Original paper

Impact of heterogeneity-corrected dose calculation using a grid-based Boltzmann solver on breast and cervix cancer brachytherapy

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Abstract

Purpose: To analyze the impact of heterogeneity-corrected dose calculation on dosimetric quality parameters in gynecological and breast brachytherapy using Acuros, a grid-based Boltzmann equation solver (GBBS), and to evaluate the shielding effects of different cervix brachytherapy applicators.

Material and methods: Calculations with TG-43 and Acuros were based on computed tomography (CT) retrospectively, for 10 cases of accelerated partial breast irradiation and 9 cervix cancer cases treated with tandem-ring applicators. Phantom CT-scans of different applicators (plastic and titanium) were acquired. For breast cases the $V_{20Gy\alpha\beta3}$ to lung, the $D_{0.1cm^3}$, D_{1cm^3}, D_{2cm^3} to rib, the $D_{0.1cm^3}$, D_{1cm^3}, D_{10cm^3} to skin, and D_{max} for all structures were reported. For cervix cases, the $D_{0.1cm^3}$, D_{2cm^3} to bladder, rectum and sigmoid, and the D_{50}, D_{90}, D_{98}, V_{100} for the CTV_{HR} were reported. For the phantom study, surrogates for target and organ at risk were created for a similar dose volume histogram (DVH) analysis. Absorbed dose and equivalent dose to 2 Gy fractionation (EQD2) were used for comparison.

Results: Calculations with TG-43 overestimated the dose for all dosimetric indices investigated. For breast, a decrease of ~8% was found for D_{10cm^3} to the skin and 5% for D_{2cm^3} to rib, resulting in a difference ~ –1.5 Gy EQD2 for overall treatment. Smaller effects were found for cervix cases with the plastic applicator, with up to –2% (–0.2 Gy EQD2) per fraction for organs at risk and –0.5% (–0.3 Gy EQD2) per fraction for CTV_{HR}. The shielding effect of the titanium applicator resulted in a decrease of 2% for D_{2cm^3} to the organ at risk versus 0.7% for plastic.

Conclusions: Lower doses were reported when calculating with Acuros compared to TG-43. Differences in dose parameters were larger in breast cases. A lower impact on clinical dose parameters was found for the cervix cases. Applicator material causes systematic shielding effects that can be taken into account.

Purpose

Dose calculation is essential for prescribing, recording, and reporting dose values in brachytherapy. An accurate dose assessment is the basis to optimize treatment plans for meeting the defined planning aims and for establishing dose-response curves to predict tumor control and morbidity. The current state of the art to calculate brachytherapy absorbed dose is the American Association of Physicists in Medicine (AAPM) Task Group No. 43 (TG-43) algorithm [1,2]. The formalism is based on the dose rate constant, geometry and radial dose functions, as well as anisotropy factor. Algorithms based on the TG-43 formalism utilize dose rate distributions pre-cal-culated in a standard, homogeneous water geometry. It neglects the specific variations in tissue composition and applicator material. Due to the different energy ranges between low energy photon sources, high energy photon sources and external beam radiation therapy (EBRT), the integration of tissue composition has been of lower priority compared to external beam therapy where state of the art dose calculation is based on the Hounsfield units of the irradiated tissue. However, particularly when including high Z materials for applicators and missing backscatter when treating close to the body surface uncertainties in dose reporting became obvious [3,4,5,6]. There is an increasing interest in development of more accurate dose calculation algorithms and

software solutions [3,7,8]. Recently, also the vendors of treatment planning software have included such algorithms in their systems. This study analyzes the impact of improved dosimetry by taking into account material inhomogeneities and patient specific scatter conditions, based on a commercially available dose planning software for two different clinical sites: breast and cervix cancer brachytherapy. The aim is to compare dose reporting based on TG-43 and a grid-based Boltzmann solver (GBBS), and to evaluate the clinical relevance of differences between these dose calculation methods.

