24±16.25	0.39±0.81	0.938
		V200 (%)	41.43±15.29	41.16±15.31	0.75±1.35	0.923
		Point A1 (Gy)	7.00 ±0.11	7.01±0.11	-0.04±0.36	0.913
		Point A2 (Gy)	7.00±0.11	6.99±0.11	0.04±0.36	0.907
	Bladder	D2cc (Gy)	5.38±1.29	5.41±1.31	-0.50±0.51	0.900
		D1cc (Gy)	5.96±1.49	5.99±1.51	-0.52±0.50	0.903
		D0.1cc (Gy)	7.39±2.15	7.43±2.18	-0.51±0.53	0.909
	Rectum	D2cc (Gy)	4.22±0.85	4.23±0.86	-0.16±0.53	0.967
		D1cc (Gy)	4.63±0.95	4.64±0.96	-0.22±0.67	0.954
		D0.1cc (Gy)	5.48±1.27	5.50±1.26	-0.28±0.89	0.952
	Sigmoid	D2cc (Gy)	3.16±1.47	3.17±1.46	-0.37±1.21	0.981
		D1cc (Gy)	3.79±1.85	3.80±1.85	-0.37±1.05	0.981
		D0.1cc (Gy)	5.27±2.90	5.28±2.89	-0.40±0.86	0.981
Ir-192	HR-CTV	D90 (Gy)	7.09±1.75	7.06±1.77	0.54±0.79	0.925
		D100 (Gy)	4.53±1.46	4.48±1.47	1.24±1.73	0.864
		V100 (%)	87.25±14.27	87.06±14.76	0.24±0.29	0.951
		V150 (%)	61.54±18.83	61.43±18.90	0.20±1.18	0.977
		V200 (%)	39.25±16.50	39.15±16.62	0.44±1.75	0.972
		Point A1 (Gy)	7.00 ±0.13	7.01±0.14	-0.09±0.51	0.792
		Point A2 (Gy)	7.00±0.13	6.99±0.14	0.08±0.52	0.819
	Bladder	D2cc (Gy)	5.37±1.32	5.36±1.36	0.35±1.06	0.972
		D1cc (Gy)	5.93±1.50	5.93±1.54	0.16±1.06	0.994
		D0.1cc (Gy)	7.27±2.07	7.28±2.12	-0.01±1.07	0.967
	Rectum	D2cc (Gy)	4.11±0.81	4.07±0.81	0.99±0.74	0.793
		D1cc (Gy)	4.48±0.92	4.44±0.92	0.92±0.71	0.815
		D0.1cc (Gy)	5.31±1.21	5.28±1.21	0.71±0.77	0.873
	Sigmoid	D2cc (Gy)	3.14±1.43	3.12±1.41	0.74±1.92	0.924

D1cc (Gy)	3.76±1.79	3.73±1.77	0.56±1.76	0.944
D0.1cc (Gy)	5.18±2.75	5.17±2.74	0.24±1.33	0.980

4. Discussion

In this work, we explored the effects of MBDCA on the dosimetric aspects of cervix patients treated separately with two radiation sources: Co-60 and Ir-192. Our findings indicated that the differences in dosimetric parameters, assessed using the TG-43 and ACE algorithms with both sources, remained within a 2% margin. Given that most published research focuses on Ir-192 source-based brachytherapy, to our knowledge, our study stands out as the first to compare MBDCA with TG-43 formalism using two different sources on the same patient cohort.

In Co-60-based treatment plans, there were no significant differences between the dosimetric parameters calculated using the TG-43 and ACE algorithms concerning target coverage and OAR doses. However, we observed a distortion in the lower isodose lines (50%, 30%, and 20%) in ACE-calculated plans, which was absent in TG-43-calculated plans.

For plans utilizing the Ir-192 source, we found no substantial disparities in the dosimetric parameters of target and OARs between the two calculation methods. Nevertheless, a distortion in the lower isodose lines (50%, 30%, and 20%) was evident in ACE-calculated plans, contrasting with the smoother isodose curves obtained from TG-43-based plans.

