Original Article

Collapsed Cone Superposition Algorithm Validation for Chest Wall Tangential Fields using Virtual Wedge Filters

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Abstract

Background: Virtual wedge (VW) is used in radiotherapy to compensate for missing tissues and create a uniform dose distribution in tissues. According to TECDOC-1583 and technical reports series no. 430, evaluating the dose calculation accuracy is essential for the quality assurance of treatment planning systems (TPSs). In this study, the dose calculation accuracy of the collapsed cone superposition (CCS) algorithm in the postmastectomy radiotherapy of the chest wall for breast cancer was evaluated by comparing the calculated and measured dose in VW fields. **Methods:** Two tangential fields with the typical VW angles were planned using ISOgray TPS in a thorax phantom. The CCS algorithm was used for dose calculation at 6 and 15 MV photon beams. The obtained dose distributions from EBT3 film spaces and TPS were evaluated using the gamma index. **Results:** The measured and calculated dose values using VW in a heterogeneous medium with different beam energies were in a good agreement with each other (acceptance rate: 88.0%–93.4%). The calculated and measured data did not differ significantly with an increase/decrease in wedge angle. In addition, the results demonstrated that ISOgray overestimated and underestimated the dose of the soft tissue and lung in the planned volume, respectively. **Conclusions:** According to the results of gamma index analysis, the calculated dose distribution using VW model with the CCS algorithm in a heterogeneous environment was within acceptable limits.

Keywords: *Film dosimetry, gamma index, treatment planning system, virtual wedge*

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Introduction

Radiotherapy is the use of ionizing radiation to treat certain forms of cancer.[1] With further advances in cancer diagnosis and treatment, breast cancer patients have a longer survival rate in recent years.[2] A high degree of precision in dose delivery is one of the primary goals of radiotherapy. According to the report 83 of the International Commission on Radiation Units and Measurements (ICRU), isodose distribution coverage between 95% and 107% is required to destroy the tumor while protecting the surrounding healthy tissues from receiving doses above their tolerance.[3] To achieve this objective, evaluation of the accuracy of dose calculation algorithms is required. The IAEA technical reports series no. 430[4] and IAEA-TECDOC-1583[5] are international guidelines for determining the dose calculation accuracy of treatment planning systems (TPSs). With the aid of three-dimensional (3D) TPSs through advanced dose calculation algorithms and contouring methods, physicians and radiation physicists can administer homogeneous dose distribution to the tumors. The algorithms responsible for the precise dose calculation in the target and surrounding tissues, such as organs at risk (OARs), constitute the central component of all TPSs. The Monte Carlo-based TPSs exhibit accurate performance in dose calculation; however, recent studies demonstrated that some model-based algorithms performed accurately as Monte Carlo while requiring less time, particularly in homogeneous tissues.[6,7] Consequently, evaluation of the precision and accuracy of other algorithms, particularly concerning interactions in heterogeneous mediums, has prompted several empirical investigations in recent years.[8-11]

Virtual wedge (VW) is typically used as a beam-modifying device to optimize dose

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distribution in target volume by moving collimator jaws. Researches have demonstrated that using VW to treat breast cancer in comparison to intensity‑modulated radiation therapy can reduce the risk of secondary cancer, OAR, and body radiation exposure.[12,13] Some studies have evaluated the dose calculation accuracy of various algorithms in the wedged field technique. Venselaar *et al.*[14] assessed the dose calculation accuracy of different algorithms of commercial TPSs, e.g., based on scatter calculation, Monte Carlo calculations, or a pencil beam algorithm. The results of their investigations indicated that some algorithms have their restrictions for dose calculations in wedged fields. Differences of up to 13% between calculated and measured dose values were reported. In this regard, Kavousi *et al.*[8] investigated the accuracy of the five dose calculation algorithms using CIRS thorax phantom based on IAEA TEC‑DOC 1583 when using wedge filters for 6 and 18 MV photon beams. The studied algorithms included Monte Carlo algorithm, pencil beam convolution (PBC), anisotropic analytical algorithms (AAAs), superposition (SP), and Clarkson algorithms employed by Monaco, Eclipse, and PCRT3D TPSs. They showed that in the wedged fields, the differences between measured and calculated doses were within the tolerance limit (± 4%), while this finding was not reported for VW filters. In another study, Alghamdi and Tajaldeen[15] evaluated the performance of five present‑day algorithms such as PBC, Acuros XB, AAA, collapsed cone convolution, and SP algorithms on modeling dose distribution in wedged fields by using 25° and 45° enhanced dynamic wedges and physical wedges, respectively. The results of their study in the heterogeneous phantom showed that there was an acceptable agreement between the measurements and the calculations, while this research was not implemented for collapsed cone superposition (CCS) algorithm. Farhood *et al.*[16] carried out a study on the precision of full scatter convolution (FSC) algorithm in TiGRT TPS for physical wedged fields in the homogeneous phantom. According to the finding of this study, the dose calculation accuracy of FSC algorithm is sufficient in clinical application.

