

# Dosimetric comparison of Acuros™ BV with AAPM TG43 dose calculation formalism in breast interstitial high-dose-rate brachytherapy with the use of metal catheters

Mourougan Sinnatamby, MSc, Dip. R.P.<sup>1</sup>, Vivekanandan Nagarajan, PhD<sup>2</sup>, Sathyanarayana Reddy K, MD(RT)<sup>3</sup>, Gunaseelan Karunanidhi, MD(RT)<sup>1</sup>, Vivekanandam Singhavajala, DMRT<sup>1</sup>

<sup>1</sup>Department of Radiotherapy, Regional Cancer Centre, JIPMER, Puducherry, <sup>2</sup>Department of Medical Physics, Cancer Institute, Adyar, Chennai,

<sup>3</sup>Regional Cancer Centre, JIPMER and Head, Oncology, Mahatma Gandhi Medical College and Research Institute, Puducherry, India

## Abstract

**Purpose:** Radiotherapy for breast cancer includes different techniques and methods. The purpose of this study is to compare dosimetric calculations using TG-43 dose formalism and Varian Acuros™ BV (GBBS) dose calculation algorithm for interstitial implant of breast using metal catheters in high-dose-rate (HDR) brachytherapy, using <sup>192</sup>Ir.

**Material and methods:** Twenty patients who were considered for breast conservative surgery (BCS), underwent lumpectomy and axillary dissection. These patients received perioperative interstitial HDR brachytherapy as upfront boost using rigid metal implants. Whole breast irradiation was delivered TG-43 after a gap of two weeks. Standard brachytherapy dose calculation was done by dosimetry. This does not take into account tissue heterogeneity, attenuation and scatter in the metal applicator, and effects of patient boundary. Acuros™ BV is a Grid Based Boltzmann Solver code (GBBS), which takes into consideration all the above, was used to compute dosimetry and the two systems were compared.

**Results:** Comparison of GBBS and TG-43 formalism on interstitial metal catheters shows difference in dose prescribed to CTV and other OARs. While the estimated dose to CTV was only marginally different with the two systems, there is a significant difference in estimated doses of starting from 4 to 53% in the mean value of all parameters analyzed.

**Conclusions:** TG-43 algorithm seems to significantly overestimate the dose to various volumes of interest; GBBS based dose calculation algorithm has impact on CTV, heart, ipsilateral lung, heart, contralateral breast, skin, and ribs of the ipsilateral breast side; the prescription changes occurred due to effect of metal catheters, inhomogeneities, and scatter conditions.

J Contemp Brachytherapy 2015; 7, 4: 273-279

DOI: 10.5114/jcb.2015.54052

**Key words:** brachytherapy, breast interstitial implant, AcurosBV, GBBS, TG-43.

## Purpose

Breast cancer is the second most common cancer in the world and the most common cancer among women. Brachytherapy is used as a method to boost radiation dose in breast conservation treatment, as a primary treatment after initial tumour removal, followed by supplemented external beam radiotherapy [1]. The benefit of boost irradiation has been reported by the European Organization for Research and Treatment of Cancer (EORTC) 22881-10882 trial, which showed a significantly improved local control among patients who received a boost irradiation to the tumour bed [2]. One of the methods of accelerated

partial breast irradiation (APBI) with the longest experience is the multi-catheter based brachytherapy [3] using either flexible or rigid metal implant.

The current approach is based on the AAPM TG-43 formalism with recent advances in acquiring single-source dose distributions. However, this formalism has clinically relevant limitations for calculating patient dose. The influence of tissue, applicator heterogeneities, and finite patient dimensions are all ignored. Heterogeneity calculations may significantly improve the accuracy of treatment planning systems because they can compensate for air in the bowel, applicator materials, and patient boundaries

**Address for correspondence:** Mourougan Sinnatamby MSc, Dip. R.P, Department of Radiotherapy, Regional Cancer Centre, Jawaharlal Institute of Postgraduate Medical Education and Research, Puducherry 605 006, India, phone: +91 94423 38389, ✉ e-mail: mourougans@yahoo.co.in; ✉ mourougan.s@jipmer.edu.in

Received: 14.05.2015

Accepted: 16.08.2015

Published: 30.08.2015

[4-9]. Deterministic Grid Based Boltzmann Solver (GBBS; Acuros™ BV software; Transpire Inc., Gig Harbor, WA, USA) was developed specifically to perform accurate and rapid dose calculations for radiation therapy [4]. For brachytherapy, Acuros™ BV solves the linear Boltzmann transport equation for photons on a locally adaptive Cartesian grid. A commercial TPS with a GBBS is now available for use with some number of <sup>192</sup>Ir sources [5]. Based on the review of the literature, the author concluded that accepted clinical dose parameters can be over or underestimated by 5% in numerous situations [5-8]. Model-based dose calculation algorithms (MBDCAs) offer the possibility of departing from water-only geometries by modelling radiation transport in non-water media (tissues, applicators, air-tissue interfaces), resulting in a much more physically accurate reconstruction of the dose distribution actually delivered to the patient [8]. The purpose of this study is to compare the dosimetric parameters in breast interstitial metal implant using rigid metal catheters Varian Acuros™ BV (GBBS) algorithm and TG-43 dose formalism.