Our study revealed that plans computed with the ACE algorithm and TG-43 exhibited a consistent pear-shaped distribution for higher isodose lines (200%, 150%, and 100%). However, discrepancies emerged in the lower isodose curves (50%, 30%, and 20%). Specifically, ACE-calculated plans displayed irregularities in the lower isodose curves compared to the smooth curves obtained from TG-43 calculations for both radiation sources.

Srivastava et al. [17] found no significant differences in dosimetric parameters of the target and OARs calculated with TG-43 formalism using Co-60 and Ir-192 sources in cervix cancer patients. However, in the present work, we have determined the impact of MBDCA on dose-volume parameters in cervix patients and investigated the differences in dosimetric parameters between Co-60 and Ir-192-based plans using the ACE algorithm over the traditionally used TG-43 formalism. It was found that ACE calculated plans showed no difference in dosimetric parameters when planned with Co-60 and Ir-192 sources, similar to the findings of Srivastava et al. [17]. While the other authors have studied the impact of MBDCA using Ir-192 source-based brachytherapy, we have compared the results of our present study from both the sources with these published findings.

Mikell et al. [18] used a grid-based Boltzmann equation solver (GBBS) Acuros algorithm in Brachy Vision TPS to study inhomogeneity's impact and compare it with TG-43 in cervical cancer patients. They found that the difference between GBBS and TG-43 regarding dosimetric parameters (dose to point A, bladder and rectum) was less than 5%. Abe et al. [13] used ACE and Monte Carlo simulations to evaluate the impact of MBDCA in cervix cancer and compared it with the TG-43 formalism. Their results suggested that when the air was assigned as a rectal material, the differences in the dose-volume parameter D2cc were around 11.92± 2.25% for rectum, 0.51 ± 1.11% for bladder and 0.81 ± 1.37% for HR-CTV. These differences between TG-43 and ACE for rectum doses were reduced when water was used as rectal material, implying that the ACE algorithm gives more accurate results than the TG-43 formalism in cervix cancer in a scenario of many gases in the rectum.

There was a reduction in the target coverage by 0.54±0.79% with ACE. This was similar to the findings of Jacob et al. [12], where ACE calculated plans showed a reduction of 2.7±0.2% in target coverage in patients with cervix cancer. Hofbauer et al. [19] analyzed the impact of heterogeneity on dosimetric indices in cervix and breast brachytherapy with the Acuros algorithm. TG-43 overestimated the doses for both sites. The differences between TG-43 and Acuros GBBS were significant in the breast. However, minor differences were found in cervix cases which ranged between -1% to -2% for OARs and -0.1% to -0.5% for the HR-CTV.

In another study by Ma et al. [20], the difference between TG-43 and ACE algorithm was evaluated in sites like the prostate, chest wall and breast. Their results indicated that for V100, ACE showed a difference of 0.89% with the TG-43 formalism in prostate cases, while in the breast, this difference was around 2%. In a study on accelerated partial breast irradiation (APBI) patients conducted by Thrower et al. [21], it was concluded that lower target coverage and doses of OARs were obtained with the ACE algorithm compared to TG-43. Zourari et al. [22] did the dosimetric comparison of MBDCA and TG-43 in the APBI patient cohort. Their results indicated significant differences in the dose-volume parameters of PTV and OARs calculated with MBDCA (ACE) and TG-43. For PTV, mean percentage differences were less than 1% for V100 and D90 and around 4% for OARs like lungs and ribs.

5. Conclusion

It was concluded that ACE and TG-43 did not show significant differences in the dosimetric parameters of target and OARs with both sources. Therefore, any changes in treatment protocol are not required. We suggest that Model-based dose calculations should be performed along with TG-43 calculations to further understand and improve the MBDCA dosimetry. Application of MBDCA would be more useful in more heterogeneous tumour sites like breast and, head & neck.

Financial disclosure

None declared

Conflicts of interest

The authors have declared that they have no conflicts of interest.

