Original Article

Dosimetric Impact of Air Pockets in the Vaginal Cuff Brachytherapy Using Model-based Dose Calculation Algorithm

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Abstract

Background: Endometrial cancer is the most common disease of the female reproductive system. Vaginal cuff brachytherapy (VCB) has intrinsic advantages compared to external beam therapy when treated with radiation. A single-channel cylinder is a standard applicator in VCB. The present study aims to estimate a change in the dose to vaginal mucosa due to air pockets between the cylinder and vaginal mucosa by calculating with the Acuros BV algorithm and comparing it to the Task Group 43 (TG-43) algorithm. **Materials and Methods:** Patients who presented with air packets were included retrospectively. For each patient, three plans were created: the first plan used TG-43, the second plan used dose recalculation with Acuros BV, and the third plan was generated by re-optimization by Acuros BV. On the same axial computed tomography image, the point doses at the cylinder's surface and the displaced mucosa were recorded and the ratios were then estimated. **Results:** The average volume of air pockets was 0.08 cc (range of 0.01–0.3 cc), and 84% of air pockets displaced the vaginal mucosa by ≥0.2 cm. The average ratios of dose were 0.77 ± 0.09 (1 standard deviation [SD]) and 0.78 ± 0.09 (1 SD) for TG-43 and Acuros BV algorithms, respectively. Due to the air pocket, mucosa received a reduced dose by an average of 22.72% and an average of 23.29% for TG-43 and Acuros BV, respectively. The maximum displacement of mucosa and the ratio of doses were negatively correlated for both. In the Optimized Acuros BV plan, total dwell time increased by 1.8% but no considerable change in the dose ratios. **Conclusion:** The calculated dose of mucous membrane forced out of the cylinder surface by air pockets by the Acuros BV algorithm was nonsignificantly different from TG-43. Therefore, even in the presence of air pockets, the TG-43 algorithm for calculating the VCB dose is appropriate.

Keywords: Acuros BV algorithm, air pocket, endometrial cancer, task group 43 algorithm, vaginal cuff brachytherapy

Received on: 05-07-2023 **Review completed on:** 17-08-2023 **Accepted on:** 26-08-2023 **Published on:** 05-12-2023

Introduction

Endometrial cancer is the 6th most common cancer in women worldwide and the most common cancer of the female reproductive system in the West.[1] Total abdominal hysterectomy and bilateral salpingo-oophorectomy with pelvic and para- aortic lymph node sampling are the standard management for this disease. External beam radiation therapy (EBRT) or vaginal cuff brachytherapy (VCB) may be beneficial for selected patients with risk factors.[2,3] However, VCB has intrinsic advantages compared to EBRT due to the close contact between radioactive sources, the volume to treat, and the movement of the vagina.[4] The American Brachytherapy Society recommended that the applicator for VCB should be based on the patient and the geometry of the target volume.[5] Most institutions use the standard segmented cylinder as the applicator. The applicator with the largest diameter should be selected to ensure close mucosal apposition. It is necessary to deliver an appropriate uniform dose to vaginal lymphatic channels.[6] However, the presence of air pockets between the vaginal mucosa and the applicator results in an underdose of the target that could potentially lead to relapse. The occurrence of air pockets is frequent in postmenopausal patients or patients treated with brachytherapy alone. In addition, they also depend on the

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Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_88_23

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How to cite this article: Puriparthi LV, Talluri AK, Akkineni NP, Bajwa HK, Tumu VR, Sresty NV, *et al*. Dosimetric impact of air pockets in the vaginal cuff brachytherapy using model-based dose calculation algorithm. J Med Phys 2023;48:373-7.

cylinder size and vary from fraction to fraction and patient to patient.[7-9]