## Material and methods

### Patients

Twenty patients were considered for breast conservative surgery (BCS) and underwent a lumpectomy and axillary dissection. These patients received perioperative interstitial High Dose Rate brachytherapy as upfront boost using rigid metal implants. Whole breast irradiation was delivered after a gap of two weeks. The patient characteristics are tabulated in Table 1.

### Implant technique

After a lumpectomy, the implant procedure was done under general anaesthesia, and rigid template system inserted needles. The decision of doing a double plane or a triple plane implant was based on the depth and size of the lumpectomy cavity. The interplane separation was 1 cm and inter-catheter separation was 1 cm.

### Contouring

All patients in this study underwent computed tomography simulation, using Siemens™ (Siemens AG, Munich, Germany) computed tomography scanner. A 3 mm slice

**Table 1.** Patient characteristics

	Minimum	Maximum	Median
Age	41	53	47
Number of catheters	15	19	17
Number of plane	2	3	2.5
CTV volume (cc)	24.8	127.3	76.05
CTV distance from ipsilateral lung (cm)	3.12	5.92	4.52
CTV distance from skin (cm)	0.12	0.34	0.23

CTV – clinical target volume

thickness was used to get 3D image data set. The clinical radiation oncologist delineated contours. The Clinical Target Volume (CTV) was drawn using the surgical clips placed at the time of lumpectomy in medial, lateral, cranial, caudal, superficial, and deep margins. The other delineated contours include contralateral breast, heart, ipsilateral lung, contralateral lung, ribs, and skin. Contours such as ipsilateral breast excluding CTV,  $V_{ref}$ ,  $V_{150\%}$ , and  $V_{200\%}$  ( $V_{150\%}$ ,  $V_{200\%}$  – volume of the anatomic volume receiving 150%, 200% of the prescribed dose) were created after dose calculation.

### Treatment planning

The treatment planning system (TPS) used was Brachy Vision version 10.0 software (Varian Medical Systems, Palo Alto, CA, USA) and Acuros™ BV with version 1.4.0 software. The <sup>192</sup>Ir Gammamed HDR plus source listed in the library of origin was used. The Grid Based Boltzmann Solver (GBBS) Acuros™ BV uses the Gammamed plus HDR <sup>192</sup>Ir source (Varian Medical Systems, Palo Alto, CA, USA).

Initially, all plans were optimized by using AAPM TG-43 formalism so that the prescribed dose encloses CTV with adequate sparing of organs at risk. Geometrical and graphical optimizations were used to get the required CTV coverage and to spare OARs. Some patients required manual optimization as well. Acuros™ BV was used to compare these plans. American Brachytherapy Society, Breast Brachytherapy Task Group recommendations were followed for dosimetric evaluation. The three-dimensional calculation was done, and DVH-based analysis was used for evaluation. Tumour bed boost radiation of 15 Gy in 6 fractions, delivered twice daily with a minimum of 6 hours interval between fractions for all patients in this study.

Paired *t*-ratio, statistical analysis tool using SPSS 21 software were used to compare doses estimated to CTV, OAR by two algorithms.

### Plan evaluation

The prescription dose must encompass the target volume. Breast dose parameters should include Clinical Target Volume (CTV), Clinical Target Volume reference (CTV<sub>ref</sub>),  $V_{ref}$ ,  $V_{150\%}$ , and  $V_{200\%}$ . Ipsilateral breast excluding CTV is taken into account for dose estimation, which include  $D_{mean}$ ,  $D_{max}$ ,  $D_{2cc}$ ,  $D_{0.1cc}$ ,  $V_{5\%}$ ,  $V_{10\%}$ . Contralateral breast, contralateral lung, skin, and ribs dose parameters include  $D_{mean}$ ,  $D_{max}$ ,  $D_{2cc}$ ,  $D_{0.1cc}$ . The indices used in this study [10-14] are as follows:

1. Coverage index (CI):  $CTV_{ref}/CTV$  volume Ideal (Ideal CI = 1).
2. Dose homogeneity index (DHI):  $1 - V_{150\%}/CTV_{ref}$  (Ideal DHI = 1).
3. Overdose volume index (OI):  $V_{200\%}/CTV_{ref}$  (Ideal OI = 0).
4. External volume index (EI):  $1 - CTV_{reference}/V_{ref}$  (Ideal EI = 0).
5. Conformity Index (COIN):  $C1 \times C2$   
Where  $C1 = CTV_{ref}/CTV$  Volume and  $C2 = CTV_{ref}/V_{ref}$  (Ideal COIN = 1).