By considering VW advantages, particularly in crowded radiotherapy departments with high throughputs, it is essential to ensure TPS performance in dose calculations, especially in inhomogeneous fields such as thorax, as well as the presence of dose fluctuation due to VW fields. To the best of our knowledge, no comprehensive study has been conducted on evaluating the dose calculation accuracy of the CCS algorithm for chest wall tangential fields using VW filters. Therefore, in this study, we aimed to assess the ISOgray CCS algorithm accuracy in prediction of dose fluctuation levels in radiotherapy of chest wall in breast cancer by comparing calculated and measured doses for VW fields in anthropomorphic thorax phantom. To this end, an appropriate dosimetry method such as film dosimetry should be used to determine the accuracy of the TPS calculations. Gafchromic films with special advantages and capabilities are among the acceptable tools for quality assurance (QA) of TPSs.[17‑19] In this regard, we used the practical measurements of the radiochromic film to obtain the two‑dimensional (2D) dose distribution. The findings of this study can be useful in assessing the calculations of CCS algorithm for clinical use in the chest wall radiotherapy of breast cancer.

This study was conducted in light of the growing use of model‑based algorithms, particularly the CCS algorithm, in modern TPSs, as well as the importance of ensuring dose calculation algorithms in heterogeneous medium in radiotherapy with high‑dose fluctuations owing to VW applications.

Materials and Methods

Phantom fabrication

Dose measurements were conducted in the inhomogeneous homemade thorax phantom. The structures such as soft tissue, lungs, and heart were considered in this phantom. The scales and sizes of the phantom's components were simulated based on information obtained from the computed tomography (CT) scans of patients. Plexiglas and air were considered soft tissue and lung, respectively. The material is a slab phantom consisting of 48 slices with 1 cm thickness. Fabrication of the phantom was done using 30 cm × 20 cm plexiglass sheets with mass density of 1.17 g/cm^3 and a relative electron density of 1.003. Film strips were compressed between the slabs of the phantom to measure dose in two dimensions. The CT images of the phantom in DICOM format were transferred to the TPS and used for contouring target volume.

Film dosimetry

Film dosimetry protocols (AAPM TG‑235 and TG‑55) and vendor‑recommended technical considerations were considered in the measurements.[20,21] Films were scanned with a Microtek 9800XL flatbed scanner in a 48‑bit red‑green‑blue color representation mode and analyzed using MATLAB software (R2015a). The red channel of the film images was utilized for film dosimetry. The calibration curves were obtained using 5 cm × 5 cm film pieces from the same sheet. Films were placed at a depth of 3 cm inside the slab phantom. The surface of the slab phantom was set at 100 cm SSD. A field size of 10 cm × 10 cm was set by the jaws. Afterward, films with 18 different dose levels were exposed, including 50–900 cGy with 50 cGy intervals. In order to achieve full backscatter, the total thickness of the standard slab phantom below the film was 15 cm. All measurements were performed in a single session to reduce the fluctuation of working conditions. To this end, the effect of accelerator output changes at different time intervals was minimized, as was the variation in the uncertainty of scanner readouts. In addition, the effect of long-term background radiation on the film's sensitive layer was reduced.