The Task Group-43 (TG-43) dose calculation algorithm from the American Association of Physicists in Medicine[10,11] is currently widely used in brachytherapy treatment planning systems (TPS). It improved the accuracy of dose calculations by assuming full scatter in a water medium compared to conventional methods. Overall, the TG-43 algorithm significantly improved the standardization of dose calculation methodologies and dose distributions used for brachytherapy. However, the TG-43 algorithm did not properly exploit the information available from the patient's imaging,[12,13] as it relies on parameters precalculated or measured in homogeneous standard water geometry. It does not consider tissue inhomogeneity, patient finite geometry conditions, and applicators in dose calculation, resulting in significant errors. For the past two decades, brachytherapy planning has progressed well in terms of the utilization of three-dimensional image-based TPS and dose delivery. Newly developed model-based dose calculation algorithms (MBDCAs) significantly improved dose calculation accuracy compared with TG-43.[14,15] Acorus BV (Acuros BV, Varian Medical Systems, Charlotte, NC) is one of the model-based algorithms developed for brachytherapy radionuclides such as Iridium-192 (Ir-192).[16-18] It is based on the finite element solver of the linear Boltzmann transport equation and can largely agree within 2% with Monte–Carlo (MC) calculations for single source models.[19] In contrast to the TG-43 dosimetry algorithm, MBDCA considers heterogeneities and the actual scatter conditions and calculates either the dose delivered to water or the dose delivered to the actual medium. Studies are conducted to validate the Acuros BV algorithm for conditions of tissue heterogeneity and the absence of full scatter.[20,21] A few studies investigated the dosimetric effects of air pockets using the TG-43 algorithm and found that air pockets significantly reduced the dose to vaginal mucosa.[7-9] To our knowledge, there are no studies to compare TG43 and model-based Acruos BV algorithms directly to assess the dosimetric impact of air pockets in VCB. The present study aims to assess the dosimetric effect of air pockets on vaginal mucosal dose using the Acuros BV algorithm and compare the results with those of TG-43.

Materials and Methods

This was a retrospective study with a population of 23 patients who presented with carcinoma of the endometrium and were approved by the institutional ethics committee. The patients had received either postoperative external beam radiotherapy of the whole pelvis (a dose of 45 Gy in 25 fractions, one fraction per day and five fractions per week) followed by high dose rate (HDR) VCB or HDR VCB alone. Each patient had a pelvic examination before the brachytherapy procedure to assess a cylinder diameter that snugly fits. The range of universal stump cylinder (Varian medical systems) diameters in use varied between 2 cm and 3.5 cm, and most patients were treated with a cylinder diameter of 3.0 cm. Each patient was imaged after insertion of the cylinder for the first fraction on a GE Discovery RT computed tomography (CT) scanner with a slice thickness of 2.5 mm (GE Healthcare, Chicago, USA). The CT images were transferred to the Eclipse Brachytherapy planning system of version 15.6 (Varian Medical System, Palo Alto, CA) for the generation of a treatment plan with a dose calculation grid size of 2.5 mm.

For each patient, three plans were created. The first plan used TG-43 dose calculation such that a reference line drawn at 0.5 cm from the surface of the cylinder received the prescribed dose (5–7 Gy) with a dwell step size of 0.5 cm, and the second plan was calculated using the Acuros BV, maintaining the same dwell positions and dwell times. The plan with the TG-43 dose calculation was considered a reference plan, and the Acuros BV calculation plan was compared to it. The third plan was generated by optimizing dwell times and using the Acuros BV algorithm to deliver the prescribed dose. Results from the optimized plan were compared to the initial plans. Air pockets that were present between the cylinder and the vaginal mucosa were contoured on axial CT slices, enabling TPS to measure their volume. Air pockets that were located within 5–6 cm of the upper vagina were included in the study. A total of 33 air pockets were found in the selected patient's CT scans. The change in the mucosal dose due to the air pocket was assessed by taking ratios of point doses from the TPS at the surface of the cylinder and mucosa surface on the same axial slice where maximum separation was presented. Figure 1 shows the location of points for one of the representative patients. The Student's t-test was performed to find the statistical significance between the dose ratios of TG-43 and Acuros BV plans. A $P < 0.05$ was considered statistically significant. The correlation between the dose ratio and the separation of the vaginal mucosa due to the air pocket was calculated using the Pearson's correlation test.