**Table 2.** Comparison between <sup>192</sup>Ir Acuros BV and <sup>192</sup>Ir TG43 by parameters related to clinical target volume (CTV)

Parameters	<sup>192</sup> Ir Acuros BV		<sup>192</sup> Ir TG-43		Diff. %	Paired <i>t</i> -ratio	<i>p</i> -value
	Mean	SD	Mean	SD			
CTV <sub>ref</sub> (cc)	50.07	23.99	51.96	25.33	-4%	4.512	< 0.001
V <sub>ref</sub> (cc)	53.07	24.36	55.91	25.87	-5%	6.397	< 0.001
V <sub>150%</sub> (cc)	15.57	11.04	19.19	12.51	-19%	4.774	< 0.001
V <sub>200%</sub> (cc)	2.37	3.78	4.96	3.96	-52%	7.492	< 0.001
Coverage index (CI)	0.9	0.04	0.93	0.03	-3%	5.735	< 0.001
Dose homogeneity index (DHI)	0.7	0.1	0.65	0.08	8%	6.036	< 0.001
Overdose volume index (OI)	0.04	0.06	0.09	0.05	-56%	10.021	< 0.001
External volume index (EI)	0.06	0.03	0.08	0.04	-25%	0.39	< 0.001
Conformity index (COIN)	0.84	0.04	0.86	0.05	-2%	2.345	0.03

CTV – clinical target volume, Diff. – difference, V – volume

COIN describes how well the reference dose encompasses the CTV and excludes non-target structures.

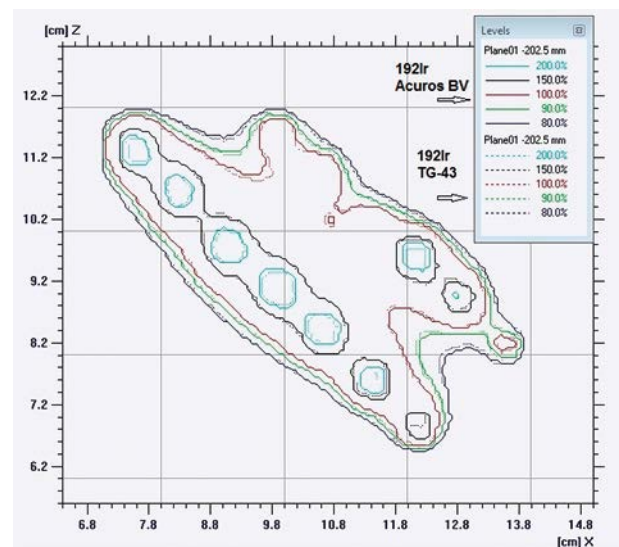
**Results**

The Cumulative Dose Volume Histogram (DVH), different dose-volume indices were derived as shown in Table 2. Differences in the relative response as high as 11.5% were found from the homogeneous setup when the heterogeneous materials were inserted into the experimental phantom. The results derived from the phantom measurements show good agreement with the simulations and TPS calculations, using Acuros™ algorithm [15]. In this study, Acuros™ BV estimated mean CTV<sub>ref</sub> was 4% less and reference dose enclosing CTV was 5% less (*p* < 0.001) compared to TG-43 dose calculations. Similarly, Acuros™ BV estimated V<sub>150%</sub> and V<sub>200%</sub> was 19% and 52% less than that of TG-43 estimates. In spite of higher percentage differences, in terms of absolute value, it is trivial. CI of 0.91 has been achieved for breast implant [3] but in this study using TG-43 formalism 0.93 was achieved. When using Acuros™ BV, 3% decrease was noted, which was due to heterogeneity correction. Mean DHI 0.70 ± 0.10 was 9% greater than TG-43 dose calculation indicates that homogeneity was better. OI and EI estimates were 53% and 19% less than the TG-43 based calculation. In Acuros™ BV calculations, mean COIN was 2% less, and a *p*-value of 0.03 was observed. Figure 1 shows the isodose distribution for comparison between Acuros™ BV and TG-43 formalism on the same CT slice using <sup>192</sup>Ir Gammamed plus source. The DVH shown in Figure 2 depicts the noteworthy difference in DVH at a higher dose. The comparison of indices along with mean values are shown in Figure 3.

