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# Effects of Siemens TT-D carbon fiber table top on beam attenuation, and build up region of 6 MV photon beam

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ABSTRACT

*Aim:* This study deals with Monte Carlo simulations of the effects which the 550 TXT carbon fiber couch can have on the relevant parameters of a 6 MV clinical photon beam in three field sizes.

*Background:* According to the reports issued by the International Commission on Radiation Units and Measurements (ICRU), the calculated dose across a high gradient distribution should be within 2% of the relative dose, or within 0.2 cm of the isodose curve position in the target volume. Nowadays, the use of posterior oblique beam has become a common practice. It is clear that, in radiotherapy, the presence of the couch affects the beam intensity and, as a result, the skin dose.

*Materials and methods:* Firstly, Siemens linear accelerator validation for 6 MV photon beam was performed, and satisfactory agreement between Monte Carlo and experimental data for various field sizes was observed. Secondly, the couch transmission factor for the reference field size and depth was computed, and the skin dose enhancement by the couch was assessed.

*Results:* The largest impact of the carbon fiber couch effect was observed for the $5 \times 5\,cm^2$ field size. Such evaluation has not been reported for this couch before.

*Conclusion:* Despite providing minimal attenuation for the primary radiation, the assumption that carbon fiber couches are radiotranslucent is not valid, and the effects of couches of this type on the transmission factor, and on the skin dose should be carefully investigated for each field size and depth.



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## 1. Background

The ultimate goal in radiotherapy is to deliver the prescribed dose to the target tissue while sparing the surrounding normal organs. To achieve this goal, instead of aiming the target from one direction, it is better to rotate the gantry and bombard the target from different directions to reduce the normal tissue complications, and to strengthen the dose homogeneity in the organ of interest. Therefore, in such occasions, the passage of the beam through the treatment couch, and "couch effects" on beam parameters should be taken into consideration.

In conventional radiotherapy, treatment couches were made of a "tennis-racket type" to reduce the beam attenuation and the skin injury. However, due to the lack of strong rigidity, the tennis racket region may cause sag for patient positioning during a long time use of the couch for therapeutic purposes. To avoid couch sagging and achieve more reproducible and accurate patient positioning, a range of carbon fiber couches (CFCs) have been introduced.[1,2] Carbon fiber has properties such as high rigidity and tensile strength which allow minimal bending under loading conditions.[3–10] Based on the current literature, several investigations have reported that CFCs attenuate the radiation beam, and reduce the dose received by the target.[5,7–9,11–23]

In posterior and posterior oblique beams, when the beam passes through the couch prior to reaching the patient, it acts like a bolus material and produces secondary charged-particles. In addition, the build-up region is shifted toward the surface, resulting in skin injuries, including skin toxicity, erythema, desquamation, or fibrosis as early effects,[6,8,21,24,25] and telangiectasia as a late effect.[23]

The dose received by the most radiosensitive layer of epidermis, called a basal cell layer, is usually a criterion for the skin dose.[23] For the basal layer, an estimate of about 0.07 mm is recommended by the International Commission on Radiation Units and measurement (ICRU), and International Commission on Radiological Protection (ICRP) reports.[26,27] However, dose measurement at the depth of the basal cell layer is not practical, and evaluation at greater effective depths will overestimate the skin dose.[28] In practice, 0.1 mm depth has been frequently used as a reasonable depth for the basal layer[28,29] to report the skin dose. However, the skin is in the region of "beam build-up" with a high dose gradient and non-electronic equilibrium condition, where an accurate dose measurement is difficult to perform, if not impossible.

A range of dosimeters, such as TLDs, diodes, MOSFETs, plane-parallel ionization chambers, diamond detectors, and radiographic films are usually used to measure radiation dose at a build-up region, or near the skin,[23] but dose evaluation at high dose gradient regions may not be very reliable due to the presence of significant uncertainties. Monte Carlo (MC) dose calculation method can be addressed as a suitable tool for "double-checking" for these measurements.

Powerful MC-based computational codes have been widely used in radiation oncology, and their outcomes have been validated successfully by measurements.[30] One of the features of the MC codes is to simulate the physics processes of radiation energy deposition in a medium, and to track the possible interactions, on the basis of the cross-section libraries they have been provided with.[31] MCNPX is a general-purpose Monte Carlo N-Particle radiation transport code that can track many particles over a broad range of energies. This code allows the development of a detailed three-dimensional (3D) model of a linear accelerator treatment head, and dose calculations in complex geometries and materials.[32] This study uses the MCNPX (2.6.0) code method to assess the perturbing effects of the 550 TXT carbon fiber couch for 6 MV photon beam of a Siemens Primus Plus linear accelerator. Since the geometries and materials of different treatment couches are not exactly the same, the effect of each table top should be evaluated separately. Our search in relevant literature shows that nothing similar has been done so far on this couch model.

Our first task was to validate the 6 MV photon beam simulation of the Siemens Primus Plus linac. To achieve this aim, the MC calculations were compared with experimental measurements, using the gamma function.

