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# Dosimetric impact of Acuros XB on cervix radiotherapy using RapidArc technique: a dosimetric study

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## ABSTRACT

**Background:** Acuros XB (AXB) may predict better rectal toxicities and treatment outcomes in cervix carcinoma. The aim of the study was to quantify the potential impact of AXB computations on the cervix radiotherapy using the RapidArc (RA) technique as compared to anisotropic analytical algorithm (AAA) computations.

**Materials and methods:** A cohort of 30 patients previously cared for cervix carcinoma (stages II–IIIB) was selected for the present analysis. The RA plans were computed using AAA and AXB dose computation engines under identical beam setup and MLC pattern.

**Results:** There was no significant ($p > 0.05$) difference in $D_{95\%}$ and $D_{98\%}$ to the planning target volume (PTV); moreover, a significant ($p < 0.05$) rise was noticed for mean dose to the PTV (0.26%), $D_{50\%}$ (0.26%), $D_{2\%}$ (0.80%) and $V_{110\%}$ (44.24%) for AXB computation as compared to AAA computations. Further, AXB estimated a significantly ($p < 0.05$) lower value for maximum and minimum dose to the PTV. Additionally, there was a significant ($p < 0.05$) reduction observed in mean dose to organs at risk (OARs) for AXB computation as compared to AAA, though the reduction in mean dose was non-significant ($p > 0.05$) for the rectum. The maximum difference observed was 4.78% for the rectum $V_{50Gy}$, 1.72%, 1.15% in mean dose and 2.22%, 1.48% in $D_{2\%}$ of the left femur and right femur, respectively, between AAA and AXB dose estimations.

**Conclusion:** For similar target coverage, there were significant differences observed between the AAA and AXB computations. AAA underestimates the $V_{50Gy}$ of the rectum and overestimates the mean dose and $D_{2\%}$ for femoral heads as compared to AXB. Therefore, the use of AXB in the case of cervix carcinoma may predict better rectal toxicities and treatment outcomes in cervix carcinoma using the RA technique.

**Key words:** cervix carcinoma; AAA; Acuros XB; RapidArc; dose calculation

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## Introduction

GLOBOCAN 2018 has evaluated the cancer incidence rate among inhabitants of 185 nations around the globe. Cervical cancer keeps on being a general health issue influencing the middle-aged women, especially in less-resourced nations and is positioned as the fourth most common cancer in women, after breast (2·1 million cases), colorectal (0·8 million) and lung cancer (0·7 million) [1]. Cervical cancer is the main source of disease-related death in women worldwide. India alongside China contributed in the excess of 33% of the worldwide cervical burden, with 106,000 cases in China and

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97,000 cases in India, and 48,000 deaths in China and 60,000 deaths in India [2].

Radiotherapy (RT) is generally utilized in the management of cervix carcinoma. Because the cervix is surrounded with a heterogeneous medium such as bone and air pockets, the accuracy of a dose computation engine assumes an important role in order to achieve the maximum therapeutic benefits from the radiation treatment. Dose computation in RT, utilizes a radiation beam model to compute the beam fluence impinging on the patient body, subsequently, dose engine computes the particle transport and energy deposition in the body. Energy deposition hinges on the heterogeneities that exist in the patient body and their influence on the primary and secondary particle fluence.

For photon, there are two dose computation engines employed in the Eclipse (Varian Medical System, USA) treatment planning system (TPS) viz., the anisotropic analytical algorithm (AAA) and the Acuros XB (AXB) algorithm. The AXB deploys the same multiple-source model previously derived for AAA. However, AXB and AAA dose engines are mainly separated into: source model, configuration part, dose deposition engines for AAA and AXB. The AXB primarily processes the dose distribution based on the explicit solutions of the linear Boltzmann transport equation (LBTE) [3, 4]. The LBTE is a set of integro-differential equations that depict the interaction and transport of various particles (electrons, photons and neutrons, etc) in matter at the macroscopic level. The AXB patient dose computation consists of discrete steps viz., transport of source model fluence, fluence calculation for scattered photon, electron and final dose calculation in the patient. The AXB requires the macroscopic cross-section of the every element within the computation grid. The Eclipse TPS offers AXB material type and mass-density in each voxel of the image grid using a lookup table for 5 biological (adipose tissue, lung, muscle, cartilage and bone) and 16 non-biological materials, with a maximum supported Hounsfield units of 8000 (steel) [5–7].

