Original paper

Head and neck ^{192}Ir HDR-brachytherapy dosimetry using a grid-based Boltzmann solver

Frank-André Siebert, PhD[1], Sabine Wolf, MD[1], George Kóvacs, MD, PhD[2]

[1]Clinic of Radiotherapy, University Hospital of Schleswig-Holstein, Kiel, [2]Interdisciplinary Brachytherapy Unit, University of Luebeck, Luebeck, Germany

Abstract

Purpose: To compare dosimetry for head and neck cancer patients, calculated with TG-43 formalism and a commercially available grid-based Boltzmann solver.

Material and methods: This study included 3D-dosimetry of 49 consecutive brachytherapy head and neck cancer patients, computed by a grid-based Boltzmann solver that takes into account tissue inhomogeneities as well as TG-43 formalism. 3D-treatment planning was carried out by using computed tomography.

Results: Dosimetric indices D_{90} and V_{100} for target volume were about 3% lower (median value) for the grid-based Boltzmann solver relative to TG-43-based computation ($p < 0.01$). The V_{150} dose parameter showed 1.6% increase from grid-based Boltzmann solver to TG-43 ($p < 0.01$).

Conclusions: Dose differences between results of a grid-based Boltzmann solver and TG-43 formalism for high-dose-rate head and neck brachytherapy patients to the target volume were found. Distinctions in D_{90} of CTV were low (2.63 Gy for grid-based Boltzmann solver vs. 2.71 Gy TG-43 in mean). In our clinical practice, prescription doses remain unchanged for high-dose-rate head and neck brachytherapy for the time being.

J Contemp Brachytherapy 2013; 5, 4: 232-235
DOI: 10.5114/jcb.2013.39444

Key words: acuros, brachytherapy, head and neck, heterogeneity correction, HDR, GBBS.

Purpose

High-dose-rate (HDR) brachytherapy (BT) is a successful treatment option for many head and neck (H&N) cancer diseases [1-4]. In general, plastic tubes are implanted into the target volume followed by computed tomography (CT) in order to prepare a treatment plan. An important question in modern H&N BT is the accuracy of dose calculation. Nowadays, dose calculation is performed usually using the TG-43 formalism [5]. Nevertheless, it is known that results of the TG-43 formalism can be suboptimal in several scenarios, in particular when tissue inhomogeneities, like bony structures and air cavities, are present [6,7], or finite patient dimensions are taken into account. Thus, modern treatment planning systems (TPSs) might be used to account for these inhomogeneities and provide the user with a more accurate calculated dose. Rivard *et al*. [8] gave an overview for which treatment sites and dose rates (high or low) vary between TG-43 formalism [6] and modern algorithms, like Monte-Carlo (MC), and model-based dose calculation algorithms (MBDCAs) are to be expected. Since H&N treatments are not included in discussion, a retrospective analysis was performed and is presented here. Data of H&N BT patients treated by a HDR ^{192}Ir BT source were evaluated, and dosimetry of a commercially available MBDCA grid-based Boltzmann solver (GBBS) [9-13] was compared with TG-43 based dosimetry.

Material and methods

Treatment plans for 49 consecutive H&N BT patients were analyzed in this project. The patient cohort (15 female, 34 male) were treated with a HDR ^{192}Ir BT afterloader of type VariSource (Varian Medical Systems, Palo Alto, CA, USA) between 2001 and 2009, applying a single fraction dose of 2.5 Gy. Overall doses varied between 25 and 40 Gy depending on the patient. The 2.5 Gy single fraction, with 2 fractions per day, dose was chosen to be radiobiologically equivalent with a pulse-dose-rate (PDR) regimen of 5 fractions of 1 Gy single fraction dose each 2 hours [14]. The mean age of the patients was 57.1 years, standard deviation (SD) 12 years, maximum age 86 years, and minimum age 36 years. The diagnoses comprised floor of mouth carcinoma, larynx carcinoma, and parotid carcinoma with varying stages and grading. Plastic catheters (median: 5.2, SD: 2, min: 2, max: 12) were implanted. All patients underwent a 3D computed tomography (CT) for treatment planning purposes using a Picker PQ 2000 CT (Philips Healthcare, Eindhoven, The Netherlands) with 2 mm slice thickness. The patient's treatment plans were calculated with the BrachyVision v8.8 (Vari-