Ethical approval

This study was approved by Institutional Ethics Committee (Reference no. 116th ECM IIA/P27).

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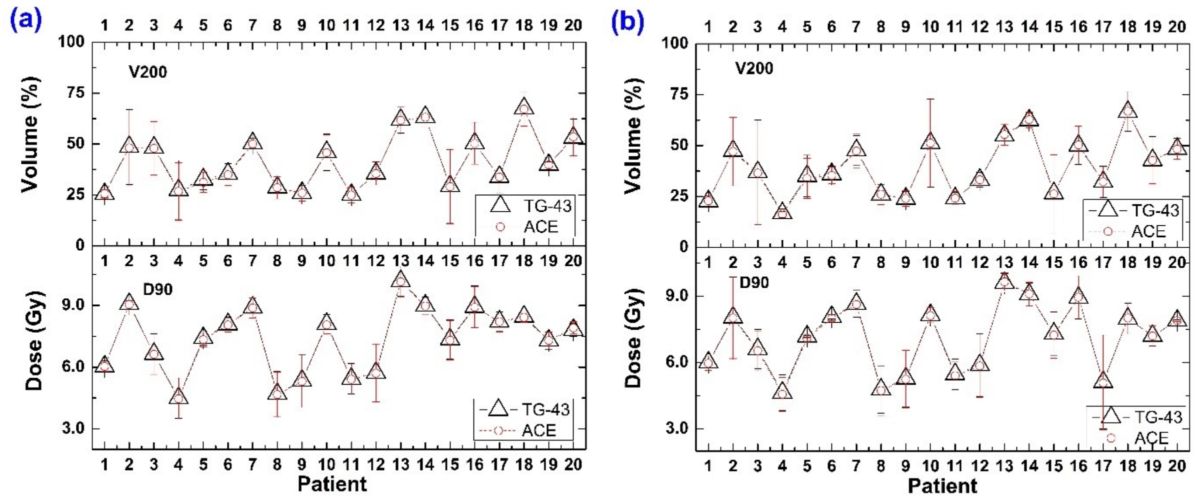

Fig. 1 Comparison of D90 and V200 values calculated with ACE algorithm and TG-43 formalism using (a) Co-60 source and (b) Ir-192 source

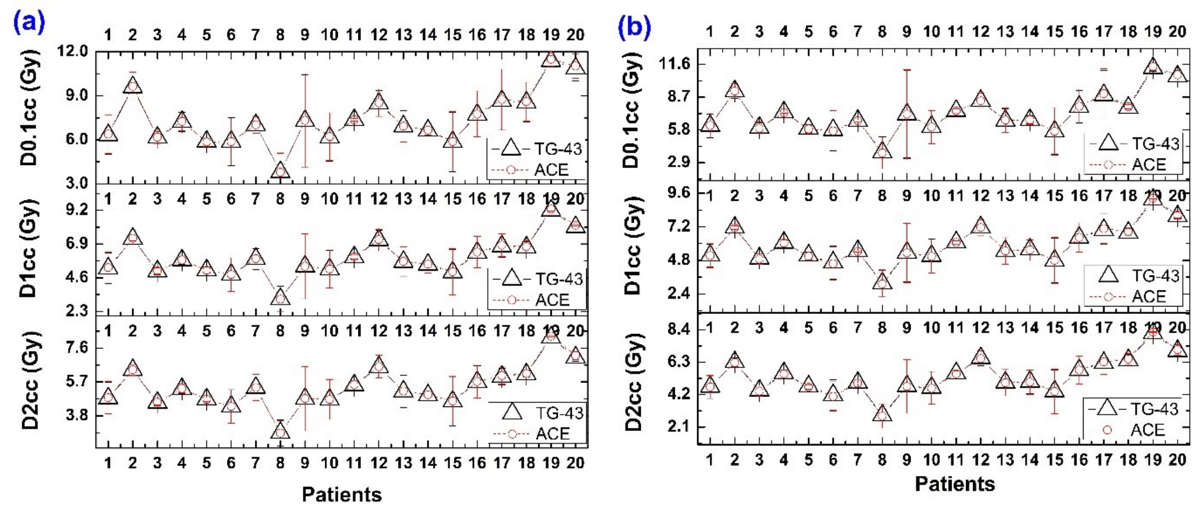

Fig. 2 Comparison of D2cc, D1cc and D0.1cc values of bladder calculated with ACE algorithm and TG-43 formalism using (a) Co-60 source and (b) Ir-192 source