Gamma function developed by Low et al.[33] is a method for comparison of the "*reference*" and evaluated dose distributions. In this method, the adopted criteria are defined as the dose difference (DD), and the distance to agreement (DTA). These variables are defined in terms of percentage dose difference (%), and spatial tolerance (maximum allowable separation of isodose lines in mm) between two given dose distributions.[34] The second task was to quantify variations in the carbon fiber transmission and attenuation factors as functions of depth and field size. Finally, the CFC effects on the skin dose were assessed.

## 2. Materials and methods

### 2.1. *Monte Carlo simulation*

In this study the MCNPX (version 2.6.0, Los Alamos) radiation transport Monte Carlo code was used to simulate 6 MV photon beam of Siemens Primus Plus linear accelerator, and the 550 TXT couch with TT-D carbon fiber table top (Siemens Medical Solution, Erlangen, Germany).[32]

Beam modeling was the first task to obtain a phase space (PS) file on which the particle flux above the collimator is scored. The main structural components of the linac in photon beam are: (a) multi-layer target; (b) tungsten primary collimator; (c) stainless steel (SST) flattening filter; (d) mirror; (e) ion chamber; and (f) X and Y tungsten jaws. The Visual editor software was used for visual creation and graphical display of the input files of the MCNPX. The software read both 2D and 3D Computer Aided Design (CAD) files, allowing the user to electronically generate a valid MCNPX input geometry.[35] The schematic diagram of the linac's head components and the phantom, drawn by the Visual editor software, is illustrated in Fig. 1.

In order to verify the validity of the simulation procedure, the percentage depth dose (PDD) curves were calculated for three field sizes. An electron source was positioned at a distance of 100 cm from the water phantom surface. To achieve the best match between MC calculations and measurements, the conditions under which dose calculations are done and experimental measurements are performed, should be as close together as possible.[36] The PDD and beam

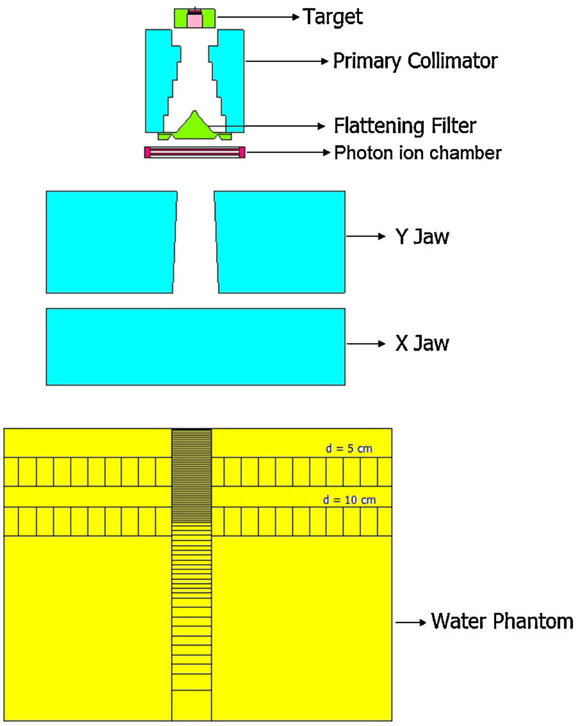


**Fig. 1 – Monte Carlo simulation of the Siemens Primus Plus head and phantom.**

profile measurements have usually been done in a MP3-M PTW water phantom with PTW Semiflex ionization chambers 31010 at a radiotherapy and oncology center. The phantom size being 50 × 50 × 50 cm$^3$; the MC phantom was also defined with these dimensions, and the source to surface distance (SSD) was set to be 100 cm for both setups.

As shown in Fig. 1, for depth-dose calculations, a cylinder with a radius less than one-tenth of each field size along the central axis of the beam was defined.[37] In the build-up region, which is a high dose gradient area, the cylinder was divided into scoring cells of 1 mm height. For larger depths, thicker scoring cells were considered. Two types of MC programs were run to simulate the 6 MV beam. The initial program was run for $2 \times 10^9$ particle histories to produce a PS file. This space was defined at a plane before raising the collimator jaws; the surface source write (SSW) card was utilized here. Particles assembled in the PS file were then re-used as an input file for dose calculations in the phantom; the surface source read (SSR) card was used for this purpose. The second type programs were run for the 5 × 5, 10 × 10, and 20 × 20 cm$^2$ field sizes. *F8 tally (energy deposition in units of MeV per photon) was used to score the photon dose distribution, with the inclusion of secondary electrons and electron contamination, in each voxel of the phantom. To obtain the Monte Carlo dosimetric output per photon, in units of MeV/photon, the MC results were divided by the mass of the corresponding voxels.[38] The track length estimation of energy deposition (F6) was employed to get the mass of the scoring cells.

To reduce MC calculation uncertainties, several variance reduction techniques have been used. For example, the energy cut off for photons and electrons[39,40] were set at 10 and

**Table 1 – Composition and thickness of various layers of the 550 TXT couch.**

| Material component | Mass density (g/cm$^3$) | Thickness (mm) |
|---|---|---|
| Carbon fiber layers | 1.7 | 1.8 |
| Inner material (Rohacell 71IG foam) | 0.075 | 61.4 |

1 keV, respectively. The photon and electron "*importance*" in all scoring cells were considered to be 50. In addition, each MC program was run with different seed numbers more than once by defining DBCN card in the input file. Then, the average values of the MC calculations were established. The total uncertainties for MC calculations were less than 1%.