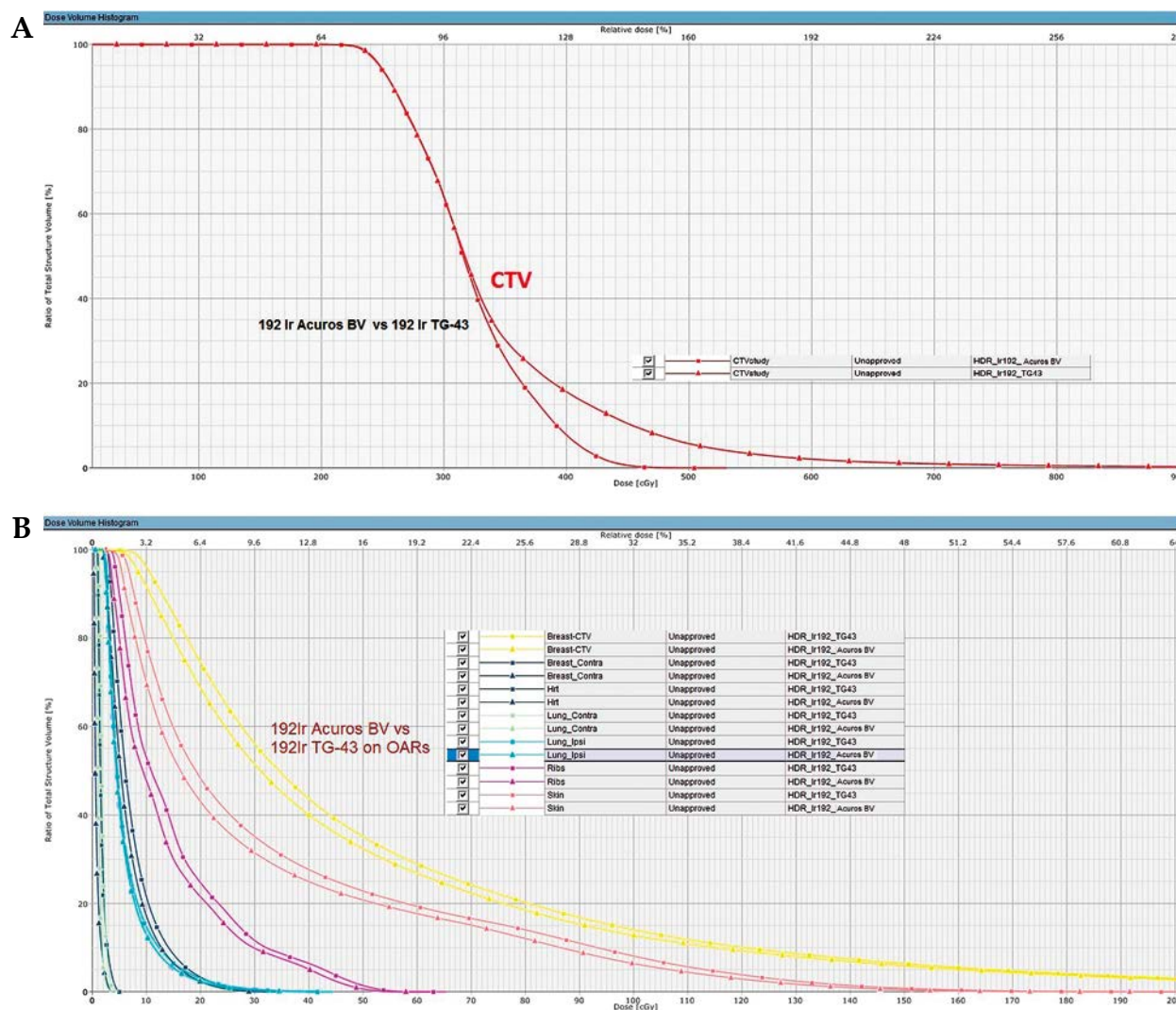
The skin, ipsilateral lung, and contralateral breast can develop complications as a result of breast radiotherapy. Dose to these organs must be considered when comparing the profiles of two planning algorithms [16]. A reduction of 39% and 17% is observed in the D<sub>mean</sub> and D<sub>max</sub> values of the contralateral breast. Mean D<sub>2cc</sub> and D<sub>0.1cc</sub> of the contralateral breast show 20% and 18% reduction in

Acuros™ BV estimates compared to that of TG-43. GBBS dose estimates to heart for D<sub>mean</sub> and D<sub>max</sub> was 13%, and 5% less than TG-43 based calculation (Figure 4). V<sub>5%</sub> and V<sub>10%</sub> showed a decrease of 22% (*p* = 0.001) and 26% (*p* = 0.055), respectively. For contralateral lung, the Acuros™ BV estimates for D<sub>mean</sub> and D<sub>max</sub> was 22% and 17% less than TG-43 calculations, and D<sub>0.1cc</sub> and D<sub>2cc</sub> values were 16% and 19% lesser.

In ipsilateral lung, Acuros™ BV dose estimate for D<sub>mean</sub> decreased by 5% (*p* = 0.007) and by 7% for D<sub>max</sub>. Both D<sub>2cc</sub> and D<sub>0.1cc</sub> show 7% reduction in the dose compared to TG-43 calculations. V<sub>5%</sub> and V<sub>10%</sub> had a greater reduction of 13% and 25% dose compared to TG-43 estimates. The Box and Whisker plot for D<sub>mean</sub>, D<sub>max</sub>, V<sub>5%</sub> and V<sub>10%</sub> of the ipsilateral lung are shown in Figure 5. Due to the proximity of ribs to CTV, the contribution of dose to



**Fig. 1.** Isodose distribution on Left Breast using <sup>192</sup>Ir Gammamed HDR plus source with Acuros™ BV and isodose distribution on the same CT slice using <sup>192</sup>Ir Gammamed HDR plus source with TG-43 formalism



**Fig. 2. A)** DVH comparison of CTV between  $^{192}\text{Ir}$  Acuros<sup>TM</sup> BV and  $^{192}\text{Ir}$  TG-43 formalism in BrachyvisionV10.0 treatment planning system. The difference in the dose are larger at higher doses. **B)** DVH comparison of OAR's between  $^{192}\text{Ir}$  Acuros<sup>TM</sup> BV and  $^{192}\text{Ir}$  TG-43 formalism in BrachyvisionV10.0 treatment planning system. Dose difference seen all along the volume

the ribs was included in the comparison. Acuros<sup>TM</sup> BV  $D_{\text{mean}}$  and  $D_{\text{max}}$  values show a reduction of 11% and 5% compared to TG-43 dose values. The skin was demarcated as 5 mm from the surface on the ipsilateral breast area as skin contour. Acuros<sup>TM</sup> BV dose values show a reduction of 14% in  $D_{\text{max}}$  and 11% in  $D_{\text{mean}}$  values computed by TG-43 dose formalism (Figure 6).  $D_{2\text{cc}}$  and  $D_{0.1\text{cc}}$  show a dose reduction of 5% compared to conventional TG-43 dose calculations.