Address for correspondence: Frank-André Siebert, PhD, Clinic of Radiotherapy, University Hospital of Schleswig-Holstein, Kiel, Arnold-Heller-Str. 3, Haus 50, 24105 Kiel, Germany, phone: +49 431597-3022, fax: +49 431597-3110, ✉ e-mail: Frank-Andre.Siebert@uksh.de

Received: 11.09.2013
Accepted: 01.12.2013
Published: 31.12.2013

Table 1. Dose parameters for the investigated H&N patient cohort showing results for the TG-43 and GBBS based dose calculation

	TG-43			GBBS			
	Median	Min.	Max.	Median	Min.	Max.	*p*-value
D_{90} [Gy]	2.71	2.59	2.74	2.63	2.56	2.79	< 0.01
V_{100} [%]	99.05	94.63	99.53	96.13	95.58	99.56	< 0.01
V_{150} [%]	57.35	53.32	59.68	56.43	49.46	60.19	< 0.01
DHI	0.42	0.39	0.46	0.41	0.39	0.48	0.24

an Medical System, Palo Alto, CA, USA) software, using the commercial GBBS Acuros module (v1.3.1) of BrachyVision without reoptimization of dwell weights as well as the TG-43 formalism. Dose output was reported to dose-to-water in Gy. For commissioning of the GBBS, level 1 recommendations of the TG-186 report were followed [6]. For calculation in water of a single dwell position, constant dwell time of 10 s, the GBBS algorithm was compared in defined dose points against TG-43 dose distribution of the used VariSource 2000 source in 1 and 5 cm distance. The vendor anisotropy function for the VS2000 HDR ^{192}Ir-source was used; relevant data were published by Mikell *et al*. [12]. Tissue assignment was performed using CT data. According to the Varian Reference Guide, nine classes of densities are defined and mapped to materials. Low densities (< 0.001 g/cm^3) as well as high densities (> 8 g/cm^3) remained leveled at minimum/maximum values (BrachyVision-Acuros Algorithm Reference Guide, Varian Medical Systems, March 2009).

Dosimetric indices D_{90}, V_{100}, and V_{150} of the CTVs, and the dose homogeneity index (DHI) [15] were evaluated and compared between two dose calculation methods. Because target delineation was not performed in all cases, for all patients the 100% prescription dose outline of the TG-43 dose calculation was converted into a 3D contour, and used as an artificial clinical target volume (CTV). Statistical significance (p-value < 0.05) was analyzed by the two-sided Mann-Whitney rank sum test. For the correlation analysis, the Pearson correlation coefficient was determined. We assumed a trend meaningful, when the Pearson correlation coefficient is > 0.5.

Results

Results of the commissioning process are presented here in summarized form only. Differences between GBBS and TG-43 based doses in orthogonal and semi-orthogonal (45 degree) directions from the source direct axis are in mean –2.1% in 1 cm distance, and 2% in 5 cm distance. In direct axis directions of the source dose differences up to –89.1% were found. The negative signs indicate that doses from the TG-43 were lower than computed by GBBS algorithm. This dose difference was found at a test point 1 cm in distal direction of the source (direction to the source cable). Absolute doses of 0.522 Gy (TG-43) resp. 0.987 Gy (GBBS) were calculated by the TPS in a reference point for a dwell time of 10 s.

