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Measurement and Evaluation of the Impact of a Carbon Fiber Couch in Radiation Oncology

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ABSTRACT

In radiotherapy treatment couches, rigid carbon fiber couch inserts reduce set-up errors caused by couch sagging. These inserts have been described in several studies as radio-translucent with negligible radiation field attenuation. The majority of these tests were carried out with the radiation field normally incident on the center of the couch, and there appears to be no evidence in the literature of the effect of the thickest region (edge of the couch) on the attenuation and dose distribution during external beam radiotherapy. In this study, we evaluated and improved the calculated dose attenuation for the under-couch fields to reduce the skin surface dose.

Using the difference between the measured and calculated attenuation doses obtained using the ion chamber and the "TPS" treatment planning system; an algorithm that identifies the influence of couch attenuation on patient dose verification. According to our results, the attenuation is affected by the gantry angle, where the maximum attenuation was at 180°, the angle at which the couch attenuates the 6 MV photon beam by 9.3 % for 10×10 cm^2 field sizes, while the attenuation at 160^0 and 140^0 was less where the lowest attenuation recorded at 140^0 at which angle the couch attenuated the ٦ MV photon beam by 2.4. It would appear, therefore, that Connexion central opening couch with posterior beams results in significant decreases in the dose delivered to the target.

The measured data were compared to the calculated values from the Monaco Treatment Planning System, and computed using the Monte Carlo (MC) and Collapsed Cone (CC) algorithms. The most minor agreement was observed at an angle of 180^0 between the calculated and the measured attenuation for the 5 x 5 cm^2 field size with 6 MV and 10 MV photon beam energy where the difference was 5.3 % and 4 % for the MC and CC algorithm, respectively. Excellent agreement was observed at an angle of 160 between calculated and measured attenuation with the field sizes of 10 x 10 cm^2 for 6 MV, in which the difference (lose dose) was ±1.5 %.

INTRODUCTION

In radiotherapy, high conformal distribution with high dose concentration is the goal, while preserving the adjacent organs at risk [1], Although the accuracy of the TPS can be ensured by adjusting the company's computer model of the linear accelerator (LINAC), many factors related to the design of the radiotherapy plan influence the dose delivery implemented, such as the lying system therapy, in particular, modern radiotherapy techniques such as intensity-modulated radiotherapy (IMRT), image-guided radiotherapy (IGRT), and volumetric arc therapy (VMAT) use gantry rotation and irradiate the target in different directions [2-4]. As such, it becomes complicated to investigate the effect of the Connexion central opening couch on dose distribution.

The widely used LINAC tabletop system is rigidly connected to the carbon fiber treatment couch via a movable base, which has advantages over other materials commonly used in RT devices in terms of hardness, lightweight, and radiation attenuation [5]. These characteristics make carbon fiber materials ideal for patient support assembly.

Even though carbon fiber couches are less attenuating than conventional solid steel couches [6,7], these new couches produce greater skin dose and dose attenuation than old tennis racket inserts on conventional couches [8-10], a dose error remains which can cause a potentially serious impact on skin-sparing [11]. If the increased attenuation is not accounted for this can result in an underdosage of the target volume. However, the TPS does not take into account the influence of the actual tabletop on the calculation of the expected dose. In particular, the position of the computed tomography (CT) scan of the treatment table was not determined; Therefore, the plan creator cannot add the actual treatment couch to the plan image to be computed on TPS. Combined with treatment fractions at different sites, this uncertainty factor will always affect the dose delivery accuracy of the actual treatment plan.

The attenuation factor for 6 MV X-rays passing vertically through the couch is 2.4 %, which meets the physical requirements of IMRT [12]. This requirement cannot be met by all radiation fields, however. It is estimated that radiation fields with different gantry angles, different field sizes, and different energies will attenuate by approximately 4.14 %. The majority of treatment plan creators at the moment employ real measurement data or incorporate a virtual treatment couch mode into the treatment plan to correct the effect of dosage attenuation. Even with the addition of the TPS unreal tabletop model, the dosage impact of the couch on the irradiation field cannot be accurately established due to violations related to positioning errors and a lack of information about the actual position of the couch tops on the planned CT images.