Film scanning

The EBT3 films were scanned in landscape orientation using the Microtek ScanWizard Pro V7.26 software 48 h after irradiation. No filters or image processing tools were employed to obtain unfiltered data. The films were scanned with a full dynamic range, the transmission mode, at a spatial resolution of 127 dpi, and saved as TIFF file format. To reduce the film dose–response uncertainty and improve the calibration curve's precision, each dose level was repeated three times, and the mean *net*-optical density (*net*OD) was used to generate the calibration curve. Finally, after irradiation, the *net*OD was received using Eq. 1:[22]

$$netOD = -log_{10}(\frac{PV_{\text{exp}}}{PV_{blank}}) \quad (1)$$

where PV_{exp} denotes the pixel value of the exposed film and PV_{blank} represents the pixel value of the blank or unexposed film. A 1 cm^2 area was extracted from the film's center for film analysis. The algorithm presented in Moré study[23] was utilized to determine an appropriate calibration curve and minimize fitting uncertainty. The experimental and fitted dose uncertainties were computed through error publication as recommended by Devic *et al*.[24] Experimental error is the estimation of uncertainty in dose determination due to the efficiency of the dosimetry system (film/scanner). Fit error is related to the uncertainty introduced by the fit that is required to convert measured *net*OD into the absorbed dose. Finally, a third-degree polynomial curve was used to fit the calibration curve.

Treatment planning and measurements

All measurements were made at the Radiotherapy Department of Ardabil Imam-Khomeini Hospital using an ARTISTE 160 Multi-leaf Collimator linear accelerator (Siemens, Erlangen, Germany). Selecting photon beam energy in therapeutic areas (such as the breast, chest wall, esophagus, and others) is critical for achieving adequate dose coverage in tumoral and OAR tissues.[25-27] In the present study, we used low- and high-photon beam energies (6–15 MV) in treatment planning. The VW provides each nominal wedge angle, of which we used 15°, 30°, 45°, and 60° in this study. VW is a treatment modality that generates wedge-shaped dose distributions by moving a collimator jaw from closed to open while varying the dose rate at every 2 mm jaw position.[28] For instance, 1VW demonstrated that the Y1 jaw moved during irradiation. Before using the VW, the linearity and repeatability of the output and positional accuracy were measured and verified.[29,30] In this study, VeriSoft software (version 6.2, PTW, Freiburg, Germany) was utilized to evaluate the measured and calculated dose based on a gamma index with 3%–3 mm criteria. The gamma index was developed as a tool for QA in advanced treatment delivery methods to compare measured and calculated dose distributions.[31,32] Both dose difference (DD) and distance-to-agreement (DTA) parameters are utilized in the comparisons. The gamma index is a dimensionless function that simultaneously evaluates both parameters. DD and DTA parameters are expressed in percentage and millimeter, respectively.

ISOgray TPS (version 4.2.3.45 L, Dosisoft, Cachan, France) was used to calculate the dose distribution. VW angles of 15°, 30°, 45°, and 60° were used to create two 6.5 cm × 15 cm tangential fields for 6 and 15 MV photon beams. The calculation point was defined in the soft tissue of the chest wall, according to ICRU report 50,[33] and the confidence index was 1. The treatment machine's gantry was set to 53° and 229° in the medial and lateral fields, respectively. The prescribed dose was 600 cGy. The calculated and measured dose distributions in thorax phantom irradiated by designed plan (6 MV, 1VW45) are shown in Figure 1a and b, respectively. Each experiment was repeated three times to reduce the films' dose–response uncertainty and improve measurement precision, and the mean *net*OD was used to generate the results.

Due to the differences in spatial resolution between TPS (2 mm) and film (0.2 mm), a homemade MATLAB code was developed to unify the spatial resolution of the film identical to that of TPS. Before downsampling the film, the code also considered the 5 × 5 average filter (25-pixel area) to improve the signal-to-noise ratio.

Results

Figure 2a depicts the film calibration curve. Using the relationships established in the study by Devic *et al*.,[24] all the uncertainties associated with film dosimetry were calculated, including the measurement uncertainty ($\sigma_{Experimental}$) and the uncertainty in fitting the calibration curve (σ_{Fit}) and the total uncertainty (σ_{Total}). Figure 2b relates to the uncertainties mentioned. As can be seen, the total uncertainty is less than 5%, corroborating with Devic *et al*.[24]

Four wedge angles with 6 and 15 MV X-rays were considered to analyze the VW field's predicted and measured