Median CTV volume was 30.0 ml (SD: 26.3 ml, minimum: 4.1 ml, maximum: 132.1 ml). The collected data is summarized in Table 1. Median D_{90} and V_{100} for TG-43 calculation are about 3% higher, and statistically significant (p < 0.01) than for GBBS. The V_{150} dose parameter showed a 1.6% increase from GBBS to TG-43, also statistically significant (p < 0.01). Nevertheless, these are median parameters and clinical assessment must be performed individually for each patient. The dose parameters D_{90}, V_{100}, and V_{150} showed larger variations for the GBBS than for the TG-43 calculations. This is expressed in a larger range of the parameters (Min./Max. values in Table 1). The DHI was almost constant for both calculation methods used in this study. No significant differences were observed.

In Fig. 1, a typical isodose distribution for both calculation methods is demonstrated and illustrates the influence of the medium to the dose calculation results. It is obvious that the GBBS resulted in a lower dose, in particular in the right anterior region of the head of this patient. This is mainly due to the consideration of air cavities and air outside the head, producing less backscatter in these regions.

Dose values of the GBBS algorithm were subtracted from corresponding TG-43 values and are depicted against

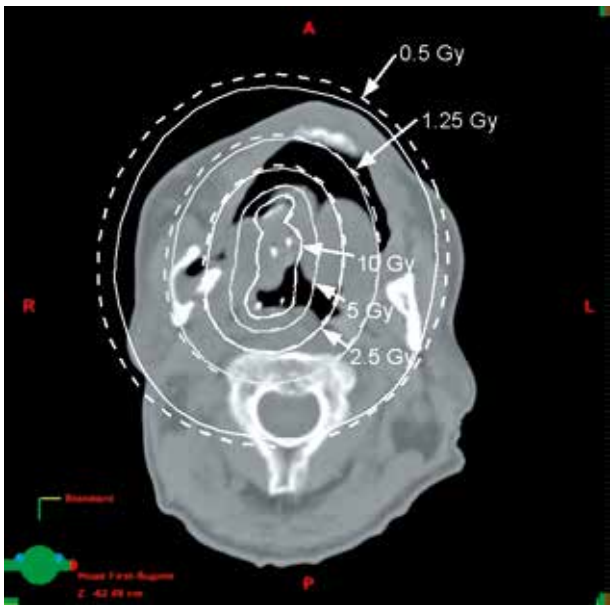

Fig. 1. Transversal CT slice of a patient with mandibular cancer with infiltration of the floor-of-mouth and tongue using a single prescription dose of 2.5 Gy. Dotted isodose lines represent doses of TG-43 formalism, whereas straight lines show isodose lines of computations of the GBBS algorithm

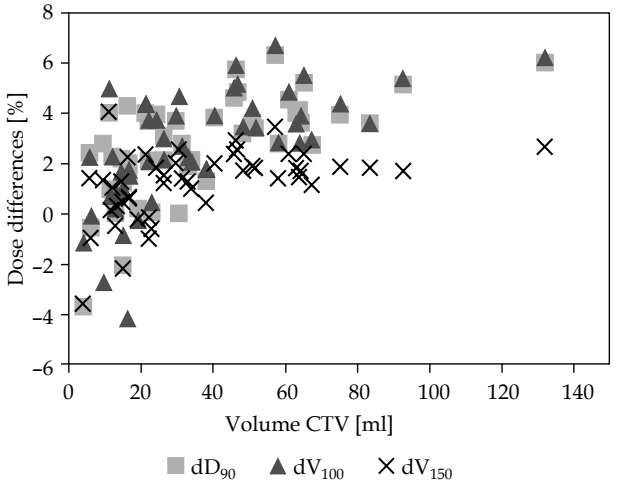

Fig. 2. Dose differences in percent between TG-43 formalism and the GBBS (TG-43 minus GBBS) for D_{90}, V_{100}, and V_{150} of the CTV versus volume of the CTV. A positive dose difference means that TG-43 result was larger than the GBBS results

the volume of the individual CTVs, as it is show in Fig. 2. There seems to be a trend for differences in D_{90} and V_{100} to increase when treating larger target volumes. The Pearson correlation coefficients are 0.62 for $D_{90,}$ and 0.64 for V_{100}. In the V_{150} this trend is not so clear, with a Pearson correlation coefficient of 0.47.