As shown in Fig. 1, for beam profile calculations in the water phantom, two cylinders of 2 mm radius were considered at 5 and 10 cm depths, respectively, perpendicular to the beam. These cylinders were partitioned into scoring cells of 2 mm thickness. The energy cut off, cell importance, and SSR card were similar to those of PDD calculations. To obtain beam profiles, the F4 tally (flux in units of photons cm$^{-2}$) was used. To convert the F4 tally output values to photon dose, the photon flux to dose rate conversion factors were used from Appendix H (Table H-2) of MCNPX 2.6.0 manual.[32] The uncertainties in MC calculations were less than 1% at the flat region, and 3% at the penumbra region. To check the accuracy of the simulations, the MC results were compared with the experimental data using the gamma function. Special gamma function software has been developed by DOSISoft company (Cachan, France). The software (Gamma_index.exe) works in a Gnuplot software environment (version: 4.4 patch level 3, Geeknet Inc. Fairfax, VA). Dose difference (DD) criterion and distance to agreement (DTA) were defined at 3.0% and 3.0 mm, respectively.

Next, the effect of 550 TXT couch with TT-D carbon fiber table top on beam attenuation, and the skin dose of the 6 MV clinical photon beam for the 5 × 5, 10 × 10, and 20 × 20 cm$^2$ field sizes was investigated. The couch has a homogeneous non-meshing "sandwich" design with a uniform thickness. The sandwich design is a Rohacell 71IG foam covered by two carbon fiber layers. The material specifications, and the components' thicknesses used for the MC modeling of the couch are listed in Table 1.

### 2.2. *Skin dose enhancement and beam attenuation*

According to the report of task group No. 176 of the American Association of Physicists in Medicine (AAPM), the skin dose is referred to the ratio of the absorbed dose at 0.1 mm depth to the maximum absorbed dose along the central axis of the beam.[28,29] To calculate the skin dose, a voxel with thickness of 0.1 mm was defined, while the couch is in direct contact with the surface of the phantom. Since the skin dose on the central axis is a function of various parameters, such as beam energy, field size, presence of the beam-modifying devices, SSD, setup and beam obliquity,[41] this study concentrates on the effect the field size has on skin dose enhancement for the 5 × 5, 10 × 10, 20 × 20 cm$^2$ field sizes. As electrons have an important role in energy absorption by the skin, the electron energy cut off

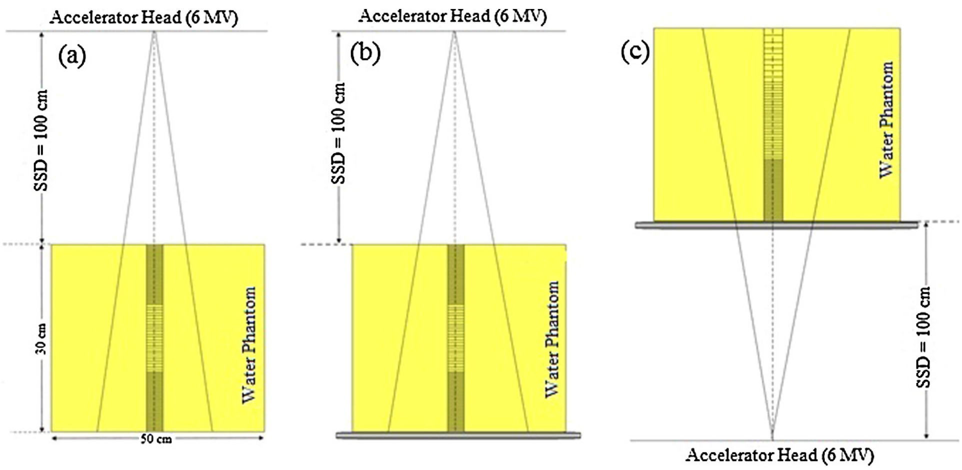


**Fig. 2 – Schematic representation of Monte Carlo simulation set-up for evaluation of couch effect on radiation beam. (a) Open beam; (b) anterior field; (c) posterior field.**

of 1 keV was chosen to achieve the skin dose as accurate as possible. To reduce the high MC calculation uncertainties due to the smallness of the cells, several MC programs with different seed numbers were run for each simulation case. For the 10 × 10 and 20 × 20 $cm^2$ field sizes, each program was run five times. Since the calculation uncertainties for the 5 × 5 $cm^2$ field size were not acceptable, due to the small radius of the cylinder defined in the central axis (0.5 cm), 16 programs were run to achieve more precise results.

To evaluate the effects of the carbon fiber couch on the skin dose and beam attenuation, two different scenarios without a couch (open beam (Fig. 2a)), and with a couch (in such a way that the radiation field normally passed through the carbon fiber couch (Fig. 2c)) were run.

In treatment with 0° gantry angle, the couch produces backscattered radiation, and this may change at the exit dose areas. This effect was also evaluated (Fig. 2b). For MC evaluation in this case, the PS file from the previously described case was used. Other parameters, such as SSD, cell importance, photon energy cut off, and tally types were considered to be the same as in the previous cases.