The AXB has been reported to be precise and equivalent to Monte-Carlo (MC) in dealing with heterogeneities encountered in clinical settings [8, 9]. In cervix RT, there is a chance of alteration in the precision of dose computation engine due to the heterogeneities that exist around the tumor target volume. Therefore, it is important to evaluate the dosimetric difference in dose distribution computed using AAA and AXB for cervix carcinoma. The literature on the dosimetric comparison of AAA and AXB algorithms for carcinoma cervix RT is at a premium. The RapidArc (RA) technique has been reported superior for cervix RT as compared to the intensity modulated radiation therapy (IMRT) technique [10–12]. Hence, the present study is aimed to quantify the potential benefits of AXB computations on the cervix RT using RA technique as compared to AAA computations. The present study analyzes the dosimetric parameters in terms of target coverage, organ-at-risk (OARs) sparing and various physical dosimetric indices.

## Materials and methods

A cohort of 30 patients previously cared for cervix carcinoma (stages II–IIIB) was selected for the present analysis. The computed-tomography (CT)-scan of 3 mm slice thickness was acquired on Siemens SOMATOM Sensation Open CT-scanner (Siemens Medical Solutions, Erlangen, Germany) for each patient. Patients were immobilized in a supine position using an All-In-One (AIO) board with full bladder according to the departmental protocol.

The target volume delineation was executed on the CT-images in accordance with Radiation Therapy Oncology Group (RTOG) recommendations [13]. The clinical target volume (CTV) incorporated the uterus, cervix, pelvic nodes comprising parametrial and presacral tissues. An edge of 5.0 mm was employed around the CTV to characterize the planning target volume (PTV) [14]. The accompanying OARs, i.e.: bladder, rectum, bowel and femoral heads, were additionally delineated.

The treatment plans were optimized for the RA technique using a double arc (clockwise: gantry angle 179–181 degree and counter clockwise: gantry angle 181–179 degree, collimator rotation: 10–30 degree). The plans were intended to deliver a prescription dose (PD) of 50.4 Gray (Gy) to PTV in 28 sittings at the rate of 1.8 Gy per part. The plans were optimized to deliver 100% PD to 95% of PTV with not more than 5% of PTV volume obtaining 110% of PD. The dose to the bladder and rectum was optimized in such a way that $V_{50Gy}$ (volume receiving 50 Gy) ought to be under 50% of OAR volume.

RA plans were created using Eclipse TPS for 6 mega-volt (MV) photon beam (Varian Medical System, Palo, Alto, USA) generated from True-Beam-STx (Varian Medical System, Palo, Alto, USA) linear accelerator (linac). Each treatment plan was computed using a grid resolution of 2.5 mm for AAA and AXB version 11 under identical beam geometry and MLC setup. For AXB computation, a physical material table was set to AXB version 11; for mapping of physical material using CT-Hounsfield units. The dose-to-medium ($D_m$) was used for dose reporting for AXB computation.

## Dosimetric analysis

The cumulative dose-volume histograms (DVH) were generated to evaluate and compare the various dosimetric parameters for the PTV and OARs. The following dose metrics were calculated for PTV and OARs.

- PTV: mean dose, $D_{95\%}$ (dose to the 95% volume), $D_{98\%}$, $D_{50\%}$, $D_{2\%}$, $V_{110}$% (volume receiving 110% of the PD), maximum and minimum doses to the PTV;
- bladder: mean, $V_{50Gy}$ (percentage of volume receiving dose of 50 Gy), maximum dose and $D_{2\%}$;
- rectum: mean, $V_{50Gy}$, maximum dose and $D_{2\%}$;
- bowel: mean, maximum dose and $D_{2\%}$;
- femoral heads: mean, maximum dose and $D_{2\%}$.

The dose conformity index (CI), homogeneity index (HI), gradient measure (GM) and integral dose to normal tissues (NTID) was calculated using the following formulae:

- conformity index (CI):

$$CI = Volume\ of\ 95\%\ isodose / Volume\ of\ PTV$$ [15];

- homogeneity index (HI):

$$(HI) = \frac{(D_{2\%} - D_{98\%})}{D_{50\%}}$$ [16].

The value of CI close to 1 and HI close to 0 signifies a better conformal and homogenous dose distribution to the PTV:

- gradient measure (GM): GM was determined as radius difference between the equivalent spheres of prescription and half prescription isodose volumes, which demonstrates dose falloff around PTV. The lower value for GM confirms a higher gradient in dose distribution around the target [16];
- integral dose to normal tissues (NTID): mean dose × normal tissues volume outside PTV [17].