Material and methods

General

Defined dose volume histogram (DVH) parameters from computed tomography(CT)-based treatment plans of randomly selected patients were analyzed using treatment planning system BrachyVision v10.0 (Varian Medical Systems, Palo Alto, CA, USA). Plans were created based both on TG-43 formalism and using the GBBS Acuros v1.4.0 algorithm [9,10], and dose was reported as kerma-to-water in medium. Two cohorts of patients, for breast and cervix cancer brachytherapy were examined and an additional phantom study was performed for gynecological applicators. Simulated 3D image-based treatment plans were based on CT scans acquired with a Somatom Plus scanner (Siemens, Erlangen, Germany), and a slice thickness of 2 mm for breast and 4 mm for cervix brachytherapy plans, respectively. Absorbed dose values were compared, as well as clinically relevant equieffective doses using the EQD2 concept [11]. Throughout the study, an α/β ratio of 3 Gy was used for organs at risk and 10 Gy for target volumes with 1.5 hours for half-time of repair.

Breast cases

Ten cases of accelerated partial breast irradiation (APBI) with flexible plastic implants were analyzed. Dwell paths were digitized manually. Ipsilateral lung and the most exposed rib were contoured as regions of interest (Figure 1). A help structure for evaluating skin dose was delineated outside the skin surface as described in [12], the thickness of this structure being 4 cm from surface. Reported DVH-parameters were $V_{20Gy\alpha\beta3}$ for lung, $D_{0.1cc}$, D_{1cc} and D_{2cc} for rib, and $D_{0.1cc}$, D_{1cc} and D_{10cc} for the skin help structure. Also for all structures D_{max} was reported. These values were calculated based on the TG-43 and Acuros algorithms and compared to each other. All treatment plans were generated based on our clinical protocol for a pulsed-dose-rate (PDR) schedule of 63 pulses and a total planning aim dose of 50.4 Gy. The total treatment dose was calculated using the linear quadratic model.

Cervix cases

Also cases of 9 cervix cancer patients treated with plastic tandem-ring applicators (Nucletron, Veenendaal, The Netherlands) were scanned. For brachytherapy treatment planning, an HDR schedule consisting of four brachytherapy fractions was assumed. Five out of nine patients were treated with a combined intracavitary/interstitial technique with 3 to 10 additional needles. Applicator source paths were digitized manually. High-risk clinical target volume (CTV$_{HR}$) as well as organs at risk (OAR) such as bladder, rectum, and sigmoid were contoured as regions of interest (Figure 1). The reported DVH parameters were D_{50}, D_{90}, D_{98}, and V_{100} for the CTV$_{HR}$ and $D_{0.1cm^3}$ and D_{2cm^3} for the OAR, respectively. For Acuros, no additional density information than the CT data was used, as the system did not provide the fitting applicator model used in these cases.
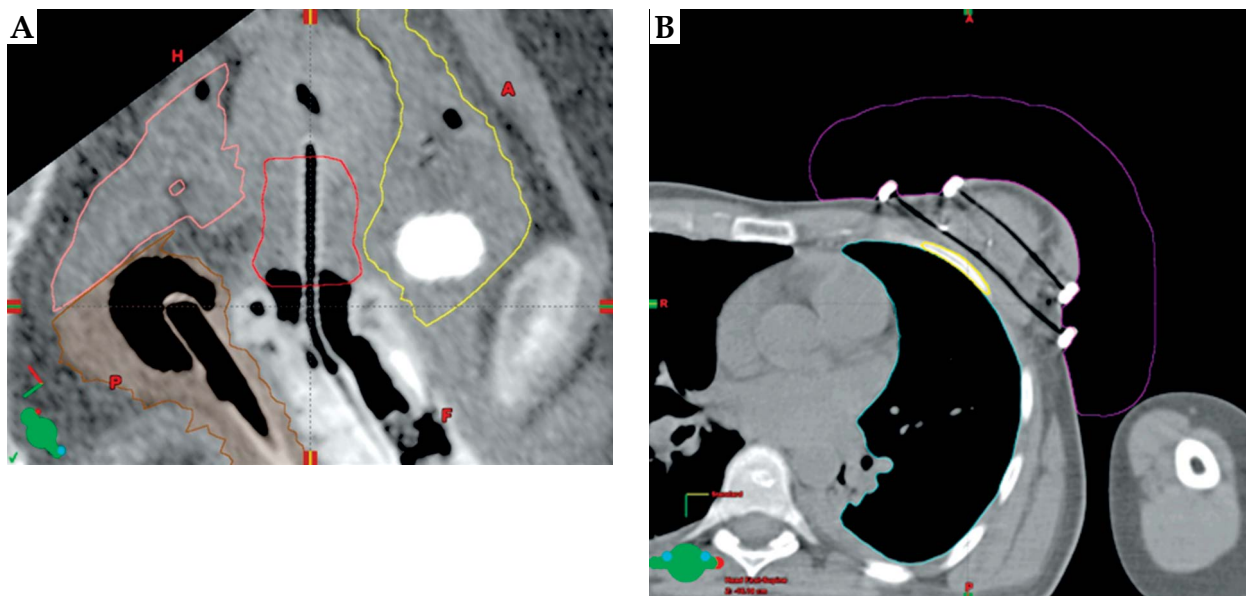
Fig. 1. Computed tomography slice showing target and organs at risk delineation. **A)** Clinical cervix case, in sagittally reconstructed applicator view, with high-risk clinical target volume (CTV$_{HR}$), rectum, bladder, and sigmoid delineated. **B)** Transversal cut for a breast case, with skin surrogate, rib, and lung delineation