As mentioned before, one of the effects of the treatment couch that should be taken into consideration is the beam transmission factor. This factor was calculated as the ratio of the absorbed dose with (gantry angle of 180°), and without carbon fiber couch (open beam) along the beam's central axis for various treatment depths.[4] In addition, the attenuation factor is defined as [(1 − transmission factor) × 100],[9,19,20] and depends on the field size, the photon beam path length in the couch, and photon beam energy.[19,22]

**Table 2 – Displacement (cm) in depth of maximum dose due to the presence of CFC.**

| Field size ($cm^2$) | $\Delta d_{max}$ (cm) |
|---|---|
| 5 × 5 | 1.10 |
| 10 × 10 | 0.83 |
| 20 × 20 | 1.30 |

## 3. Results

### 3.1. *Monte Carlo simulation*

The gamma function method comparisons of the MC and the measured PDD curves and dose profiles are shown in Figs. 3 and 4, respectively.

### 3.2. *Skin dose enhancement*

In the posterior field, comparisons between the PDD curves for the "open" beam (when the carbon fiber couch is not in the beam path), and for the case in which the couch is present, are shown in Fig. 5 for different field sizes. These comparisons were carried out by focusing on the skin dose, couch transmission, and couch attenuation. Practically, the exact position of $d_{max}$ is difficult to find due to the errors associated with the measurements, and because of the "regional saturation" of the build-up, etc. However, these errors were reduced to less than 1% in MC calculations by running a number of programs. The PDD shifts are listed in Table 2. The skin dose evaluations for different field sizes are listed in Table 3. The

**Table 3 – Skin dose in various field sizes for 6 MV photon beam with and without CFC in the posterior field.**

| Field size ($cm^2$) | Skin dose (%) | | Diff. (%) | Percentage increase in skin dose (%) |
|---|---|---|---|---|
| | Without CFC | With CFC | | |
| 5 × 5 | 13.68 ± 0.82 | 91.68 ± 3.67 | 78.00 | 670.17 |
| 10 × 10 | 18.92 ± 0.76 | 97.35 ± 3.89 | 78.43 | 514.53 |
| 20 × 20 | 28.76 ± 0.52 | 99.53 ± 1.39 | 70.77 | 346.07 |