## Discussion

An ideal brachytherapy treatment planning system should take into consideration the effect of the applicator, tissue inhomogeneity, and patient finite dimensions while computing dose distribution. For high-Z materials utilized in clinical practice for shielding purposes, satisfying accuracy at points just beyond the distal end of bounded inhomogeneities. This accuracy was found to deteriorate, however, with increasing distance due to the

inability of the proposed model to account for the effect of laterally scattered photons [17]. The attenuation due to the interposition of a stainless steel catheter is expected to lead to a dose reduction. The influence of applicator material used in the calibration setup was found to be 1.7% for stainless steel dosimetry applicator compared to the plastic 5F applicator [18]. While Acuros<sup>TM</sup> BV dose calculation engine is not currently used for optimization and dose prescription, it was found to correctly account for heterogeneities and patient specific scatter conditions providing accuracy comparable to Monte Carlo (MC) simulation [19]. The Acuros<sup>TM</sup> BV used for brachytherapy dose calculation reduces the total error (3%) in determination of the dose to any given point, and allows for further development towards methods for accounting not only for heterogeneities within the patient volume but for the actual shape and size of the patient in the clinical situation [20].

When dose calculated using the two algorithms (Acuros<sup>TM</sup> BV and TG-43) were compared, the dose to CTV

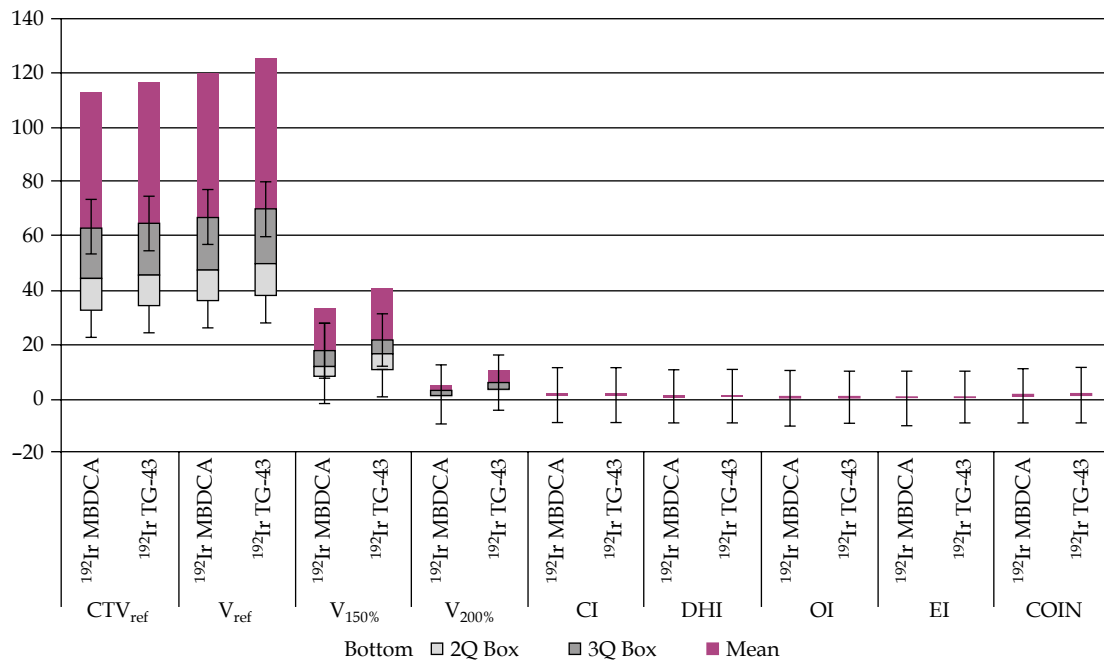


Fig. 3. Comparison between <sup>192</sup>Ir Acuros™ BV and <sup>192</sup>Ir TG-43 of various indices along with mean value