Discussion

Dose differences that were measured in our commissioning process were partly discussed in [6]. In particular, high dose differences near the source delivery cable are described by Mikell *et al*. [12]. They observed dose differences of > 20% in between TG-43 and Acuros. For analysis they exported the doses and analysed it separately, whereas in our study we only used the TPS itself. This as well as slightly different positioning of the source center, with respect to the voxel data, might have caused variations in the results of the dose differences.

This study of HDR ^{192}Ir BT for H&N patients showed small variations between doses from GBBS and TG-43 algorithm. However, the differences were about 3% for D_{90}, and V_{100} of the CTV between GBBS and TG-43 calculations. Further analysis showed that dose differences are patient dependent. There was a trend for larger target volumes to provide higher dose differences than for smaller volumes.

Poon and Verhaegen [16] compared results from TG-43 calculations with an analytical approach for one H&N BT patient case with two catheters implanted, and found that the isodose lines > 50% of reference dose (no reference dose was provided) for TG-43 and their analytical dose calculation algorithm were almost the same. Hyer *et al*. [17] reported for cervical cancer patients treated with HDR ^{192}Ir BT for the D_{90} of the CTV a decrease of –1.9% when accounting for heterogeneities. Agnostopoulos *et al*. [18] calculated dose differences due to tissue inhomogeneities for oesopharingeal HDR ^{192}Ir BT patients, and showed that presence tissue inhomogeneities do not significantly change the planning target volume (PTV) dose distribution. Investigations for breast HDR ^{192}Ir BT patients between TG-43 and MC were presented by Pantelis *et al*. [19], and found isodose contours > 60% of the prescribed dose were not affected by the presence of the lung or finite breast dimensions.

The trend for higher dose differences in larger volumes should be assessed with care, because uncertainties in DVH dose calculation are higher for smaller volumes than for larger ones, as was shown by Kirisits *et al*. [20]. In the used TPS, the end caps of structures are rounded automatically. The impact on this to volume computation is larger for small structures than for large ones, and might be a reason for the decrease of the V_{150} differences presented in Fig. 2. In particular, when the higher doses at the distal and proximal end of the source calculated with the GBBS is taken into account; the shown "drop" of the V_{150} is applicable. But as demonstrated in other publications, dose differences are higher when further away from the implant [16,19]. The reason for this is that with increasing distance from the source, the scattered dose proportion is growing. Close to the source, the primary dose has the most ruling influence. Thus, in larger target volumes this effect might be considered as presented in our work.

Conclusions

The presented H&N dosimetry study demonstrate complementary data to existing literature on dose distributions of modern treatment planning algorithms for various treatment sites in HDR BT. Dose differences between GBBS and TG-43 for HDR H&N BT patients to the target volume were found. Differences of about 3% for D_{90}, and V_{100} of the CTV between GBBS and TG-43 dose computations were observed. In our clinical practice, prescription doses remain unchanged for high-dose-rate head and neck brachytherapy for the time being.

Acknowledgements

The authors thank Varian Medical system for the technical support of this study.

Disclosure

Authors report no conflict of interest.

References

1. Mazeron JJ, Ardiet JM, Haie-Méder C et al. GEC-ESTRO recommendations for brachytherapy for head and neck squamous cell carcinomas. *Radiother Oncol* 2009; 91: 150-156.
2. Nag S, Cano ER, Puthawala AA et al. The American Brachytherapy Society recommendations for high-dose-rate brachytherapy for head-and-neck carcinoma. *Int J Radiat Oncol Biol Phys* 2001; 50: 1190-1198.
3. Martínez-Mongue R, Alcalde J, Concejo C et al. Perioperative high-dose-rate brachytherapy (PHDRB) in previously irradiated head and neck cancer: Initial results of a Phase I/II reirradiation study. *Brachytherapy* 2006; 5: 32-40.