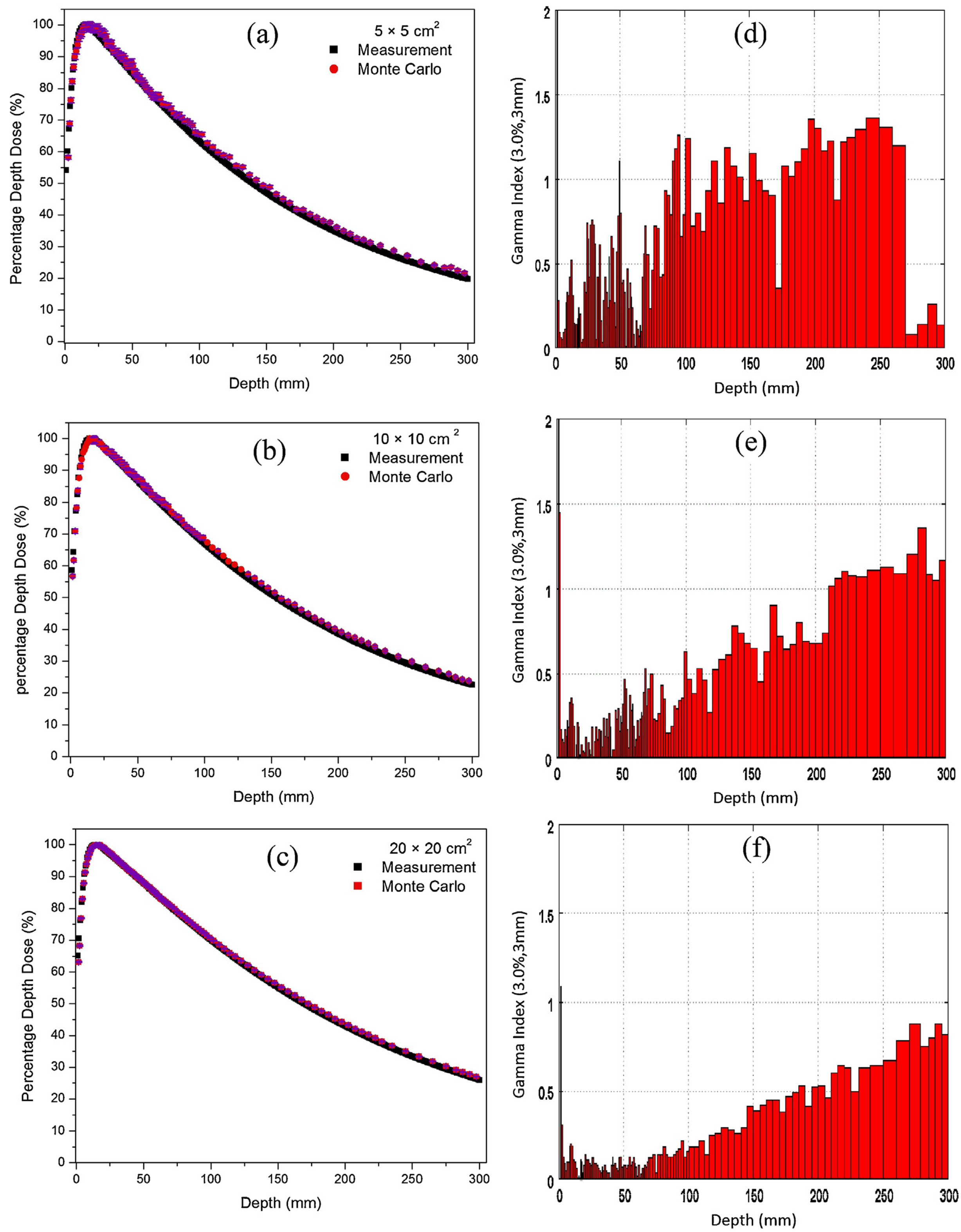


**Fig. 3 – (a–c) Calculated and experimental percentage depth dose (PDD) values for 6 MV photon beam; and (d–f) their corresponding gamma function results. The error bars in MC calculations are shown in violet.**

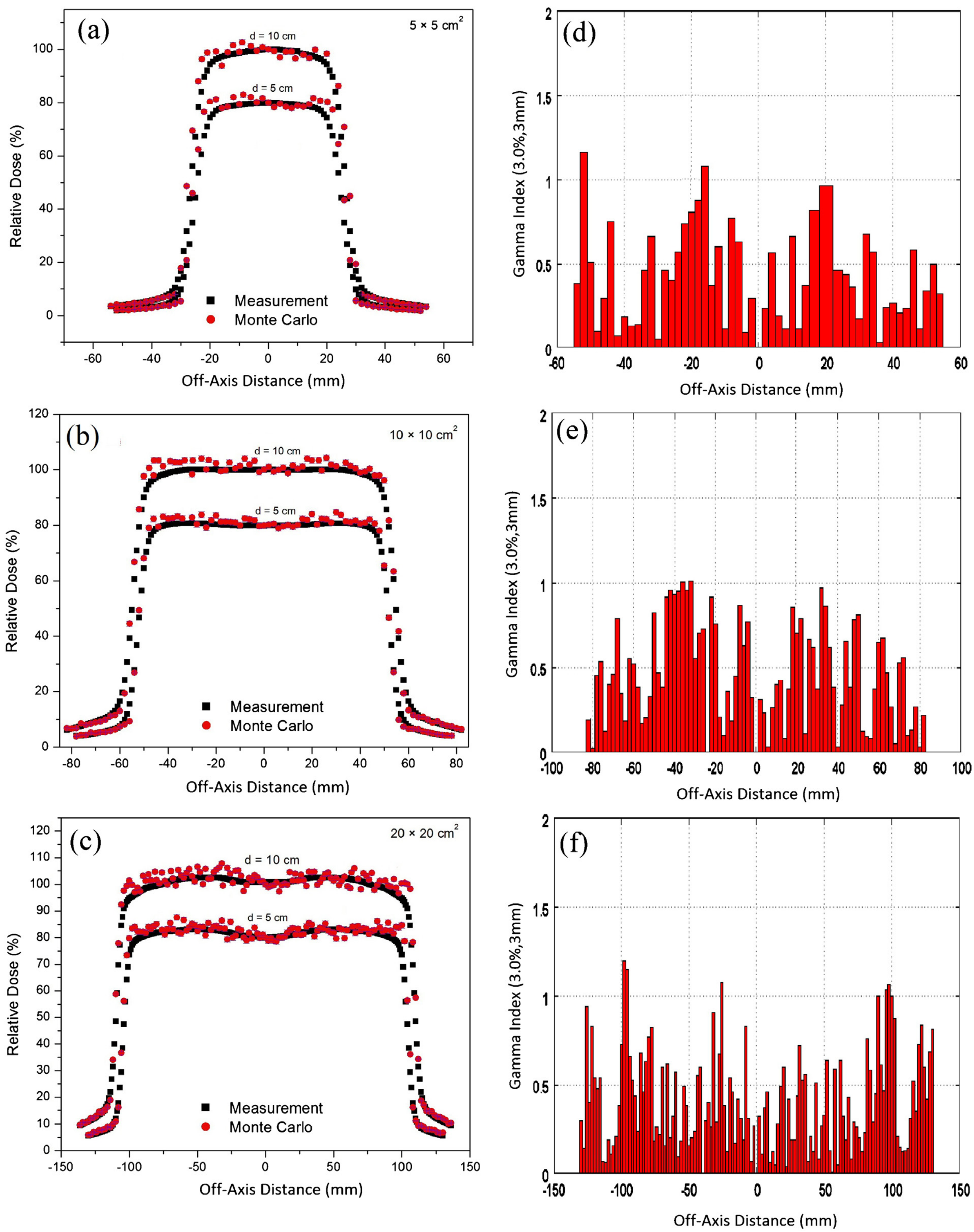


**Fig. 4 – (a–c) Calculated and experimental dose profiles for 6 MV photon beam; and (d–f) their corresponding gamma function results. The error bars in MC calculations are shown in violet (just one series of gamma function are shown for comparison).**