The computation efficiency of dose engine was also examined by evaluating the Monitor units (MUs) and calculating time required for an individual dose computation engine.

## Statistical analysis

The Estimation Statistics (ES) avoids the pitfalls of significance testing, and highlights the magnitude of the effect (the effect size) and its accuracy. ES provides a profound comprehension of the metrics used, and how they relate to the natural processes being considered. On the other hand, significance testing computes the probability (p-value) that the experimental data would be observed, if the intervention did not generate an alteration in the metric estimated (i.e. the null hypothesis). This leads to a false dichotomy on the experimental intervention [18]. The main advantage of ES is to report an effect size along with its confidence interval (CI). The CI helps to evaluate the clinical as well as statistical significance of the difference [19]. Therefore, ES was utilized to determine the variations in dosimetric indices for the present study. The metric of interest was demonstrated for every patient by means of swarm plots, with every patient's information for both algorithms shown via a line joining the two algorithms. The distribution on the right of every graph illustrates the CI of the variation in the means, with the zero location of this axis aligned with the mean of the control dose computation engine. The statistical analysis was executed using Python software version 3.8.3 (Python Software Foundation, Beaverton, USA).

# Results

RapidArc treatment plans were generated for both dose computation engines using the 6 MV photon beam. A comprehensive analysis was performed for PTV and OARs in order to analyze the dosimetric variations between both dose computation engines. The dosimetric parameters for PTV coverage were detailed in Table 1. For a representative patient, Figure 1 illustrates the 95% PD coverage for cervix carcinoma using (a) AAA and (b) AXB dose computation. There was no significant ($p > 0.05$) difference in $D_{95\%}$ and $D_{98\%}$ to the PTV; moreover, a significant ($p < 0.05$) rise was noticed

**Table 1.** Dose-volume parameters for planning target volume (PTV) and dosimetric indices calculated for dose distribution generated using anisotropic analytical algorithm (AAA) and Acuros XB (AXB)

| Structure | Parameters | AAA (Mean ± SD) | AXB (Mean ± SD) | p-value |
|---|---|---|---|---|
| PTV | Mean [Gy] | 52.73 ± 0.52 | 52.87 ± 0.53 | 0.000 |
| | $D_{95\%}$ [Gy] | 50.40 ± 0.02 | 50.40 ± 0.01 | 0.148 |
| | $D_{98\%}$ [Gy] | 49.59 ± 0.17 | 49.56 ± 0.22 | 0.100 |
| | $D_{50\%}$ [Gy] | 52.87 ± 0.57 | 53.01 ± 0.58 | 0.000 |
| | $D_{2\%}$ [Gy] | 54.88 ± 0.91 | 55.32 ± 0.90 | 0.000 |
| | $V_{110}$ [%] | 1.84 ± 2.60 | 3.30 ± 3.68 | 0.000 |
| | MAX [Gy] | 57.29 ± 1.36 | 52.26 ± 0.23 | 0.000 |
| | MIN [Gy] | 43.93 ± 2.05 | 43.04 ± 2.13 | 0.011 |
| | HI | 0.100 ± 0.018 | 0.108 ± 0.019 | 0.000 |
| | CI | 1.000 ± 0.015 | 1.006 ± 0.016 | 0.006 |
| | GM | 3.903 ± 0.315 | 3.874 ± 0.319 | 0.000 |
| | NTID (liter-Gy) | 11.78 ± 2.58 | 11.72 ± 2.56 | 0.000 |

SD — standard deviation; PTV — planned target volume; CI — conformity index; HI — homogeneity index; GM — gradient measure; NTID — integral dose to normal tissues