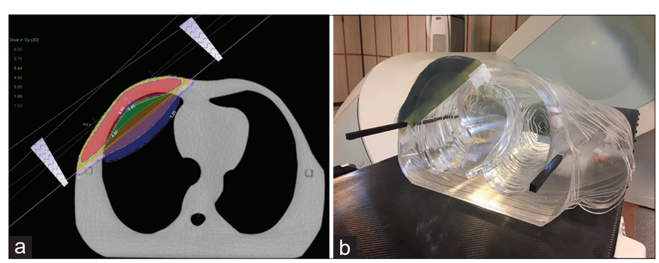

Figure 1: (a) Dose distribution obtained from the ISOgray TPS for virtual wedged tangent fields (1VW15) at 6 MV energy in thorax phantom, (b) View of the phantom with the film embedded in it after irradiation. TPS – Treatment planning system

dose distribution in the chest wall region. In other words, considering three repetitions of each experiment, a total of 24 film measurements were conducted. Figure 3a illustrates a qualitative representation of the gamma maps (2D matrix of the obtained gamma index values) of various VW angles in both energies with 3%–3 mm gamma criteria in local mode. The red areas (gamma index >1) indicate areas that do not meet with the specified criteria. According to this gamma distribution, Figure 3b depicts the failed points in blue (cold) and red (hot) colors. The cold regions

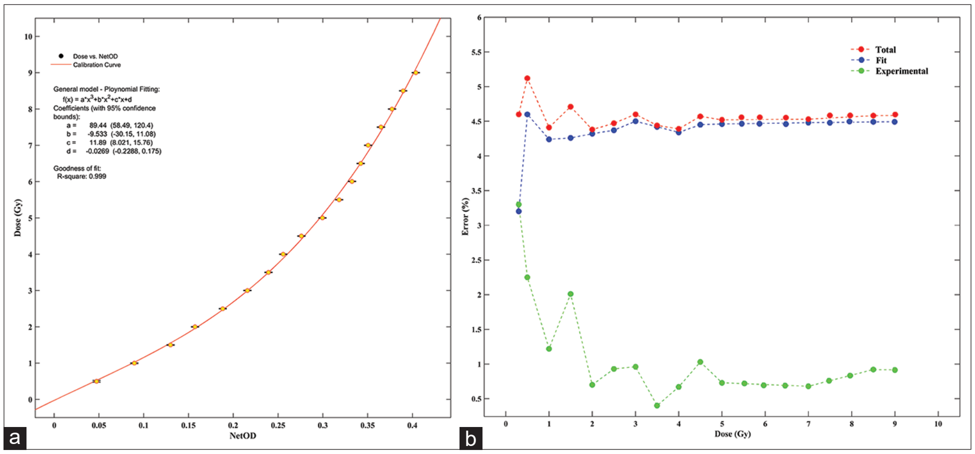

Figure 2: (a) Calibration curve of EBT3 film, (b) Curves related to estimating total uncertainty and its constituent components