**Table 4 – Relative and absolute skin dose in various field sizes for 6 MV photon beam with and without CFC in the anterior field.**

| | Field size ($cm^2$) | Skin dose (%) | | Diff. (%) | Percentage increase in skin dose (%) |
|---|---|---|---|---|---|
| | | Without CFC | With CFC | | |
| Relative dose | 5 × 5 | 17.21 ± 0.69 | 20.61 ± 1.23 | 3.40 | 119.75 |
| | 10 × 10 | 20.18 ± 0.40 | 23.51 ± 0.94 | 3.33 | 116.50 |
| | 20 × 20 | 22.25 ± 0.09 | 25.37 ± 0.10 | 3.12 | 114.02 |
| | Field size ($cm^2$) | Skin dose (cGy) | | Diff. (%) | Percentage increase in skin dose (%) |
| | | Without CFC | With CFC | | |
| Absolute dose | 5 × 5 | 26.63 ± 0.65 | 32.16 ± 0.90 | 5.53 | 120.76 |
| | 10 × 10 | 29.46 ± 0.35 | 34.54 ± 0.63 | 5.08 | 117.24 |
| | 20 × 20 | 31.52 ± 0.33 | 35.87 ± 0.35 | 4.35 | 113.80 |

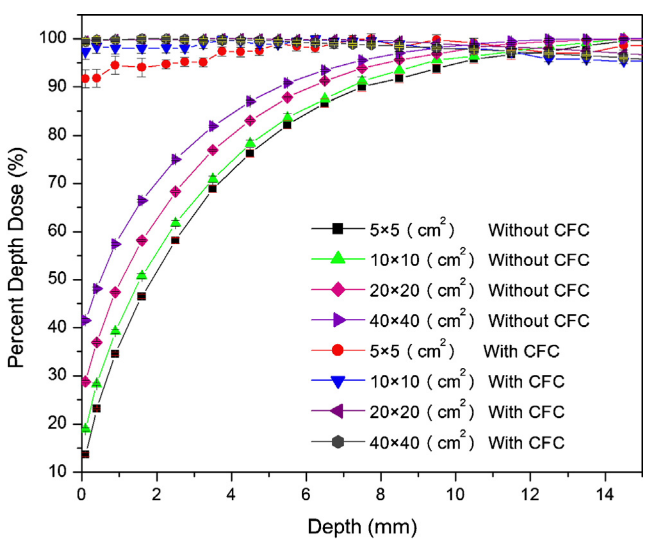


**Fig. 5 – PDD curves with and without presence of CFC for various field sizes in 6 MV photon beam. The error bars obtained from MC calculations are colored.**

percentage increase in the skin dose due to the presence of the carbon fiber couch was calculated as the ratio of the fractional skin doses with, and without, the presence of the carbon fiber couch.

### 3.3. *Couch transmission and attenuation*

The variation of couch transmission factor with treatment depth and field size is illustrated in Fig. 6a. Furthermore, couch attenuation factors as functions of radiation field size are also illustrated in Fig. 6(part (b)). In the anterior field, the comparison between PDD curves for the open beam, and in the presence of the carbon fiber couch for different field sizes are shown in Fig. 7. Comparisons indicate that the carbon fiber couch acts like a backscattering agent, and increases the exit dose. Therefore, attachment the data in Table 4, patient's back receives additional dose due to the proximity of the carbon fiber layer. In this table, absolute and relative skin dose values are reported. The absolute dose values in this table were calculated based on prescription dose of 100.00 cGy to the 10 cm depth in the water phantom. It should be noted that

**Table 5 – The percentage of backscattered dose from the 550 TXT carbon fiber couch in the anterior field.**

| Field size ($cm^2$) | Percentage of backscattered dose (%) |
|---|---|
| 5 × 5 | 19.75 |
| 10 × 10 | 16.50 |
| 20 × 20 | 14.02 |

for each field size the dose of 100.00 cGy was prescribed for the same field size. Contribution from the backscattered radiation caused by the carbon fiber layer is listed in Table 5.

## 4. Discussion

On the basis of the 3% criterion for DD, and the 3 mm limit for DTA, little differences are seen for the 5 × 5 $cm^2$ field size. As one usually expects higher uncertainties associated with smaller field sizes, it is valuable to check the level of agreement between the experimental data and MC calculations for the reference field size (10 × 10 $cm^2$). As shown in Fig. 3(part (b)), this expectation seems to be reasonable. Since the MC uncertainties are relatively low, the error bars shown in violet color in this figure cannot be seen.