Treatment plans were generated based on a typical clinical protocol for EBRT (45 Gy) and high-dose-rate (HDR) brachytherapy delivered in 4 fractions. The planning aim was to achieve a D_{90} for $CTV_{HR} \geq 7$ Gy per fraction, which results in a total treatment $D_{90} \geq 84$ Gy EQD2, based on the linear quadratic model using $\alpha/\beta = 10$ Gy. For OARs, the planning aims were to achieve a total $D_{2cm^3} \leq 90$, 70, and 75 Gy EQD2 using $\alpha/\beta = 3$ Gy, for bladder, rectum, and sigmoid, respectively.

Phantom study

In addition, a phantom study was executed to investigate the impact of applicator material only. Tandem-ring applicators built of titanium (Varian Medical Systems), as well as of the clinically used plastic tandem-ring applicators as mentioned above were CT-scanned in a water phantom. The plastic applicator was scanned twice without and with additional titanium needles inserted.

For the phantom plans, the applicator model of the titanium applicator was used from the library providing matching source path, as well as corresponding vendor-provided density information. Heterogeneity corrected dose calculation for the plastic applicator was based on CT-scan information only. Since both types of applicators were of comparable physical dimensions, the same dwell path was used for both in order to break down comparison to the applicator material. In this phantom study, a region near the applicator surface was created as a surrogate for an OAR, as well as a region around the applicator itself as surrogate for a target volume. Corresponding dosimetric quality parameters were investigated as D_{50}, D_{90}, D_{98}, and V_{100} for the target surrogate and $D_{0.1cm^3}$ and D_{2cm^3} for the OAR surrogate, respectively.

Library applicator analysis for different metals

In order to test the difference between different types of metal applicators, 5 patient plans based on magnetic resonance imaging (MRI) were calculated using titanium and steel applicator model from the treatment planning system's applicator library. All plans were standard plans with no optimization and a prescribed dose of 7 Gy to point A. All plans were calculated with or without heterogeneity correction for the applicator material and differences between TG-43, and Acuros were reported for the CTV_{HR} D_{90}, D_{98} and D_{50}, and the rectum $D_{0.1cm^3}$ and D_{2cm^3}.

Results

Breast cases

A summary of the simulated treatment plans for the 10 breast cases is given in Table 1. In general, TG-43 calculated higher dose for breast cases compared to the Acuros dose calculation. All structures show an overestimation of dose when calculated by TG-43, because this algorithm is based on calculation in water. Lung tissue as well as medium outside the patient's surface do not provide the same amount of back scatter [13], which leads to lower doses calculated by the heterogeneity-corrected algorithm. Obviously, this effect results in a greater difference for skin surrogate of up to –8% for the D_{10cm^3}, meaning

Table 1. Summary of dosimetric parameters calculated by TG-43 algorithm and GBBS Acuros in absorbed dose, as well as EQD2 showing results for organs at risk (skin surrogate, most exposed rib and lung) mean values ± SD for overall treatment (63 pulses) of breast cases (*n* = 10)