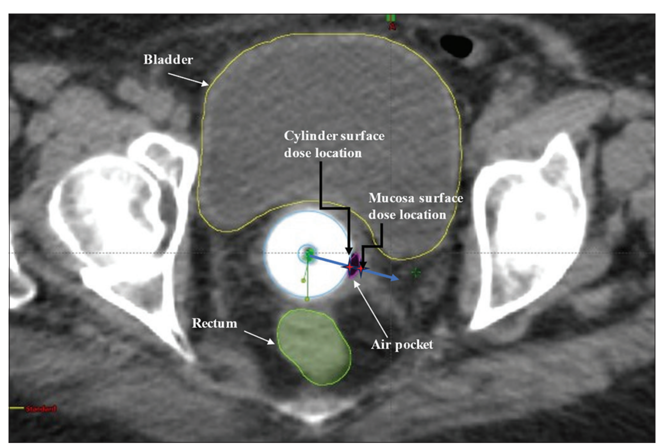

Figure 1: Computed tomography image showing the location of points representing the dose at the cylinder surface and displaced vaginal mucosa surface. Arrow shows the location of defined points and organs at risk

Results

The median age of the patient cohort was 60.0 years, with a range of 41–80 years. The most common International Federation of Gynaecology and Obstetrics stage was IB (61%), followed by IA (30%). Among 23 patients, two had three air pockets, six had two air pockets, and the remaining had only one air pocket. A total of 33 air pockets were observed. The average volume of air pockets was 0.08 cc (range of 0.01–0.3 cc), and the average displacement of the vaginal mucosa by air from the cylinder surface was 0.29 cm (range of 0.14–0.7 cm). Among 33 air pockets, 84% of the air pockets displaced the vaginal mucosa by ≥0.2 cm.

The point doses from the TPS at the intersection of a line drawn from the source center (cylinder center) outward with the cylinder surface and the maximum displaced mucosa by air were recorded on the axial CT image, the maximum displaced mucosa by air dosage to the dose at the cylinder surface was computed using the TG-43 algorithm, and it was found to be in the range of 0.53–0.89. The average ratio was 0.77 ± 0.09 (1 standard deviation [SD]). The mucosa received a reduced dose as compared to the cylinder surface by an average of 22.72% (range of 47.3%–10.65%) due to the presence of an air pocket. The ratio of doses is in the order of 0.51–0.88 when calculated using the Acuros BV with the same dwell positions and dwell times obtained with TG-43. The average ratio was 0.78 ± 0.09 (1 SD). Due to the presence of air, the Acuros BV showed that the mucosa received a reduced dose by an average of 23.29% (range of 49.00%–11.82%). The dose ratio and displacement of mucosa from axial CT images are shown in Figure 2 for two algorithms. When TG-43 and Acuros BV dose ratios were examined, we found that there was no appreciable distinction with a $P = 0.39$. The maximum displacement of the mucosa and the ratio of doses were strongly negatively correlated, both for the TG-43 and the Acuros BV (the Pearson's correlations were − 0.83 and − 0.82, respectively.) The total dwell times were increased by an average of 1.8% for the optimized Acuros BV plan compared to the initial two plans. However, the dose ratios remain similar to the initial Acuros BV plan, with an average of 0.79 ($P = 0.28$).

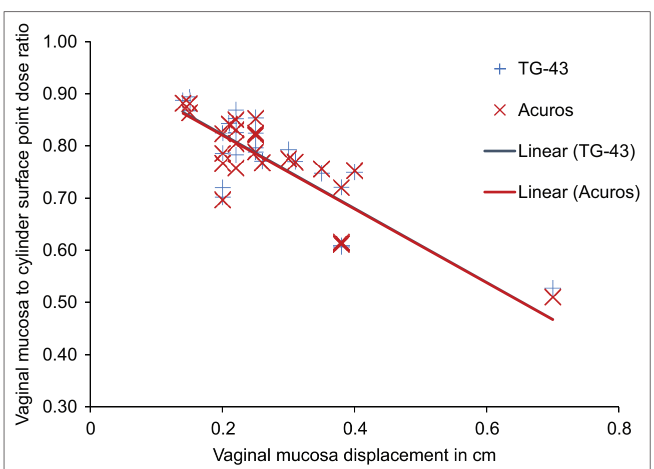

Figure 2: Vaginal mucosa displacement versus ratio of point doses of cylinder surface to the vaginal mucosa. TG 43: Task group 43