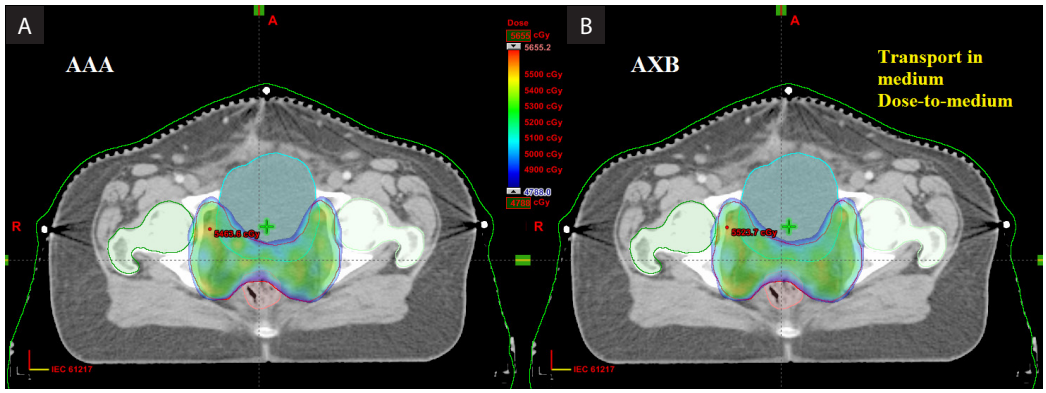


**Figure 1.** Example patient illustrating the 95% prescription dose coverage for cervix carcinoma using (**A**) AAA and (**B**) AXB dose computation

for mean dose to PTV (0.26%), $D_{50\%}$ (0.26%), $D_{2\%}$ (0.80%) and $V_{110\%}$ (44.24%) for AXB computation as compared to AAA computations. Further, AXB estimated a significantly ($p < 0.05$) lower value for maximum and minimum dose to the PTV. Figure 2 illustrates the comparison between AAA and AXB estimated (a) $D_{95\%}$, (b) $D_{50\%}$ and (c) $V_{110\%}$ of the PTV.

Additionally, AXB estimated dose distribution was slightly inferior in terms of CI ($p < 0.05$, 0.60%), HI ($p < 0.05$, 7.41%), and superior in terms of GM ($p < 0.05$, 0.75%) compared to AAA. However, AXB estimated lower NTID ($p < 0.05$, 0.51%) as compared to AAA computation. Figure 3 illustrates the comparison between AAA and AXB estimated (a) CI, (b) HI and (c) calculation time.

The dosimetric parameters for OARs computed using AAA and AXB dose engines were detailed in Table 2. There was a reduction in mean dose to the bladder ($p < 0.05$, 0.22%), rectum ($p > 0.05$, 0.02%), bowel ($p < 0.05$, 0.45%) for AXB as compared to AAA. On the other hand, a significant rise ($p < 0.05$) in maximum dose and $D_{2\%}$, was observed for the bladder (0.32% and 0.09%), rectum (0.56% and 0.49%) and bowel (0.93% and 0.29%), for AXB as compared to AAA. Similarly, a significant rise ($p < 0.05$) was observed in percentage volume of $V_{50Gy}$ for the bladder (0.93%) and rectum (4.78%), for AXB as compared to AAA.

Moreover, there was a significant ($p < 0.05$) reduction noticed for maximum dose (approx 0.50%)

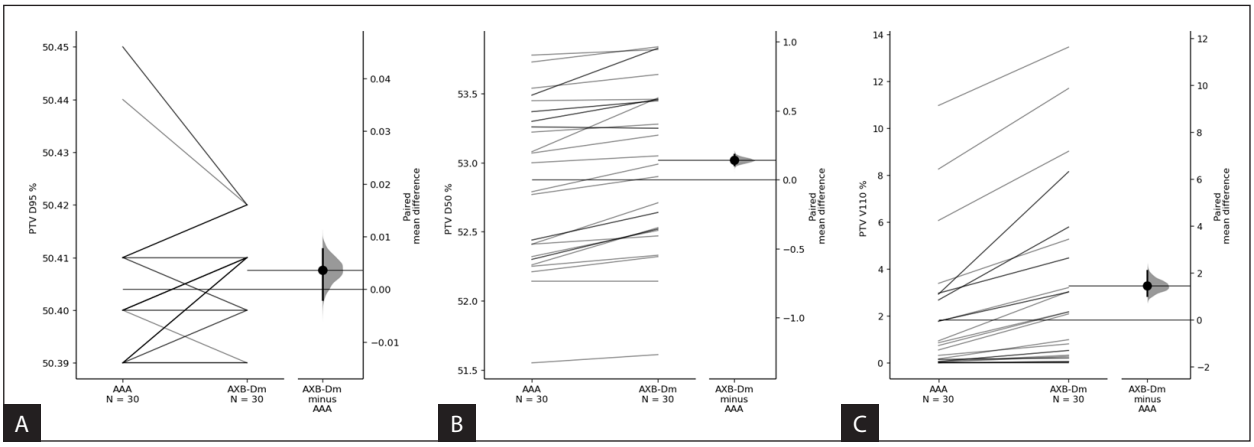


**Figure 2.** Comparison of dose to the (**A**) D95%, (**B**) D50% and (**C**) percentage volume $V_{110\%}$ for planning target volume (PTV)