		Absorbed dose				EQD2 ($\alpha/\beta = 3$ Gy)	
		TG-43	Acuros	Difference (Ac-TG-43)		Difference (Ac-TG-43)	
		Mean ± SD (Gy)	Mean ± SD (Gy)	Mean ± SD (%)	Range (%)	Mean ± SD (Gy$_{iso}$)	Range (Gy$_{iso}$)
Skin	D_{max}	29.24 ± 6.26	28.07 ± 6.35	−4.18 ± 1.45	[−5.84; −1.60]	−1.60 ± 0.53	[−2.51; −1.03]
	$D_{0.1cm^3}$	26.26 ± 5.19	24.84 ± 5.32	−5.65 ± 1.64	[−8.05; −2.30]	−1.81 ± 0.38	[−2.34; −1.29]
	D_{1cm^3}	23.01 ± 3.66	21.52 ± 3.70	−6.65 ± 1.46	[−8.70; −3.31]	−1.79 ± 0.34	[−2.28; −1.18]
	D_{10cm^3}	17.80 ± 2.34	16.34 ± 2.22	−8.21 ± 1.33	[−10.17; −5.46]	−1.55 ± 0.33	[−2.07; −0.97]
Rib	D_{max}	41.59 ± 17.78	40.84 ± 17.82	−2.34 ± 1.55	[−5.33; −0.58]	−1.27 ± 0.64	[−2.45; −0.64]
	$D_{0.1cm^3}$	35.10 ± 12.89	34.19 ± 12.76	−2.96 ± 1.27	[−5.50; −1.45]	−1.45 ± 0.62	[−2.47; −0.62]
	D_{1cm^3}	28.05 ± 9.39	26.99 ± 9.14	−4.00 ± 1.10	[−6.17; −2.73]	−1.48 ± 0.64	[−2.58; −0.60]
	D_{2cm^3}	22.30 ± 7.56	21.25 ± 7.33	−4.92 ± 1.13	[−6.61; −3.26]	−1.28 ± 0.54	[−2.23; −0.59]
Lung	D_{max}	27.31 ± 10.03	26.14 ± 9.75	−4.92 ± 1.35	[−6.82; −2.87]	−1.62 ± 0.69	[−2.79; −0.58]
	$V_{20GyEQD2}$	20 Gy volume in EQD2					
		(%)	(%)	(%)	(%)		
		0.69 ± 0.45	0.51 ± 0.38	−0.12 ± 0.12	[−0.32; 0.00]		

EQD2 – equivalent dose at 2 Gy, α/β – alpha/beta ratio, $D_{0.1cm^3}$, D_{1cm^3}, D_{2cm^3}, D_{10cm^3} – minimum dose to the most exposed 0.1 cm³, 1 cm³, 2 cm³, 10 cm³

Table 2. Summary of dosimetric parameters calculated by TG-43 algorithm and GBBS Acuros in absorbed dose, as well as EQD2 showing results for target and organs at risk for cervix cases ($n = 9$). Mean values ± SD per fraction are given for bladder, rectum, sigmoid, and CTV_{HR}

		Absorbed dose				EQD2 (α/β = 3 resp. 10 Gy)	
		TG-43	Acuros	Difference (Ac-TG-43)		Difference (Ac-TG-43)	
		Mean ± SD (Gy)	Mean ± SD (Gy)	Mean ± SD (%)	Range (%)	Mean ± SD (Gy_{ISO})	Range (Gy_{ISO})
Bladder	$D_{0.1cm^3}$	5.56 ± 1.12	5.53 ± 1.11	−0.63 ± 0.27	[−0.90; 0.00]	−0.10 ± 0.06	[−0.20; 0.00]
	D_{2cm^3}	4.03 ± 0.83	4.00 ± 0.82	−0.87 ± 0.25	[−1.41; −0.56]	−0.08 ± 0.04	[−0.17; −0.04]
Rectum	$D_{0.1cm^3}$	3.12 ± 0.67	3.07 ± 0.67	−1.42 ± 0.72	[−2.52; −0.62]	−0.08 ± 0.05	[−0.18; −0.03]
	D_{2cm^3}	2.31 ± 0.54	2.26 ± 0.53	−2.14 ± 0.63	[−3.27; −1.32]	−0.08 ± 0.03	[−0.12; −0.04]
Sigmoid	$D_{0.1cm^3}$	5.19 ± 1.13	5.12 ± 1.14	−1.43 ± 0.65	[−2.41; −0.34]	−0.19 ± 0.08	[−0.33; −0.06]
	D_{2cm^3}	3.73 ± 0.99	3.67 ± 0.99	−1.69 ± 0.81	[−2.97; −0.43]	−0.12 ± 0.05	[−0.22; −0.05]
CTV_{HR}	D_{50}	11.08 ± 1.25	11.08 ± 1.30	−0.10 ± 0.53	[−0.87; 0.68]	−0.01 ± 0.17	[−0.23; 0.28]
	D_{90}	7.61 ± 0.59	7.57 ± 0.60	−0.47 ± 0.33	[−1.25; −0.14]	−0.07 ± 0.05	[−0.18; −0.02]
	D_{98}	6.38 ± 0.49	6.35 ± 0.50	−0.50 ± 0.41	[−1.42; 0.00]	−0.06 ± 0.04	[−0.14; 0.00]
	V_{100}	[%]	[%]	[%]	[%]		
		98.89 ± 0.95	98.72 ± 1.01	−0.17 ± 0.16	[−0.51; 0.00]		