Discussion

Delivering the prescribed dose in VCB is significantly complicated by the presence of an air pocket between the vaginal mucosa and the cylinder. The dosimetric effect of air pockets has been evaluated by a few authors.[8,9] However, both these studies published results using the TG-43 dose calculation algorithm. In this present study, we evaluated the dosimetric effects of air pockets using a MBDCA (Acuros BV) and compared it with the TG-43 dose calculation results. Vaginal brachytherapy provides a better quality of life with fewer gastrointestinal toxic effects than external radiotherapy for patients with high-to intermediate-risk endometrial carcinoma. The long-term results of the postoperative radiotherapy for endometrial carcinoma trial showed that vaginal brachytherapy did not significantly differ from EBRT in minimizing vaginal relapse (VR) and it should be the adjuvant treatment of choice. The median follow-up was 116 months, and the VR rate was 3.4% for VBT and 2.4% for EBRT ($P = 0.55$). At 10 years, the overall survival for VBT versus EBRT was 69.5% against 67.6% ($P = 0.72$).[22,23]

Air gaps between the vaginal mucosa and cinder could be considered as one of the possible reasons for vaginal recurrence. Onal *et al*.[8] observed that the occurrence of air pockets is more prevalent in postmenopausal patients and patients treated with brachytherapy alone than in premenopausal patients or patients treated with EBRT and brachytherapy. The most used cylinder diameter was 3.5 cm. The authors found the occurrence of air pockets around the vaginal cylinder in 43% of patients, while 57% had no air pockets. Cameron *et al*.[24] reported that 75% (18 out of 25) of patients had an average of one air pocket. Richardson *et al*.[9] reported that 80% of patients had one or more air pockets in at least one out of six treatment fractions. In this study, we included patients with air pockets around the cylinder, as we aimed to study the dose prediction using the Acuros BV algorithm and compare it to the TG-43 algorithm. The maximum volume of air pockets was 0.3 cc, and the average volume was 0.08 cc, which is lower than that reported by Richardson *et al*. (0.34 cc). In Richardson *et al*.'s study, most patients were treated with a 2.5-cm-diameter cylinder, and only one was treated with a 3.0-cm-diameter cylinder. In our study, 87% of patients were treated with a 3 cm-diameter vaginal cylinder and 13% of cases were treated with a 2.5-cm diameter cylinder. The maximum displacement between the cylinder surface and mucosa was 0.7 cm, and the average was 0.29 cm, which is similar to previous studies.

The TG-43[10,11] is considered as an important and simplified dose calculation algorithm for brachytherapy dose calculations as it provides reliable dose distributions for clinical plans. The parameters used in this algorithm are derived for water or water-equivalent mediums either from measurements or

MC simulations. The total dose distribution is obtained by the superposition of single source distributions. However, this algorithm did not consider the finite geometry of the patient, tissue heterogeneity, or applicators with the shielding material. For high-energy brachytherapy sources, such as Ir-192, the effect of missing backscatter due to finite patient geometry is described in detail for the breast site.[25] Acuros[16] is one of the model-based algorithms that calculate dose distributions by solving the linear Boltzmann transport equation,[17,18] and results are within 2% agreement with MC results[26,27] for the thoracic model, which includes the lung, spinal cord, and trachea. Zourari *et al*.[28] investigated TG-43 and the Acuros model for two-voxel mathematical models resembling an esophageal and a breast brachytherapy patient. They found that the latter significantly improved the accuracy of dose calculations. Previous studies[29-31] evaluated dosimetric differences between TG-43 and Acuros BV for carcinoma of the cervix. It is observed that the TG-43 formalism overestimates the dose of all compared dosimetric parameters. However, the difference is considerably low for carcinoma cervix patients compared to other sites, such as breast and surface implants.[20,32]