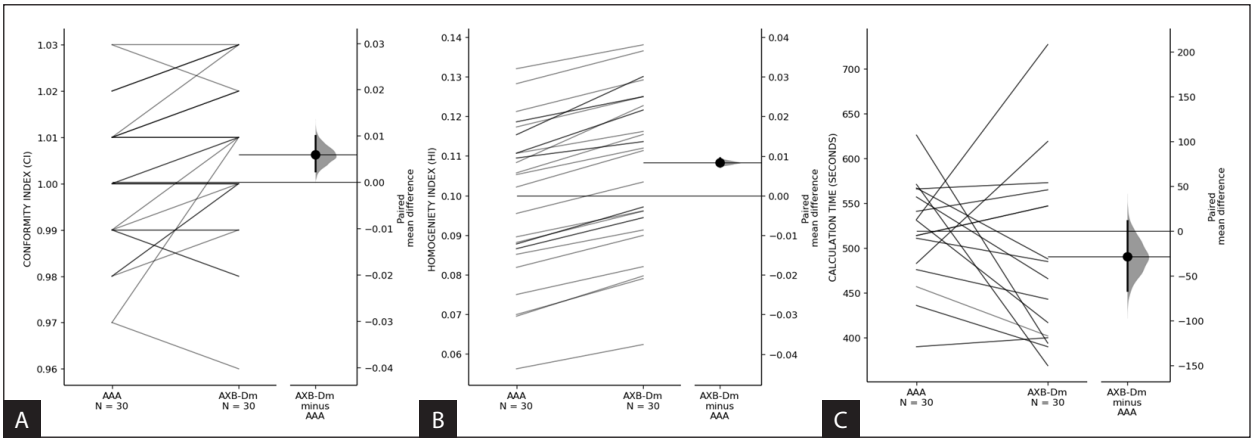


**Figure 3.** Comparison of conformity index (CI) (**A**), homogeneity index (HI) (**B**) and calculation time (in sec) (**C**) between analytical algorithm (AAA) and Acuros XB (AXB)

and $D_{2\%}$ (left femur: 1.15%, right femur: 1.48%) for both femoral heads for AXB as compared to AAA. Additionally, there was a significant ($p < 0.05$) reduction in mean dose to the left femur (1.72%) and right femur (2.22%) for AXB computations as compared to AAA.

Further, there was a significant increase in the number of calculated MUs ($p < 0.05$, 0.64%) with AXB algorithm but calculation time was 5.83% faster, though statistically non-significant ($p > 0.05$) as shown in Table 3, as compared to AAA. Figure 4 summarizes the absolute mean difference between AXB and AAA for cervix carcinoma.

## Discussion

The study presents a comprehensive analysis of dose distribution generated for cervix carcinoma using AAA and AXB computation. The present study tried to quantify the impact of AXB computations on cervix carcinoma as compared to AAA computation. The study reveals that there was no significant ($p > 0.05$) difference in PTV coverage for both dose engines. However, there was a significant ($p < 0.05$) difference in maximum and minimum dose values to the PTV between both dose computations. Additionally, there was a reduction observed ($p < 0.05$) in mean dose to OARs for AXB computation as compared to AAA, although the reduction in mean dose was non-significant ($p > 0.05$) for the rectum.

Rana et al. [20] detailed the dosimetric difference between AAA and AXB for prostate cancer and concluded the highest dose difference was up to 0.43% and 1.98% for PTV and OARs between AAA and AXB computations using a partial