Several studies have been published that describe the attenuation of various types of carbon fiber couches. McCormack° [10] found that the 6 MV photon beam is attenuated by 9 % caused by novel carbon fiber couch for a gantry angle of 70. Poppe [13] reported that the 6 MV beam at 150° on the Primus Digital Mevatron Linear was attenuated by 2.7 % to 6.4 % and the 10 MV beam by 2.3 % to 4.9 %. Njeh [14] also reported that for normal incidence, a beam attenuation of 3.4 % to 4.9 % for 6 MV photon and 0 % to 0.7 % for 18 MV photons for the BrainLAB imaging couch top was observed. Spezi and Ferri [15] evaluated a Siemens IGRT tabletop and found that for a 10 cm × 10 cm field size, a 6 MV photon was attenuated by 2.1 %. Numerous other works of literature have attested to the fact that couch attenuation affected surface dose and depth-dose curves with various intensity beams [11,16]. More recently, investigations have shown that as the beam oblique increases, there is increasing attenuation of the photon beam. McCormack [10] has shown that for a 6 MV beam, transmission values for a Sinmed BV Posisert carbon fiber sheet range from 98 % at normal incidence to 91 % at 70° incidence. Therefore, it is crucial to thoroughly investigate the effects of a carbon fiber treatment table on dose distribution in practice. However, there does not seem to be any evidence in the literature for the impact of the Connexion central opening module on the beam attenuation region and dose distribution.

The objective of the current study was therefore to:

Evaluate and improve the calculated dose for the under-Connexion Central Opening couch fields to reduce the skin surface dose using the difference between the measured and computed attenuation doses obtained using an ionization chamber, and treatment planning system (TPS) algorithm to identify the influence of Connexion central opening couch attenuation on patient dose verification. In this work, we measured the attenuation, caused by the Connexion central opening couch, Then the towing algorithms of the treatment planning system "TPS", (CC) and (MC) algorithm, are used to calculate, to evaluate the impact of Connexion central opening couch on dose attenuation and to improve the calculations of the couch using TPS to deliver better therapeutic dose distribution for patients.

MATERIALS AND METHODS

The Connexion Central Opening Module (Figure 1) is a Carbon fiber (CF) sandwich with foam (F), 52 mm Thickness at the treatment/imaging field (Carbon fiber outer shell top: 1.2 mm, Carbon fiber outer shell bottom: 3.2 mm, and Foam core: 47.6 mm) and has CF 1.2 g/m^3 and F 0.02 g/cm^3 electron density. CF thickness increases to 0.45 cm toward the edges of the couch.

Figure 1. Connexion Central Opening couch Module

Measurements achieved on Elekta Synergy Platform LINAC, at South Egypt Cancer Institute on Assiut University, which can produce three photon energies (6, 10, and 15 MV) and four electron energies (4, 9, 12, and 18 MeV). It can treat fields ranging in size from (0.5 cm × 0.5 cm) up to (40 cm × 40 cm) at 100 cm source–to–skin distance (SSD)

For all dose calculations in this study, we used Monaco TPS (version 5.11) as Monte Carlo (MC) and Collapsed Cone (CC) calculating algorithms.

Couch attenuation measurement: The attenuation was determined using a PTW30012 ion chamber with water-equivalent RW3 slap phantom (Figure 2) and a radiation treatment planning system by using two calculating algorithms (Collapsed Cone, and Monte Carlo). The measured and calculated beam attenuation were compared. We examined the impact of gantry angles on transmission through the Connexion couch with different photon beam energies and field sizes. In the beginning, the angle was set at 180°, source-detector distance (SDD) at 100 cm, 10 cm depth, and centralized beam at maximum couch thickness. Hence, the angle of incidence θ, on the Connexion couch was 180° (Radiation passes through the thicker part of the couch). Afterward, the angle was rotated counterclockwise in 20° increments toward the couch plane (at 160° and 140° gantry angles) (Figure 3).