In this study, dose distributions were obtained from the TPS using TG-43 and the Acuros BV algorithm. Using the TG-43, the average dose reduction to the mucosa surface due to the air pocket was 22.7% with a range of 10.65%–47.3%, which is in good agreement with previous findings.[9] When the dose distribution in the TPS is recalculated using the Acuros BV algorithm, the reduction is slightly different (the average reduction is 23.29% with a range of 11.82%–49%). However, the difference between the two algorithms is not statistically significant. Hofbauer *et al*.[30] observed that dosimetric differences between TG-43 and Acuros BV calculations indicated less impact on cervical carcinoma cases. Similarly, in the present study, the Acuros BV algorithm showed no significant difference in dose reduction to the mucosal surface in comparison to the TG-43 formalism of VCB with air pockets. There was an increase in total dwell times by 1.8% in delivering the prescribed dose by the optimized Acuros BV plan. Nevertheless, the results of dose ratios showed that optimized and initial plans did not differ in delivering dose to mucosa as compared to dose at the cylinder surface. The increase in dwell times proportionately increased the dose at the surface of the cylinder as well as the mucosal dose. However, the main limitation of the present study was the use of point doses. Therefore, other appropriate dose-volume parameters should be defined and used in future research to confirm these results in carcinoma cervix patients.

Conclusion

Both the TG-43 and Acuros-BV algorithms demonstrated dose reductions at the mucosal surface due to the presence of air pockets, with an average of 22.7% and 23.9%, respectively. The calculated dose of mucous membrane forced out of the cylinder surface by air pockets was not significantly different from TG-43 using the Acuros BV method. Thus, even when there are air pockets, it is still appropriate to apply the TG-43 algorithm to calculate the VCB dose.