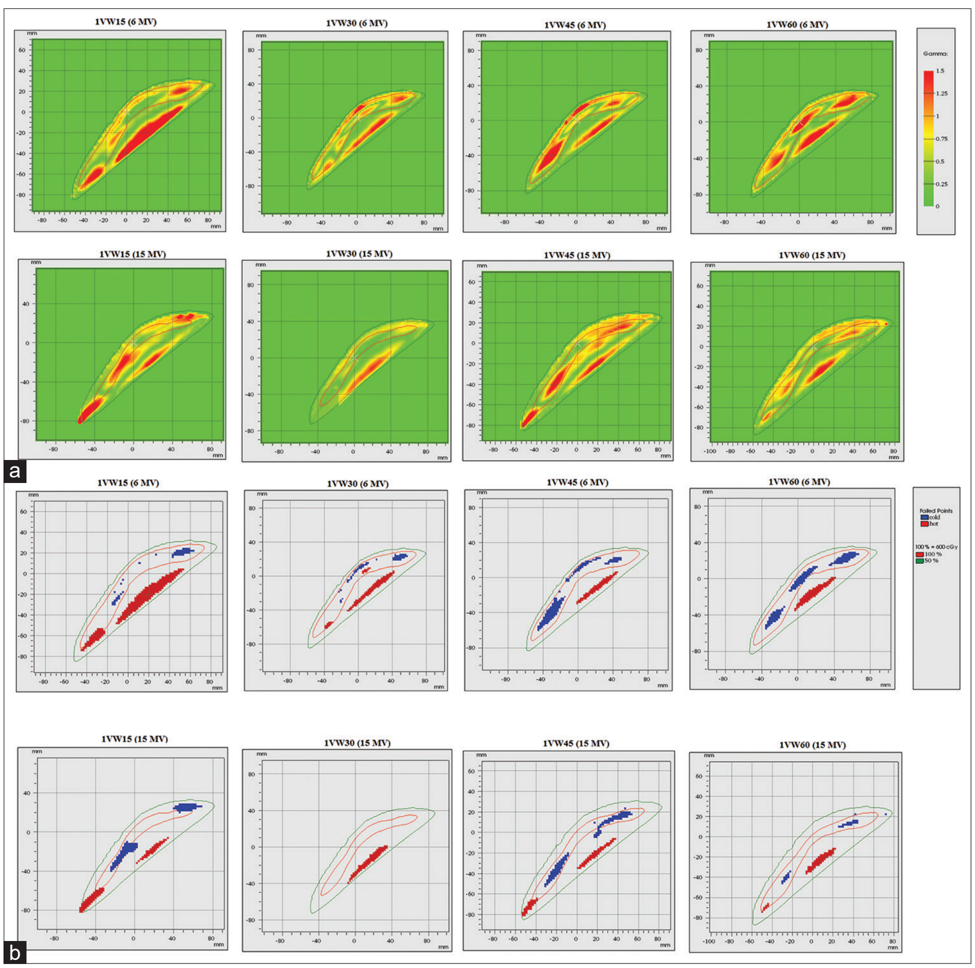

Figure 3: (a) Gamma maps (3%–3 mm, local mode) obtained from virtual wedged planning of tangential breast radiotherapy related to CCS algorithm and EBT3 film at 6 and 15 MV energies in wedge angles of 15°, 30°, 45°, and 60°, (b) Failed points of gamma map distributions are shown as cold (blue) and hot (red) areas. The red lines correspond to the 100% isodose line and the green lines show the 50% isodose line. In all gamma maps, the X and Y axes represent the distance in mm. CCS – Collapsed cone superposition

indicate that these regions were overestimated by the CCS algorithm, while the hot points show underestimated. Bar graphs depict quantitative analysis of gamma index at wedge angles of 15°, 30°, 45°, and 60° at energies of 6 and 15 MV in Figure 4. In this figure, both local and global modes are shown separately and the acceptance criteria are 3%–3 mm. Figures 3a and 4 demonstrate that the gamma pass rate (the total percentage of gamma map pixels that match the defined gamma criteria) at 15 MV energy is equal to or slightly higher than at 6 MV, quantitatively and qualitatively. This increase is up to 4.4% in local mode and 4.5% in global mode. The diagram in Figure 4 also shows that the gamma acceptance values in the global mode are always higher than in the local mode at 6 MV and 15 MV energies. This increase in 6 MV and 15 MV energies is in the range of 0.9%–1.5% and 1.0%–1.5%, respectively. Figure 5a1, a2, b1, and b2 illustrates the dose distribution predicted by the CCS algorithm and practical measurements for 1VW45 at two energies (6 and 15 MV). Figure 5a3 and b3 highlights the percentage of isodose area difference between calculated and measured isodose levels at 6 MV and 15 MV energies, respectively.