According to Fig. 5, it is obvious that the carbon fiber couch shifts the buildup curve toward the surface of the phantom. In addition, for all field sizes, the "*parasitic*" electrons, generated by the carbon fiber couch, increase the skin dose, although, with a sharp fall-off. For deeper points, the dose received by the patient decreases due to the couch attenuation. Table 3 shows that when the field size becomes lager, the skin dose rises by almost 15% due to the radiation scattering in the linac's head, and in the air. As for the presence of the couch, it can be seen that it is more harmful to the skin for smaller field sizes. For instance, the skin dose increases about sevenfold for the 5 × 5 $cm^2$, fivefold for the 10 × 10 $cm^2$, and threefold for the 20 × 20 $cm^2$ field size. Similar trends have also been reported by Meydanci and Kemikler,[23] for Mulheim-Karlich couch, and Wilson et al.[8] for Varian Exact™ couch.[8,23]

The results show that the treatment couch has an effect on beam attention and skin dose in radiotherapy with a 6 MV photon beam. While this effect may have an impact on the accuracy of dose delivery in radiotherapy, it is not currently taken into consideration in some commercially available TPSs. Therefore, it is recommended that it be considered to achieve more accurate dose delivery to the target volume and a better

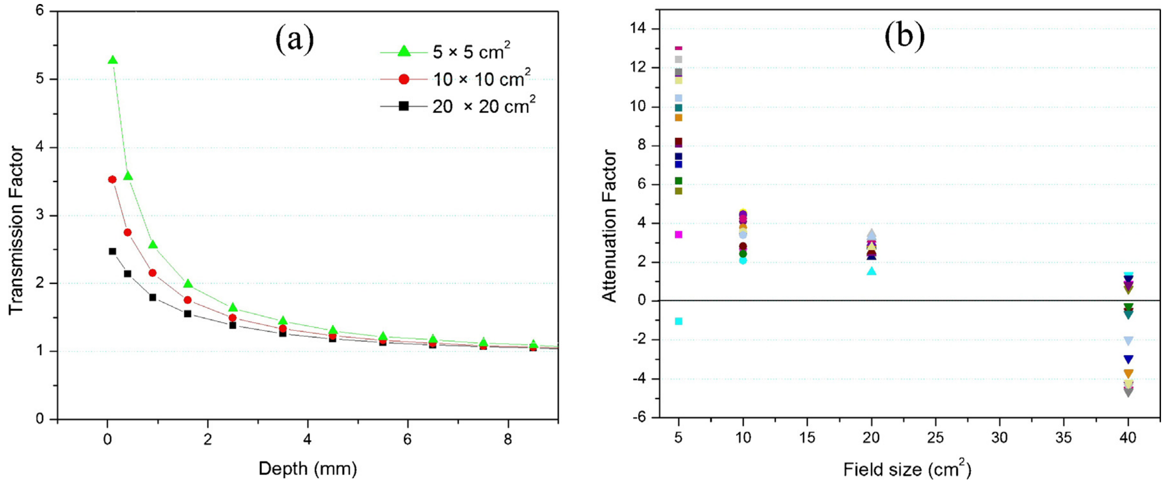


**Fig. 6 – (a) Couch transmission factor as a function of treatment depth for various field sizes, (b) couch attenuation factor as a function of field size (each treatment depth is shown with a different color).**

treatment outcome. The attenuation factors obtained in this study can be used in treatment planning calculations to take into consideration the couch effect on beam attenuation. For those TPSs for which it is not acceptable to define a transmission factor, it is feasible to include the carbon fiber couch as an organ and to introduce the Hounsfield numbers of the carbon fiber couch materials. It should be noted that the results obtained in this study are geometry specific and can be applied only for the 550 TXT couch for Siemens linacs. For other couch models, similar specific factors should be calculated.

According to the data presented in Table 3, the 550 TXT carbon fiber couch increases the skin dose from 13.68% to 91.68% for the $5 \times 5\,cm^2$; from 18.92% to 97.35% for the $10 \times 10\,cm^2$; and from 28.76% to 99.53% for the $20 \times 20\,cm^2$ field. However, these enhancements were reported to be lower in a number of previous studies on other couch types.[8,21,23] For instance, Meydanci and Kemikler[23] reported the surface dose enhancement due to the presence of Reuther Medizin Technik, Mulheim–Karlich couch with 6 MV photon beam of a Siemens Oncor linac which had an Intensity Modulated Radiation Therapy (IMRT) option. Their results showed increases in surface dose from nearly 7.5% to 63% in $5 \times 5\,cm^2$; nearly 15% to approximately 75% in the $10 \times 10\,cm^2$ field size; and 29% to 80% in the $25 \times 25\,cm^2$ field size. Wilson et al.[8] found that the skin dose at 0.5 mm depth relative to the dose at $d_{max}$ was increased from 30% to 94% for 6 MV beam of the Varian Clinac iX linear accelerator. In addition, Smith et al.[9] examined the effect of the iBEAM evo CFC for 6 MV beam of an Elekta (Beam Modulator) linear accelerator. In their investigation, the skin dose had an increase from 17.9% to 91.8%. Since the type of linac, the couch design, the depth of skin dose calculation and the phantom design differ between the present study and the other studies, the change in the skin dose due to the presence of the couch cannot be compared precisely. A reason for the differences between this study and the others may be the difference in the depth of skin dose estimation. In this study, the skin dose is referred to the ratio of the absorbed dose at 0.1 mm depth to the maximum absorbed dose along the central axis of the beam ($d_{max}$). The choice of this depth for skin dose calculation was based on previous reports on this field.[28,29] Since the skin dose at this depth cannot be easily measured, and it is associated with high uncertainties, most of the previous studies evaluated this quantity at larger depths, say, around 1 mm.[8,23] The material used in the phantom structure and the shape of the phantom can be other reasons. For more investigation in this field, performing measurement of the skin dose in the presence of various couches with the same measurement set-ups is recommended. However, it should be noticed that measurements at this depth are associated with practical difficulties. In summary, based on the results of these studies, the increase in the skin dose due to couch is remarkable, and should be taken into account in clinical practice of radiotherapy.