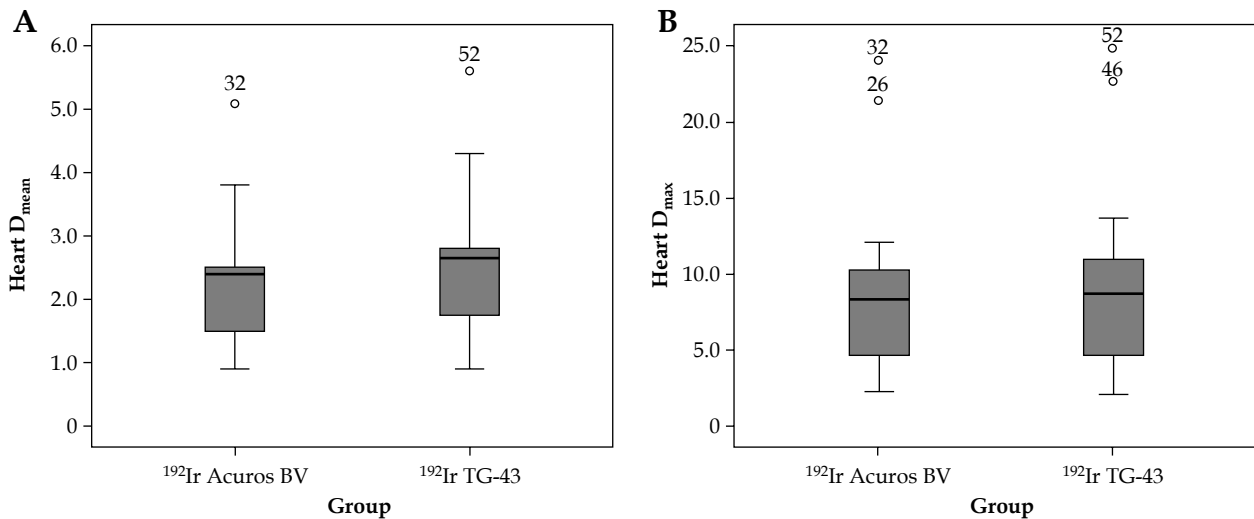


Fig. 4. Box and Whisker plot of comparison between  $D_{mean}$  and  $D_{max}$  value of heart using <sup>192</sup>Ir Acuros™ BV and <sup>192</sup>Ir TG-43

was overestimated by 4% when TG-43 formalism was used. Comparisons of MC and TG-43 results in all models (two voxelized mathematical models resembling an oesophageal and a breast brachytherapy patient, as well as an actual breast brachytherapy patient model) showed significant differences [19]. Doses at  $V_{200\%}$  and  $V_{150\%}$  were however higher (52% and 19%). TG-43 dose underestimation is observed within or close to the catheters, as well as in the drive side of the CTV [19].

Similarly, the dose to the contralateral breast, lung, ribs, and skin all showed marked variation. Dose overestimation is more evidently shown where percentage dose differences up to 10% in the lung and 20% in the breast skin are observed between TG-43 and MC results. Ample literature exists that presents data similar to the comparison between MC and TG-43 results performed in this

work to quantify the accuracy improvement achieved by Acuros™ BV [19]. The doses as depicted using TG-43 formalism showed difference ranging from 4% to CTV to about 52% to  $V_{200\%}$ . The dose computations is appreciably improved when using Acuros™ BV, as it takes into consideration the tissue homogeneity as well as attenuation and scatter in metal catheters. Appropriate dose correction can be made to CTV and the other organs of interest in the volume of irradiation. The study indicates that Acuros™ BV dose calculation makes a sizeable difference compared to TG-43 based estimate.

**Conclusions**

The implementation of Acuros™ BV for <sup>192</sup>Ir brachytherapy dosimetry in homogeneous water geometries