4. Cano ER, Johnson JT, Carrau R et al. Brachytherapy in the treatment of Stage IV carcinoma a of the base of tongue. *Brachytherapy* 2004; 3: 41-48.
5. Rivard MJ, Coursey BM, DeWerd LA et al. Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations. *Med Phys* 2004; 31: 633-674.
6. Beaulieu L, Carlsson Tedgren Å, Carrier JF et al. Report of the Task Group 186 on model-based dose calculation methods in brachytherapy beyond the TG-43 formalism: Current status and recommendations for clinical implementation. *Med Phys* 2012; 39: 6208-6236.
7. Daskalov GM, Baker RS, Rogers DW et al. Dosimetric modeling of the microselectron high-dose rate 192Ir source by the multigroup discrete ordinates method. *Med Phys* 2000; 27: 2307-2319.
8. Rivard MJ, Venselaar J, Beaulieu L. The evolution of brachytherapy treatment planning. *Med Phys* 2009; 36: 2136-2153.
9. Zourari K, Pantelis E, Moutsatsos A et al. Dosimetric accuracy of a deterministic radiation transport based ^{192}Ir brachytherapy treatment planning system. Part I: Single sources and bounded homogeneous geometries. *Med Phys* 2010; 37: 649-661.
10. Petrokokkinos L, Zourari K, Pantelis E et al. Dosimetric accuracy of a deterministic radiation transport based ^{192}Ir brachytherapy treatment planning system. Part II: Monte Carlo and experimental verification of a multiple source dwell position plan employing a shielded applicator. *Med Phys* 2011; 38: 1981-1992.
11. Zourari K, Pantelis E, Moutsatsos A et al. Dosimetric accuracy of a deterministic radiation transport based ^{192}Ir brachytherapy treatment planning system. Part III. Comparison to Monte Carlo simulation in voxelized anatomical computational models. *Med Phys* 2013; 40: 011712.
12. Mikell JK, Moutada F. Dosimetric Impact of an 192Ir Brachytherapy Source Cable Length Modeled Using a Grid-based Boltzmann Transport Equation. *Med Phys* 2010; 37: 4733-4743.
13. Mikell JK, Klopp AH, Gonzales GM et al. Impact of heterogeneity-based dose calculation using a deterministic grid-based Boltzmann equation solver for intracavitary brachytherapy. *Int J Radiat Oncol Biol Phys* 2012: 83: e417-e422.
14. Personal communication of Jack Fowler.
15. Wu A, Ulin K, Sternick A. A dose homogeneity index for evaluating 192Ir interstitial breast implants. *Med Phys* 1998; 15: 104-107.
16. Poon E, Verhaegen F. A CT-based analytical dose calculation method for HDR ^{192}Ir brachytherapy. *Med Phys* 2009; 36: 3982-3994.
17. Hyer E, Sheybani A, Jacobson GM et al. The dosimetric impact of heterogeneity corrections in high-dose rate ^{192}Ir brachytherapy for cervical cancer: Investigation of both conventional Point-A and volume optimized plans. *Brachytherapy* 2012; 11: 515-520.
18. Anagnostopoulos G, Baltas D, Pantelis E et al. The effect of patient inhomogeneities in oesophageal ^{192}Ir HDR brachytherapy: a Monte Carlo and analytical dosimetry study. *Phys Med Biol* 2004; 49: 2675-2685.
19. Pantelis E, Papagiannis P, Karaiskos P et al. The effect of finite patient dimensions and tissue inhomogeneities on dosimetry planning of ^{192}Ir HDR breast brachytherapy: a Monte Carlo dose verification study. *Int J Radiat Oncol Biol Phys* 2005; 61: 1596-1602.
20. Kirisits C, Siebert FA, Baltas D et al. Accuracy of volume and DVH parameters determined with different brachytherapy treatment planning systems. *Radiother Oncol* 2007; 84: 290-297.