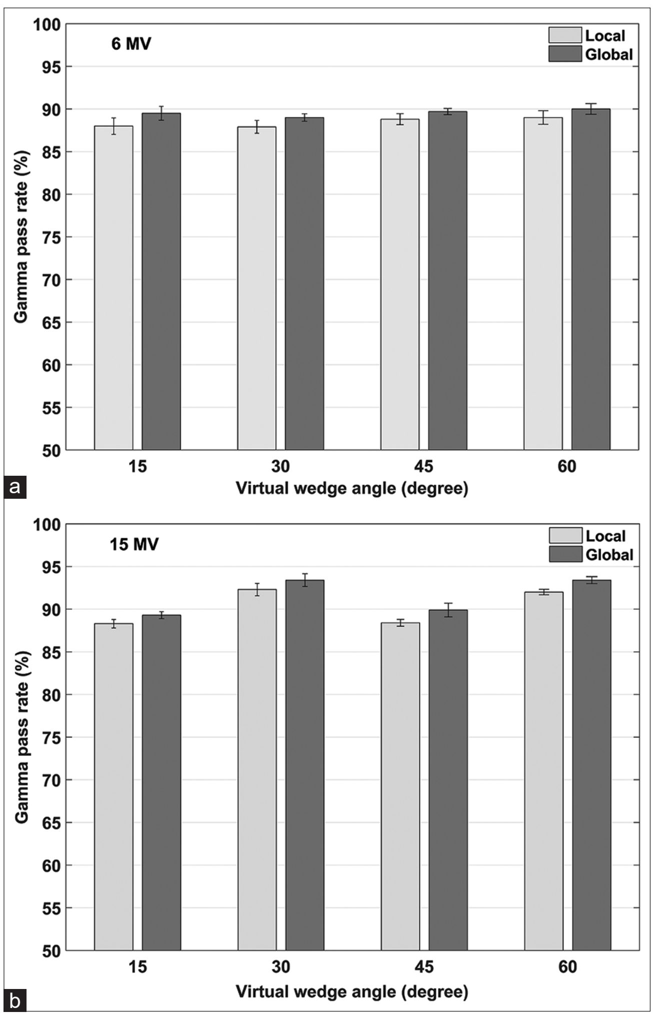

Figure 4: Gamma pass rates of modeled virtual wedges related to 8 breast plans in local and global modes for 6 MV (a) and 15 MV (b) energies using 3%–3 mm criteria

Discussion

This study examined the accuracy of CCS algorithm calculations in the presence of VW fields in the heterogeneous thorax phantom using film dosimetry. According to the obtained results, the calculated dose distribution by TPS in VW fields at 6 MV and 15 MV energies in some areas in lung and soft tissue is low and high, respectively. As shown in Figure 3b, the areas of hot and cold points in designed plan with 15 MV photon are less than that for 6 MV photon; the lower density of the lung causes the loss of lateral electron equilibrium, which leads to an increase in the range of secondary electrons and scattered photons. Therefore, the isodose curves expand a lot in the lung and chest wall areas. In other words, the VW penumbra widening calculated by CCS algorithm is higher compared to the measurements (gold standard). Finally, in cold areas of chest wall tissue (blue color regions), the TPS-calculated dose is higher than measurement. Therefore, the CCS algorithm does not accurately compute dose in low- and high-density areas containing VWs.

The global mode in dose distribution comparison has a higher acceptance rate than the local mode. Local gamma will tend to emphasize failures in high-dose gradient regions and low-dose regions, whereas global gamma will tend to cover these errors while emphasizing errors in high-dose regions of the dose distribution.[32]

It can be concluded from Figure 5a1, a2, b1, and b2 that at both energies, the extent of the calculated isodose curves is greater than the film. Figure 5a3 and b3 illustrates the isodose area difference (%) at 6 and 15 MV energies. As we can see, at 15 MV energy compared to 6 MV, the isodose level difference is higher at isodose levels above 80%.

As shown in Figure 5a2 and b2, the surface area of measured isodose curves at high-dose levels (80% and 90%) is greater for 6 MV energy compared to 15 MV energy. For 6 MV photon beam, the spread of the abovementioned isodose levels is more toward the lung. This may be due to the diminished backscattered photons arising from the low-density region of the lung to the chest wall tissue. In other words, backscattered photons from 15 MV energy have a higher penetration power and can deposit their energy in deeper chest wall tissue. Therefore, the amount of isodose shifts in chest wall tissue will be significantly greater at 15 MV energy than at 6 MV. Figure 5a1 and b1 depicts the same trend in the calculated dose distribution, although the amount of displacement in the cited isodose is less than the shifts in the measured isodose curves.

Compared to the measured curves, the 20% and 30% calculated isodose lines in Figure 5a1 and b1 extend toward the lung tissue's inner parts. The inadequate modeling of