EQD2 – equivalent dose at 2 Gy, α/β – alpha/beta ratio, $D_{0.1cm^3}$, D_{2cm^3} – minimum dose to the most exposed 0.1 cm³, 2 cm³, CTV – clinical target volume, D_{50}, D_{90}, D_{98} – the minimum dose to 50%, 90%, 98% of the CTV, V_{100} – volume of the anatomic volume receiving 100%, of the prescribed dose

–1.5 Gy EQD2 for overall treatment of 63 pulses. Similar results can be found for the most exposed ribs where the mean D_{2cm^3} was –1.3 Gy in EQD2 or nearly –5% in absorbed dose. Correspondingly, the dose difference of ipsilateral lung shows about the same percentage of –1.6 Gy EQD2 in the overall treatment. The mean equivalent volume of 20 Gy EQD2 with an α/β of 3 Gy is about 1.5 cm³ smaller on average for heterogeneity corrected calculation.

Cervix cases

An overview of the results for the 9 investigated cervix cases is given in Table 2. The comparison of dose calcula-
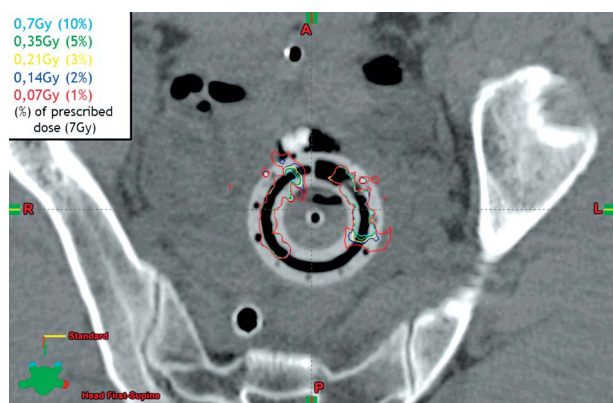
Fig. 2. Dose difference map for a plastic ring applicator. Relevant differences are limited to the vicinity of the applicator

tion algorithms shows only a small impact on the cervix cases investigated when using a plastic applicator (Figure 2). Mean differences in absorbed dose for $D_{0.1cm^3}$ and D_{2cm^3} ranged between approximately –1% and –2% for organs at risk resulting in negligible a difference of EQD2 less than 0.2 Gy per fraction, on average. For a total treatment of 4 fractions, this would result in a systematic difference of less than 1 Gy.

Even less impact was found for the CTV_{HR}, as the differences for investigated clinical parameters ranged from –0.1% to –0.5% in dose, which was equivalent up to only 0.07 Gy EQD2 per fraction. When dividing the results between intracavitary only and additional needle cases, no significant difference could be observed for all parameter except D_{50}. For the D_{50}, the mean absorbed dose difference for intracavitary/interstitial cases was –0.5% compared to 0.4% for plain intracavitary cases.

Phantom study

Regarding the phantom, the results showed shielding effects of applicator material (Table 3), D_{90} to the defined target surrogate was overestimated by TG-43 vs. Acuros by more than 1% for the titanium applicator and ~0.5% for plastic. Clinically, this would result in an overestimation of dose of less than 0.1 Gy EQD2 per fraction for plastic applicator, whereas for titanium we observed more than double the effect. For 4 fractions using a titanium applicator, this adds up to 0.8 Gy EQD2 difference. Due to the overall lower doses for OAR's, the relative difference on D_{2cm^3} was around 2% for titanium and about 0.7% for plastic, respectively. Clinically, this results in an over-

estimation of dose by TG-43 of less than 0.1 Gy EQD2 per fraction for plastic applicator and about twice the value, as seen in the outcomes for the target surrogate structure. For a simulated full treatment of 4 HDR fractions using a titanium applicator, this results in 0.8 Gy EQD2 less for Acuros-based values compared to TG-43.