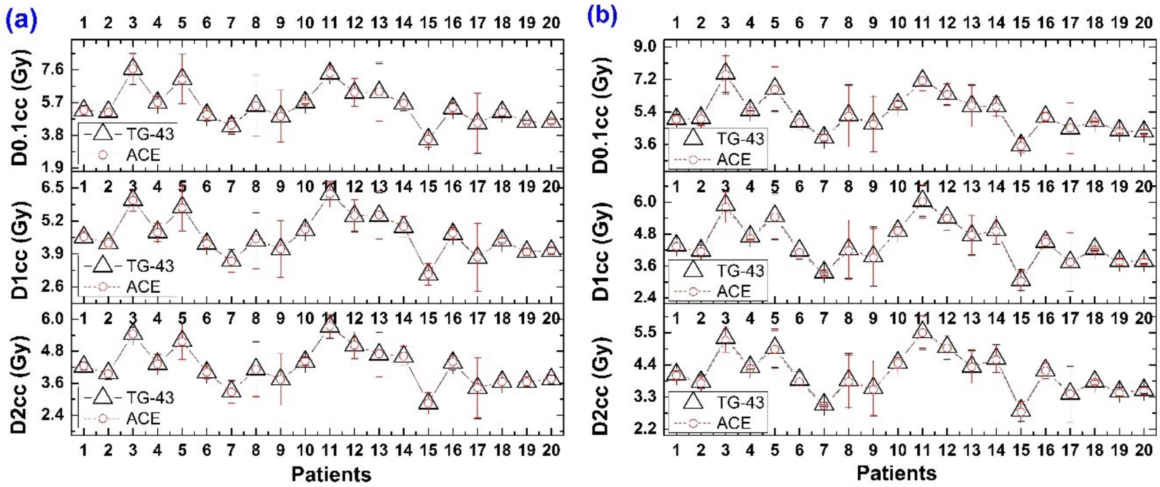

Fig. 3 Comparison of D2cc, D1cc and D0.1cc values of rectum calculated with ACE algorithm and TG-43 formalism using (a) Co-60 source and (b) Ir-192 source