**Table 2.** Dose-volume parameters calculated using anisotropic analytical algorithm (AAA) and Acuros XB (AXB) for organs at risk (OARs)

| Structure | Parameters | AAA (Mean ± SD) | AXB (Mean ± SD) | p-value |
|---|---|---|---|---|
| Bladder | Mean [Gy] | 41.45 ± 1.67 | 41.36 ± 1.67 | 0.000 |
| | $V_{50Gy}$ (%) | 33.07 ± 4.82 | 33.38 ± 4.72 | 0.003 |
| | Max [Gy] | 55.90 ± 1.28 | 56.08 ± 1.33 | 0.030 |
| | $D_{2\%}$ [Gy] | 53.95 ± 0.85 | 54.00 ± 0.87 | 0.056 |
| Rectum | Mean [Gy] | 42.93 ± 2.70 | 42.92 ± 2.73 | 0.681 |
| | $V_{50Gy}$ (%) | 25.70 ± 8.04 | 26.99 ± 8.43 | 0.000 |
| | Max [Gy] | 54.92 ± 1.09 | 55.23 ± 1.20 | 0.000 |
| | $D_{2\%}$ [Gy] | 52.90 ± 0.70 | 53.16 ± 0.74 | 0.000 |
| Bowel | Mean [Gy] | 18.01 ± 3.17 | 17.93 ± 3.18 | 0.000 |
| | Max [Gy] | 51.39 ± 3.54 | 51.87 ± 3.82 | 0.000 |
| | D2 [Gy] | 41.13 ± 3.99 | 41.25 ± 4.03 | 0.000 |
| Lt Femur | Mean [Gy] | 20.65 ± 1.83 | 20.30 ± 1.81 | 0.000 |
| | Max [Gy] | 50.84 ± 2.69 | 50.58 ± 2.76 | 0.003 |
| | $D_{2\%}$ [Gy] | 45.62 ± 3.84 | 45.10 ± 3.89 | 0.000 |
| Rt Femur | Mean [Gy] | 20.72 ± 2.18 | 20.27 ± 2.06 | 0.000 |
| | Max [Gy] | 51.56 ± 2.84 | 51.31 ± 2.95 | 0.007 |
| | $D_{2\%}$ [Gy] | 46.52 ± 4.04 | 45.84 ± 4.12 | 0.001 |

SD — standard deviation

**Table 3.** Monitor units and calculation time comparison for analytical algorithm (AAA) and Acuros XB (AXB)

| Parameters | AAA (Mean ± SD) | AXB (Mean ± SD) | p-value |
|---|---|---|---|
| MUs | 525.56 ± 32.74 | 528.93 ± 33.59 | 0.000 |
| Calculation time (s) | 519.10 ± 58.49 | 490.50 ± 99.71 | 0.164 |

SD — standard deviation; Mus — monitor units; s — seconds

single arc VMAT plan. Further, Rana et al. [20] reported that AAA estimated higher maximum and minimum doses to PTV and higher mean dose to OARs as compared to AXB estimations. Our results were in congruence with the above-mentioned study.

Additionally, Koo et al. [21] detailed the dosimetric difference between AAA and AXB for prostate cancer using endorectal balloon and concluded a higher value for $V_{107\%}$ (hot-spot), and no significant ($p > 0.05$) difference in CI and HI for AXB as compared to AAA estimation. The present study reveals a significantly higher $V_{110\%}$ value for AXB estimation as compared to AAA. The study also reveals a significant difference in CI (0.60%), HI (7.41%), GM (0.75%) and NTID (0.51%) for AXB as compared to AAA estimations.

For OARs, the maximum difference was observed for the volume of 50Gy (i.e. $V_{50Gy}$) of the rectum (4.78%), mean dose (Lt femur 1.72% and Rt femur 2.22%) and $D_{2\%}$ (Lt femur 1.15% and Rt femur 1.48%) to the femoral heads between AAA and AXB dose estimations. AAA underestimates the $V_{50Gy}$ of the rectum and overestimates the mean dose and $D_{2\%}$ for the femoral heads as compared to AXB. This larger variation in $V_{50Gy}$ to the rectum can be attributed to the possible presence of air or gas-pockets in some part of the rectum. In addition, there was a difference in the computation approach used by both dose computation engines in modeling the scatter radiation and secondary electrons, when density is different from that of water (i.e., air pockets and bony structure of femoral heads). The high-dose volume of the rectum may