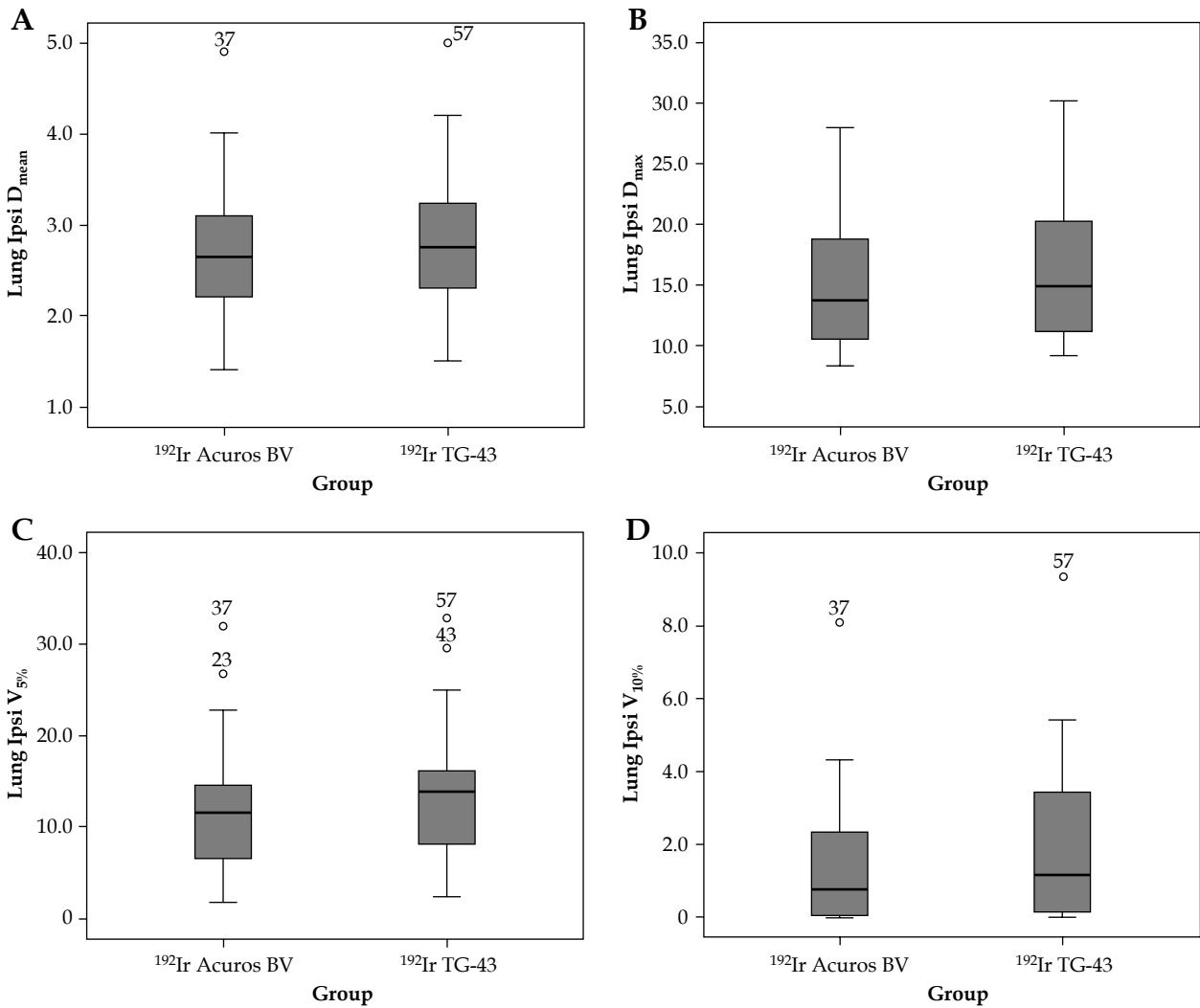


Fig. 5. Box and Whisker plot of comparison between  $D_{mean}$  and  $D_{max}$  (A and B),  $V_{5\%}$  and  $V_{10\%}$  (C and D) of ipsilateral lung using <sup>192</sup>Ir Acuros™ BV and <sup>192</sup>Ir TG-43

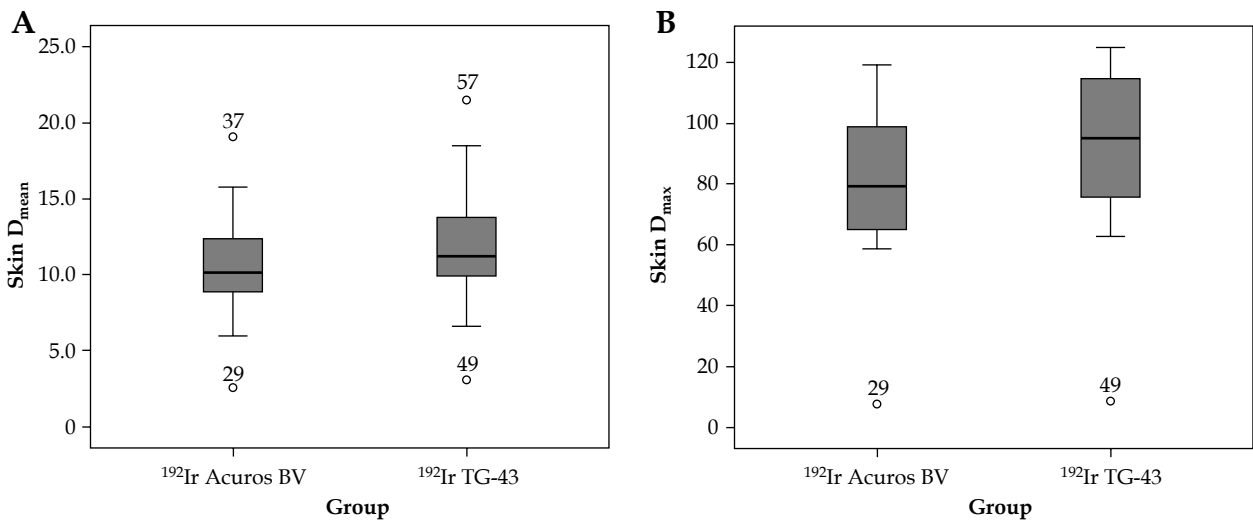


Fig. 6. Box and Whisker plot of comparison between  $D_{mean}$  and  $D_{max}$  value of skin using <sup>192</sup>Ir Acuros™ BV and <sup>192</sup>Ir TG-43

yields results of comparable accuracy to the golden standard of MC simulation [21]. The dosimetric validation of deterministic radiation transport based TPS in employing shielded applicator, TPS, and MC dose distributions were found in agreement, which is mainly within  $\pm 2\%$  [22]. The expected benefit of Acuros BV in dosimetry planning is in the amount of reduction it will achieve (through the individualization of patient dosimetry) in the variance of the response of clinical trial populations [23]. The dose to CTV was 4% less when Acuros<sup>TM</sup> BV was used for calculation. The Acuros<sup>TM</sup> BV takes into consideration absorption through the metal catheter, tissue inhomogeneity, and helps in more accurate dose computation and define actual doses delivered. Similarly, the dose to ribs, contralateral breast are overestimated by TG-43 formalism. While the differences in estimation do not alter the real treatment as the difference was less than 5% of CTV dose. The Acuros<sup>TM</sup> BV also showed lower doses to organs at risk and these guide us to make minor corrections while reporting.