Fig. 6(part (a)) shows a considerable inverse relationship between the transmission factor and the treatment depth below 0.5 cm; thereafter, the transmission factor is constant. As for the field size effect, it can be seen that not very deep under the skin, larger field sizes have lower couch transmission factors, and, as a result, the field size effect for depths of ~7 mm and beyond could be ignored altogether. A single couch transmission factor which is usually reported for the reference field size ($10 \times 10\,cm^2$) and the reference depth ($d_{max}$)[42] was found to be 0.96 in this study. For the $5 \times 5\,cm^2$ field size, the couch attenuation factor behavior is illustrated in Fig. 6(part (b)). The maximum attenuation factor variation for large field sizes is about 5%. However, it increases up to 18% for the $5 \times 5\,cm^2$ field size.

## 5. Conclusion

The impact of treatment couch on beam attention and skin dose enhancement should be taken into consideration in treatment planning systems (TPSs). This effect is not currently given a weight in some commercially available TPSs, to achieve

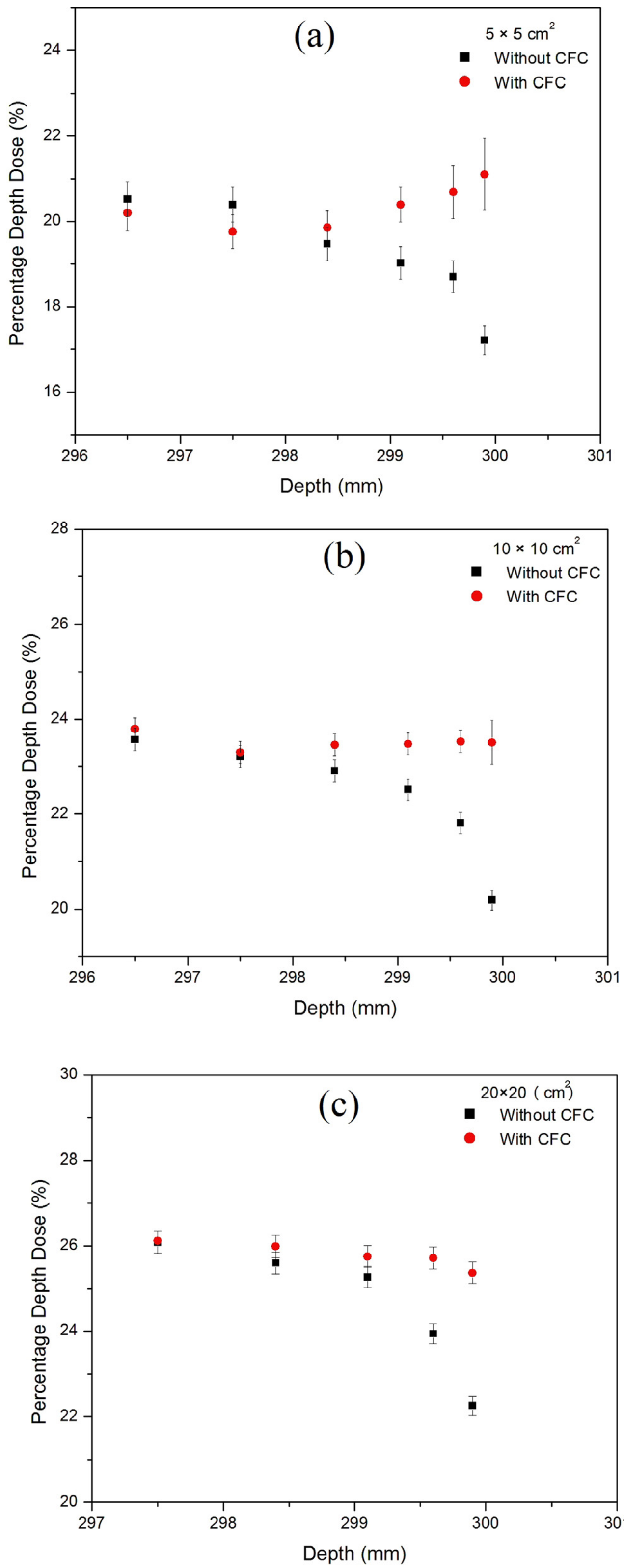


**Fig. 7 – PDD curves with and without carbon fiber couch for (a) 5 × 5 cm$^2$, (b) 10 × 10 cm$^2$, (c) 20 × 20 cm$^2$ field size. Error bars obtained in MC calculations are also shown in black.**

a more accurate dose delivery to the target volume and a better treatment outcome.

The attenuation factors obtained in this study can be used in treatment planning calculations to take into consideration the couch effect on beam attenuation. However, not all of the current TPSs accept a transmission factor; therefore, for these TPSs, it is possible to include the carbon fiber couch as an organ in order to take into account the Hounsfield numbers of the carbon fiber couch materials. The impact of a gantry angle on the beam attenuation caused by the couch is worth considering as a subject for future investigation in this field.

## Conflict of interest

None declared.


## Financial disclosure

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