Acknowledgments

The authors are thankful to the management of the Basavatarakam Indo American Cancer Hospital and Research Institute for supporting this study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, *et al.* Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 2021;71:209-49.
2. Chino JP, Jones E, Berchuck A, Secord AA, Havrilesky LJ. The influence of radiation modality and lymph node dissection on survival in early-stage endometrial cancer. Int J Radiat Oncol Biol Phys 2012;82:1872-9.
3. Lee CM, Szabo A, Shrieve DC, Macdonald OK, Gaffney DK. Frequency and effect of adjuvant radiation therapy among women with stage I endometrial adenocarcinoma. JAMA 2006;295:389-97.
4. Ahamad A, D'Souza W, Salehpour M, Iyer R, Tucker SL, Jhingran A, *et al.* Intensity-modulated radiation therapy after hysterectomy: Comparison with conventional treatment and sensitivity of the normal-tissue-sparing effect to margin size. Int J Radiat Oncol Biol Phys 2005;62:1117-24.
5. Nag S, Erickson B, Parikh S, Gupta N, Varia M, Glasgow G. The American brachytherapy society recommendations for high-dose-rate brachytherapy for carcinoma of the endometrium. Int J Radiat Oncol Biol Phys 2000;48:779-90.
6. Choo JJ, Scudiere J, Bitterman P, Dickler A, Gown AM, Zusag TW. Vaginal lymphatic channel location and its implication for intracavitary brachytherapy radiation treatment. Brachytherapy 2005;4:236-40.
7. Hassouna A, Bahadur YA, Constantinescu C. Assessment of air pockets in high-dose-rate vaginal cuff brachytherapy using cylindrical applicators. J Contemp Brachytherapy 2014;6:271-5.
8. Onal C, Guler OC, Dolek Y. The impact of air pockets around the vaginal cylinder on vaginal vault brachytherapy. Br J Radiol 2015;88:20140694.
9. Richardson S, Palaniswaamy G, Grigsby PW. Dosimetric effects of air pockets around high-dose rate brachytherapy vaginal cylinders. Int J Radiat Oncol Biol Phys 2010;78:276-9.
10. Nath R, Anderson LL, Luxton G, Weaver KA, Williamson JF, Meigooni AS. 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;22:209-34.
11. Rivard MJ, Coursey BM, DeWerd LA, Hanson WF, Huq MS, Ibbott GS, *et al.* Update of AAPM task group no. 43 report: A revised AAPM protocol for brachytherapy dose calculations. Med Phys 2004;31:633-74.
12. Thomadsen BR, Williamson JF, Rivard MJ, Meigooni AS. Anniversary paper: Past and current issues, and trends in brachytherapy physics. Med Phys 2008;35:4708-23.
13. Rivard MJ, Venselaar JL, Beaulieu L. The evolution of brachytherapy treatment planning. Med Phys 2009;36:2136-53.
14. Papagiannis P, Pantelis E, Karaiskos P. Current state of the art brachytherapy treatment planning dosimetry algorithms. Br J Radiol 2014;87:20140163.
15. Beaulieu L, Carlsson Tedgren A, Carrier JF, Davis SD, Mourtada F, Rivard MJ, *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;39:6208-36.
16. Acuros BV. Algorithm Reference Guide, Document ID B504878R01A, Revision A. Varian Med Syst 2013;8:1-36.
17. Daskalov GM, Baker RS, Rogers DW, Williamson JF. Dosimetric modeling of the microselectron high-dose rate 192Ir source by the multigroup discrete ordinates method. Med Phys 2000;27:2307-19.
18. Gifford KA, Price MJ, Horton JL Jr., Wareing TA, Mourtada F. Optimization of deterministic transport parameters for the calculation of the dose distribution around a high dose-rate 192Ir brachytherapy source. Med Phys 2008;35:2279-85.
19. Williamson JF. Comparison of measured and calculated dose rates in water near I-125 and Ir-192 seeds. Med Phys 1991;18:776-86.
20. Boman EL, Satherley TW, Schleich N, Paterson DB, Greig L, Louwe RJ. The validity of acuros BV and TG-43 for high-dose-rate brachytherapy superficial mold treatments. Brachytherapy 2017;16:1280-8.
21. Granero D, Perez-Calatayud J, Vijande J, Ballester F, Rivard MJ. Limitations of the TG-43 formalism for skin high-dose-rate brachytherapy dose calculations. Med Phys 2014;41:021703.
22. Nout RA, Smit VT, Putter H, Jürgenliemk-Schulz IM, Jobsen JJ, Lutgens LC, *et al.* Vaginal brachytherapy versus pelvic external beam radiotherapy for patients with endometrial cancer of high-intermediate risk (PORTEC-2): An open-label, non-inferiority, randomised trial. Lancet 2010;375:816-23.
23. de Boer SM, Nout RA, Jürgenliemk-Schulz IM, Jobsen JJ, Lutgens LC, van der Steen-Banasik EM, *et al.* Long-term impact of endometrial cancer diagnosis and treatment on health-related quality of life and cancer survivorship: Results from the randomized PORTEC-2 trial. Int J Radiat Oncol Biol Phys 2015;93:797-809.
24. Cameron AL, Cornes P, Al-Booz H. Brachytherapy in endometrial cancer: Quantification of air gaps around a vaginal cylinder. Brachytherapy 2008;7:355-8.
25. Lymperopoulou G, Papagiannis P, Angelopoulos A, Karaiskos P, Georgiou E, Baltas D. A dosimetric comparison of 169Yb and 192Ir for HDR brachytherapy of the breast, accounting for the effect of finite patient dimensions and tissue inhomogeneities. Med Phys 2006;33:4583-9.
26. Zourari K, Pantelis E, Moutsatsos A, Petrokokkinos L, Karaiskos P, Sakelliou L, *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;37:649-61.
27. Petrokokkinos L, Zourari K, Pantelis E, Moutsatsos A, Karaiskos P, Sakelliou L, *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;38:1981-92.
28. Zourari K, Pantelis E, Moutsatsos A, Sakelliou L, Georgiou E, Karaiskos P, *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.
29. Sinnatamby M, Nagarajan V, Reddy KS, Karunanidhi G, Singhavajala V. Comparison of image-based three-dimensional treatment planning using Acuros™ BV and AAPM TG-43 algorithm for intracavitary brachytherapy of carcinoma cervix. J Radiother Pract 2016;15:254-62.
30. Hofbauer J, Kirisits C, Resch A, Xu Y, Sturdza A, Pötter R, *et al.* Impact of heterogeneity-corrected dose calculation using a grid-based Boltzmann solver on breast and cervix cancer brachytherapy. J Contemp Brachytherapy 2016;8:143-9.
31. Mikell JK, Klopp AH, Gonzalez GM, Kisling KD, Price MJ, Berner PA, *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:e417-22.
32. Sinnatamby M, Nagarajan V, Reddy KS, Karunanidhi G, Singhavajala V. Dosimetric comparison of Acuros™ BV with AAPM TG43 dose calculation formalism in breast interstitial high-dose-rate brachytherapy with the use of metal catheters. J Contemp Brachytherapy 2015;7:273-9.