## Disclosure

Authors report no conflict of interest.

## References

- Gage I, Harris JR. Radiation therapy and breast cancer. *Curr Opin Oncol* 1997; 9: 527-531.
- Bartelink H, Horiot JC, Poortmans P et al. Recurrence rates after treatment of breast cancer with standard radiotherapy with or without additional radiation. *NEJM* 2001; 345: 1378-1387.
- Major T, Fröhlich G, Lövey K et al. Dosimetric experience with accelerated partial breast irradiation using image-guided interstitial brachytherapy. *Radiother Oncol* 2009; 90: 48-55.
- Acuros BV. Algorithm Reference Guide, Document ID B504878R01A, Revision A. 2013; 8: 1-36.
- Mikell JK, Klopp AH, Gonzalez GMN 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: 417-422.
- 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.
- Rivard MJ, Venselaar JLM, Beaulieu L. The evolution of brachytherapy treatment planning. *Med Phys* 2009; 36: 2136-2153.
- Beaulieu L, Carlsson TA, 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.
- Scheuch J, Nesvacil N, Resch A et al. 382 Oral Comparison of DVH-parameters for dose calculation by TG43 and Boltzmann based algorithm Acuros BV(tm). *Radiother Oncol* 2011; 99: S151 (abstract).
- Van der Laarse, R. The stepping source dosimetry system as an extension of the Paris system. In: Brachytherapy from radium to optimization. Mould RF, Battermann JJ, Martinez AA, Speiser BL (eds.). Nucletron International B.V., Veenendaal 1994; 319-330.
- Baltas D, Kolotas C, Geramani K et al. A conformal index (COIN) to evaluate implant quality and dose specification in brachytherapy. *Int J Radiat Oncol Biol Phys* 1998; 40: 515-524.
- Saw CB, Suntharalingam N, Wu A. Concept of dose nonuniformity in interstitial brachytherapy. *Int J Radiat Oncol Biol Phys* 1993; 26: 519-527.
- Sharma PK, Swamidas J V, Mahantshetty U et al. Dose optimization in gynecological 3D image based interstitial brachytherapy using martinez universal perineal interstitial template (MUPIT) - an institutional experience. *J Med Phys* 2014; 39: 197-202.
- Nath R, Anderson LL, Luxton G et al. Dosimetry of interstitial brachytherapy sources: recommendations of the AAPM Radiation Therapy Committee Task Group No. 43. American Association of Physicists in Medicine. *Med Phys* 1995; 22: 209-234.
- Moura ES, Micka JA, Hammer CG et al. Development of a phantom to validate high-dose-rate brachytherapy treatment planning systems with heterogeneous algorithms. *Med Phys* 2015; 42: 1566-1574.
- Lettmaier S, Kreppner S, Lotter M et al. Radiation exposure of the heart, lung, and skin by radiation therapy for breast cancer: A dosimetric comparison between partial breast irradiation using multicatheter brachytherapy and whole breast teletherapy. *Radiother Oncol* 2011; 100: 189-194.
- Anagnostopoulos G, Baltas D, Karaiskos P et al. An analytical dosimetry model as a step towards accounting for inhomogeneities and bounded geometries in 192Ir brachytherapy treatment planning. *Phys Med Biol* 2003; 48: 1625-1647.
- Baltas D, Geramani K, Ioannidis GT et al. Comparison of calibration procedures for 192Ir high-dose rate brachytherapy sources. *Int J Radiat Oncol Biol Phys* 1999; 43: 653-661.
- Zourari K, Pantelis E, Moutsatsos A et al. Dosimetric accuracy of a deterministic radiation transport based 192Ir brachytherapy treatment planning system. Part III. Comparison to Monte Carlo simulation in voxelized anatomical computational models. *Med Phys* 2013; 40: 011712.
- Russell KR, Ahnesjö A. Dose calculation in brachytherapy for a 192Ir source using a primary and scatter dose separation technique. *Phys Med Biol* 1996; 41: 1007-1024.
- Zourari K, Pantelis E, Moutsatsos A et al. Dosimetric accuracy of a deterministic radiation transport based 192Ir brachytherapy treatment planning system. Part I: single sources and bounded homogeneous geometries. *Med Phys* 2010; 37: 649-661.
- Petrokokkinos L, Zourari K, Pantelis E et al. Dosimetric accuracy of a deterministic radiation transport based 192Ir 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.
- Papagiannis P, Pantelis E, Karaiskos P. Current state of the art brachytherapy treatment planning dosimetry algorithms. *Br J Radiol* 2014; 87: 20140163.