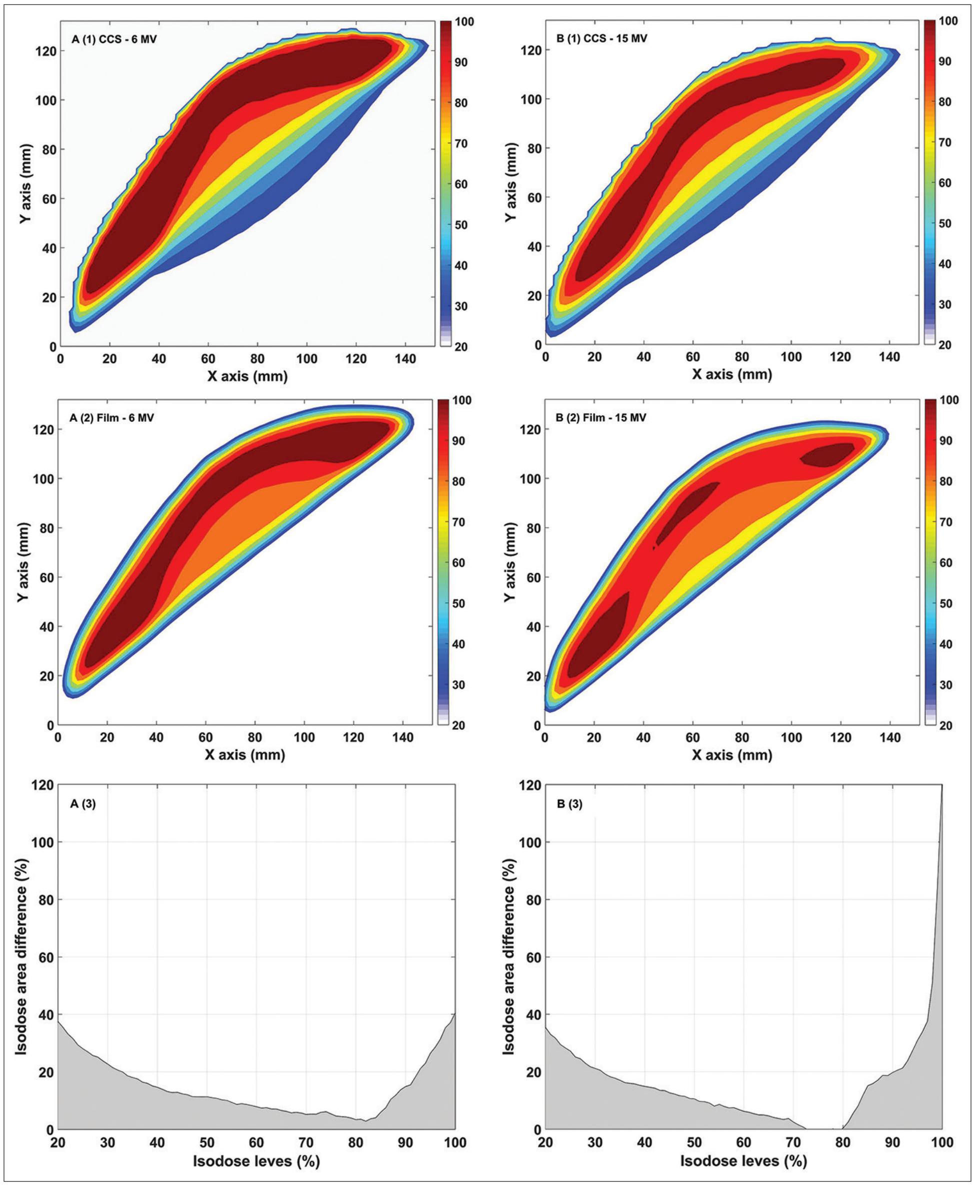

Figure 5: Dose distribution was obtained from CCS modeling and film measurements for 1VW45 at 6 MV (a1 and a2) and 15 MV (b1 and b2) energies. Isodose area difference (%) for 20%–100% isodose levels at 6 MV (a3) and 15 MV (b3) energies. CCS – Collapsed cone superposition

lateral dose profiles by TPS in penumbra regions may be a contributing factor. In other words, the calculated penumbra width in the lower isodose is greater than the penumbra width of the measured profiles.

Recent research indicates that dose calculation uncertainty with the use of different algorithms in TPS is very evident in heterogeneous areas and wedged field dose calculation that we must employ precise dosimetry methods and new algorithms for dose calculation.[34,35] Golestani *et al.* demonstrated that the validity and quality of TPS are contingent on the type of algorithms utilized at each stage of TPS. CCS was the algorithm with the good agreements between measured and calculated doses, as determined by our findings for studied wedge angles (15°, 30°, 45°, and 60°) at 6 and 15 MV energies.

Conclusions

The measured dose distribution with film and the calculated ones with CCS algorithm for VW fields in a heterogeneous medium were found to be in good agreement through the findings of this study. Despite the overestimation and underestimation observed in the dose of the soft tissue and lung in the irradiated volumes, it was observed that the VW modeling using ISOgray TPS is reasonably accurate.

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Ethical Statements

This Research was approved by the Ethics Committee of the Urmia University of Medical Sciences (Ethical Code: IR.UMSU.REC.1397.008).

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Conflicts of interest

There are no conflicts of interest.

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