Applicator library study for metals

For the test of different metal applicators based on applicator library models, 10 treatment plans were compared. The results are reported in Table 4. As expected, the difference between TG-43 and Acuros was larger for the steel applicator, both for the DVH parameters of the target, and of the rectum. For the rectum, $D_{0.1cm^3}$ and D_{2cm^3} were found to be on average ~3% larger when the applicator material was taken into account for dose calculation in the case of steel. This was about double the effect that was observed when the same cases were calculated with a titanium applicator model.

Table 3. Dose differences for phantom study split in comparison for titanium and plastic applicator for organ at risk and target surrogate. A negative difference means the value was higher for TG-43 than for Acuros-based treatment plans

			Absorbed dose			EQD2 (α/β = 3 resp. 10 Gy)		
			TG-43 (Gy)	Acuros (Gy)	relΔ (%)	TG-43 (Gy$_{ISO}$)	Acuros (Gy$_{ISO}$)	relΔ (%)
OAR	$D_{0.1cm^3}$	Titanium	5.32	5.22	−1.88	8.85	8.58	−3.06
		Plastic	4.95	4.92	−0.61	7.87	7.79	−0.98
	D_{2cm^3}	Titanium	4.43	4.34	−2.03	6.58	6.37	−3.22
		Plastic	4.23	4.20	−0.71	6.12	6.05	−1.12
Target	D_{50}	Titanium	11.43	11.28	−1.24	20.40	20.02	−1.89
		Plastic	11.25	11.24	−0.02	19.91	19.90	−0.04
	D_{90}	Titanium	7.54	7.44	−1.24	11.02	10.82	−1.76
		Plastic	7.51	7.47	−0.51	10.96	10.88	−0.73
	D_{98}	Titanium	6.79	6.71	−1.11	9.49	9.35	−1.56
		Plastic	6.77	6.77	−0.05	9.47	9.46	−0.07
	V_{100}		(%)	(%)	(%)			
		Titanium	96.37	95.35	−1.02			
		Plastic	96.14	95.75	−0.39			

EQD2 – equivalent dose at 2 Gy, α/β – alpha/beta ratio, $D_{0.1cm^3}$, D_{2cm^3} – minimum dose to the most exposed 0.1 cm³, 2 cm³, OAR – organs at risk, D_{50}, D_{90}, D_{98} – the minimum dose to 50%, 90%, 98% of the target, V_{100} – volume of the anatomic volume receiving 100%, of the prescribed dose

Table 4. Dose differences for library titanium and steel applicators for CTVHR and rectum, calculated on magnetic resonance imaging. A negative difference means the value was higher for TG-43 than for Acuros-based treatment plans

Absorbed dose Ac-TG43		Titanium		Steel	
	n = 5	relΔ (%)	SD (%)	relΔ (%)	SD (%)
Rectum	$D_{0.1cm^3}$	1.35	0.81	2.70	0.92
	D_{2cm^3}	1.58	0.77	3.29	0.78
CTV$_{HR}$	D_{50}	0.43	0.21	1.49	0.21
	D_{90}	0.58	0.12	1.61	0.21
	D_{98}	0.70	0.37	1.89	0.45
	V_{100}	(%)	(%)	(%)	(%)
		0.22	0.23	0.68	0.67

$D_{0.1cm^3}$, D_{2cm^3} – minimum dose to the most exposed 0.1 cm³, 2 cm³, CTV – clinical target volume, D_{50}, D_{90}, D_{98} – the minimum dose to 50%, 90%, 98% of the target, V_{100} – volume of the anatomic volume receiving 100%, of the prescribed dose

Discussion

The AAPM TG-43 algorithm is state of the art as it provides reliable dose distributions for clinical plans and its limitations are known. The results of this study indicate that use of heterogeneity correction shows effects on dose parameters, yet with no considerable clinical effect. Two main issues are found as expected. Whereas TG-43 calculation tends to result in overestimation of dose where lack of backscatter plays a role in APBI, possible shielding effects of applicator material might show an impact in cervix cases.