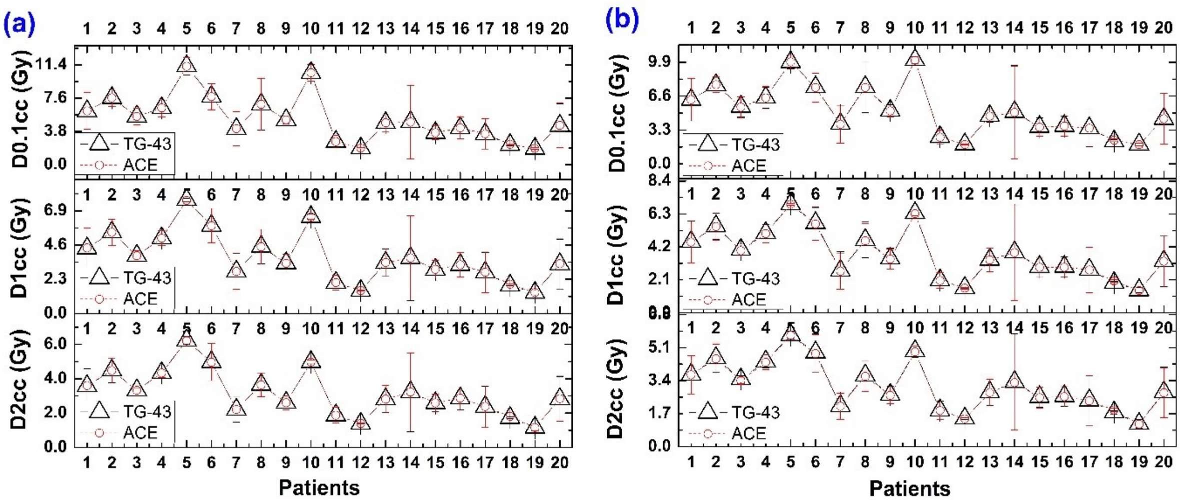

Fig. 4 Comparison of D2cc, D1cc and D0.1cc values of sigmoid calculated with ACE algorithm and TG-43 formalism using (a) Co-60 source and (b) Ir-192 source

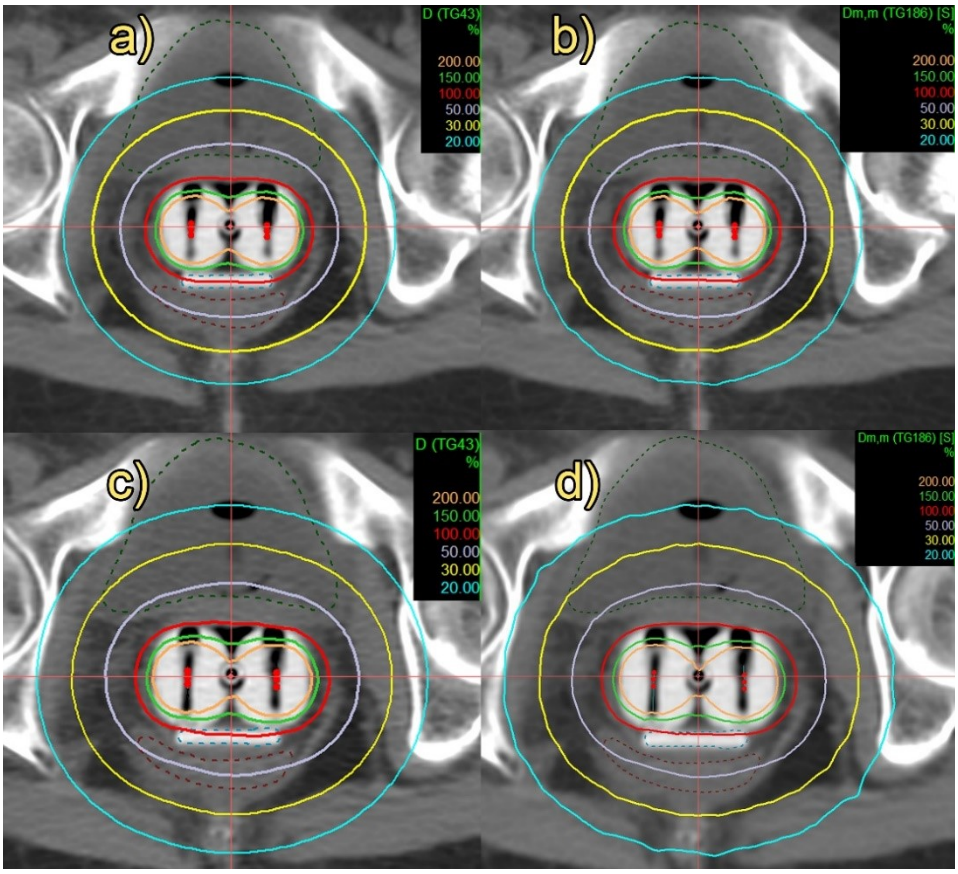

Fig. 5 Isodose distribution of an ICBT plan with Co-60 source in axial section calculated with (a) TG-43 and (b) ACE (TG-186) algorithm. Isodose distribution of an ICBT plan with Ir-192 source in axial section calculated with (c) TG-43 and (d) ACE (TG-186) algorithm