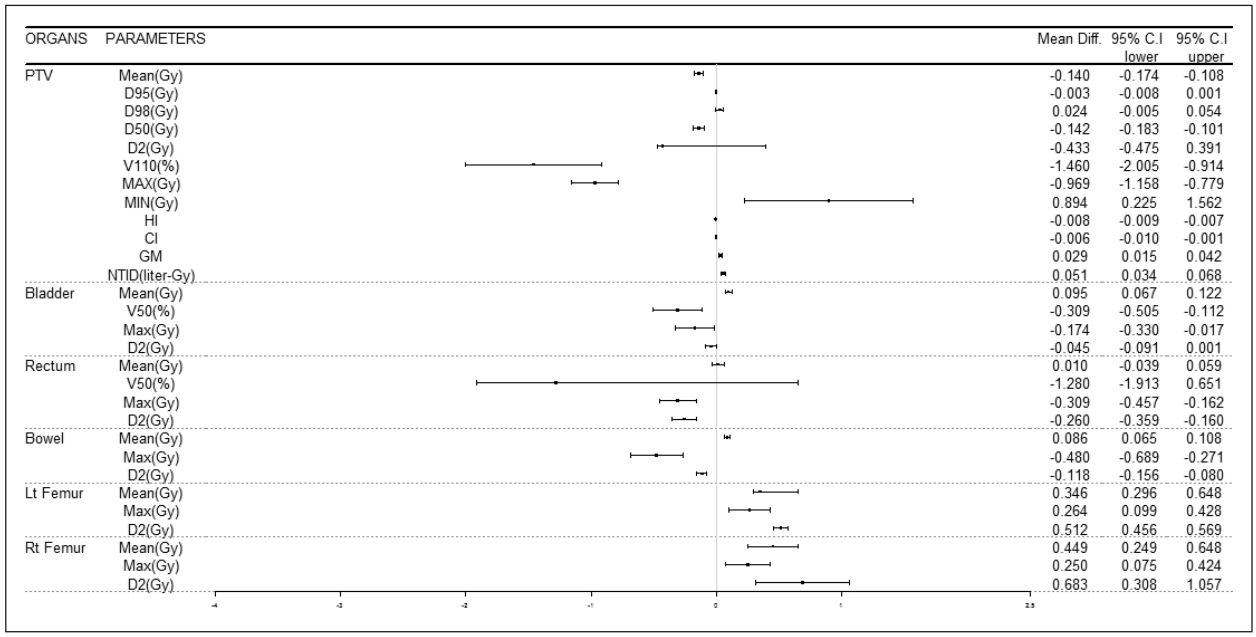


**Figure 4.** Summary of dosimetric comparison of various parameters for planning target volume (PTV) and organ at risks (OARs) for analytical algorithm (AAA) and Acuros XB (AXB) dose computations

lead to a high risk of rectal toxicity; similarly, the reduction in doses for femoral heads reduces the toxicity level for bony femoral heads. These differences in $V_{50Gy}$ of the rectum, mean that dose and $D_{2\%}$ to the femoral heads may impact the treatment outcome and, therefore, cannot be simply ignored. Koo et al. [21] demonstrated the accuracy of AXB in air pockets and air-tissue interface as compared to AAA and concluded that AXB is more precise in forecasting the dose in air pockets and air-tissue interface based on the prostate cancer study using an endorectal balloon. The AXB has been reported to be more precise and comparable to MC in different clinical studies [22, 23].

Additionally, the present study also reveals a rise in MUs ($p < 0.05$, 0.64 %) and decrease in calculation time ($p > 0.05$, 5.83 %) required for the AXB computation as compared to AAA for similar target coverage in the case of cervix carcinoma. Faster dose computation is in the interest of contemporary RT clinics.

To the best of our knowledge, this study is the first of its kind in comparing the dosimetric impact of AXB and AAA on external beam RT planning in carcinoma cervix. Owing to the lack of parallel literature on dosimetric impact of AXB on cervix carcinoma, dosimetric study executed on the prostate was used for comparative analysis against the present study.

Major drawback of the present study lies on its dependence on the dosimetric data rather than clinical evidence. However, the present study carefully investigates the potential dosimetric difference in AAA and AXB computation for cervix carcinoma and presents a possible edge of using AXB over AAA estimations for cervix carcinoma using the RA technique.

## Conclusion

The present study demonstrates that, for a similar target coverage, there were significant differences observed between the AAA and AXB computations for cervix carcinoma using the RA technique. The study reveals that AAA underestimates the $V_{50Gy}$ of the rectum and overestimates the mean dose and $D_{2\%}$ for the femoral heads as compared to AXB. AXB performs a relativity faster computation as compared to AAA. Therefore, the use of AXB in cervix carcinoma may predict better rectal toxicities and treatment outcomes in cervix carcinoma using the RA technique.

### Conflict of interest

None declared.

### Funding

None declared.

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