For high-energy sources as ^{192}Ir, the effect of missing back scatter due to the finite patient size has been described in detail [3,4,5]. Target volumes close to the skin or air filled cavities are mainly present in case of breast brachytherapy or head and neck brachytherapy [14]. Perturbations based on media different than water in case of high-energy sources have been mainly reported for shielded applicators and balloon catheters, filled with air or contrast medium. In this study, multi-catheter plastic implants are studied.

According to patient scatter, our study showed expected dosimetric uncertainties [6] in breast cases close to density gradients in tissue near lung and skins surface. The observed mean differences of the skin dose parameters based on different algorithms range from 4.2% for D_{max} to 8.2% for D_{10cm^3}. These ranges are in agreement with a 5-10% difference for skin point doses at different distances from the breast center, calculated with TG-43 and Monte Carlo simulations [4]. The difference of D_{max} of lung and ribs has been previously reported for TG-43- and Acuros-based calculations of interstitial implants with metal catheters [15]. Reported results seem to indicate a ~2% larger impact of metal catheters on the differences in D_{max} in comparison to the present results for plastic catheters. A direct comparison of reported skin doses is unreliable, as in addition to different applicator materials also the definition of the skin structure for DVH evaluation was different in the present study. Zourari *et al.* reported 4% difference of D_{max} for lung and rib when comparing TG-43 and a different commercially available model based dose calculation algorithm [16], which is in the range of the ~2% and ~5% differences we have observed for rib and lung for Acuros. As in the present study, they found the largest difference for the D_{10cm^3} of the skin (6% vs. 8% in the present study).

Even though the effect of using an advanced dose calculation algorithm as such is systematic, its impact on dose parameters is location dependent. Therefore, individual planning in principle adds to more accuracy of dose-response for retrospective analysis and prospective treatment planning.

This effect could not be found in cervix cases. Effects due to rectum filling or packing causing low density or even areas filled with air had no major impact on dosimetric parameters analyzed. However, the phantom study showed an impact of applicator material when the titanium applicator seems to have more of a shielding effect compared to the plastic. Although this effect was small (< 2%), this might lead to a systematic shift of dose response curves [17]. Only in dose response modelling as it can be performed via large clinical trials (e.g. EMBRACE – http://www.embracestudy.dk [18]), it can be tested if a systematic offset in dose correlates better with clinical outcome.

Overall, the findings of our study are consistent with recent reports of DVH parameter deviations for target and OAR's, for Acuros-based dose calculations for cervix cancer brachytherapy with tandem/ovoid applicators [19] and Monte Carlo simulations [20]. In contrast to the findings reported by Mikell *et al.* [21], none of our cases showed differences between the dose calculation methods larger than 5%. However, in the latter study, these large deviations were due to the influence of rectal contrast used for imaging. In addition, major deviations might be found when comparing point dose rather than volumes, since these might be less sensitive to intrinsic parameters of a grid-based calculation method. Especially in regions of dose gradients, spatial resolution might have a higher impact on differences in calculated dose too. Therefore, we think that for comparing these algorithms dosimetric parameters based on volumes should be favored over those based on singularities [21].

This study shows that calculation without heterogeneity correction may cause deviations of clinically used dosimetric parameters. However, this should not have an impact on common dose constraints as these refer to data retrieved from use of TG-43 algorithm. In line with the joint AAPM and GEC-ESTRO report, TG-186 dose calculation should be performed both ways.

In the present study, part of the applicator volume was included in the delineated target structure. The analysis of the D_{50}, i.e. the minimum dose to 50% of the target volume, indicated that this high dose parameter is more sensitive to the influence of applicator volume inside the defined target volume. In this case, the effect of calculating DVH for volumes containing tissue and applicator material, versus the more correct calculation of DVH for the tissue volume only, might play a bigger role than heterogeneity correction.

Conclusions

The impact of heterogeneity corrected dose calculation using a grid-based Boltzmann solver on breast and cervix cancer brachytherapy was investigated with clinical treatment planning and phantom studies. For the studied situations of non-shielded applicators and a high-energy source, dose deviations are small. However, the known systematic overestimation of the skin dose in case of breast is confirmed, also taking into account biologically equieffective dose values. A small systematic dose effect was found when replacing intracavitary plastic applicators with titanium applicators, which is increasing when using steel applicators.

The observed effects for breast and cervix cases were not considered to be clinically relevant. However, advanced dose calculation tools such as Acuros can help to identify systematic effects and increase confidence in individual planning dosimetry and dose reporting in the future.

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