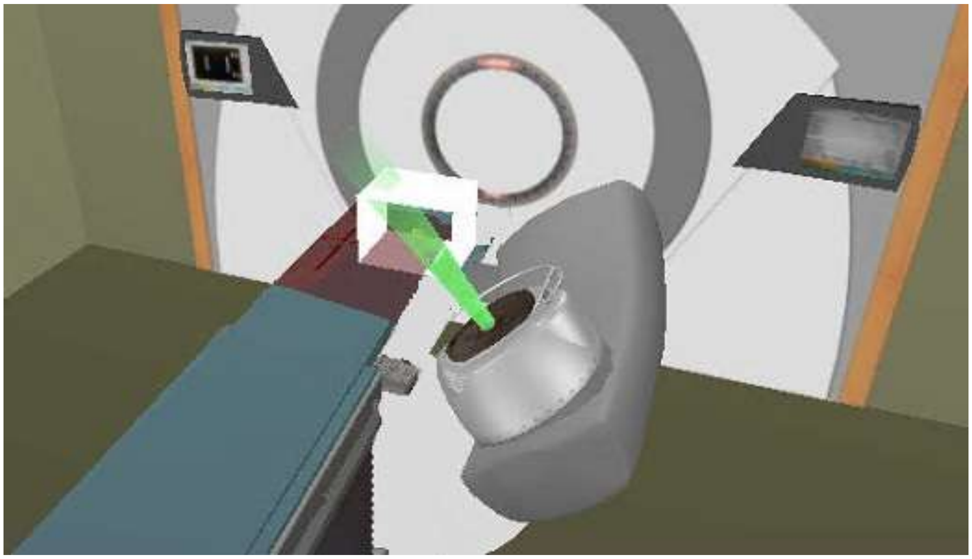

Figure 2. Experimental setup attenuation dose measurements, water-equivalent RW3 slap phantom incorporates with Farmer PTW30012 ionization chamber. for different photon energies, field sizes, SAD 100 cm, and gantry angles 180^o, 160^o, and 140^o

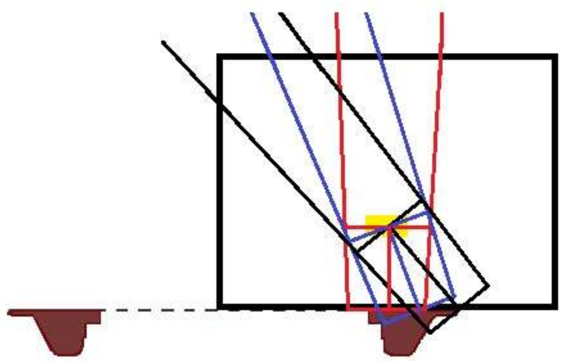

Figure 3. Illustration showing the junction lengths of posterior-to-the-couch beams based on the angle of the gantry with respect to the isocenter [17].

RESULTS

The attenuation measurements for Connexion central opening couch for the three gantry angles (180, 160, and 140) measured for the four field sizes 5 × 5, 10 × 10, 15 × 15, and 20 × 20 cm^2 are represented in Figure 3. The output measurements show that the attenuation is field size, gantry angle, and energy-dependent. Where the attenuation values measured were highest at 180° (Figure. 4) – at which angle the couch attenuated the 6 MV photon beam by 10.5 % for the 5 × 5 cm^2, 9.3 % for the 10 × 10 cm^2, 8.9 % for the 15 × 15 cm^2 and 8.6 % for the 20 × 20 cm^2 field sizes. Similarly, a 10 MV photon beam was attenuated by 8.6 % and 7.7 % for the 5 × 5 cm^2 and 10 × 10 cm^2, respectively, and 7.3 % for both 15×15 cm^{2}and 20×20 field cm^2 sizes, furthermore, a 15 MV was attenuated by 7.4 %, 6.6 %, 6.5 %, and 6.4 % for 5 × 5 cm^2, 10 × 10 cm^2, 15×15 cm^{2}and 20×20 cm^2 field sizes, respectively. While the attenuation at 160^0 and 140^0 was less where the lowest attenuation was recorded at 140^0 at which angle the couch attenuated the 15 MV photon beam by 1.5 % (Table 1).

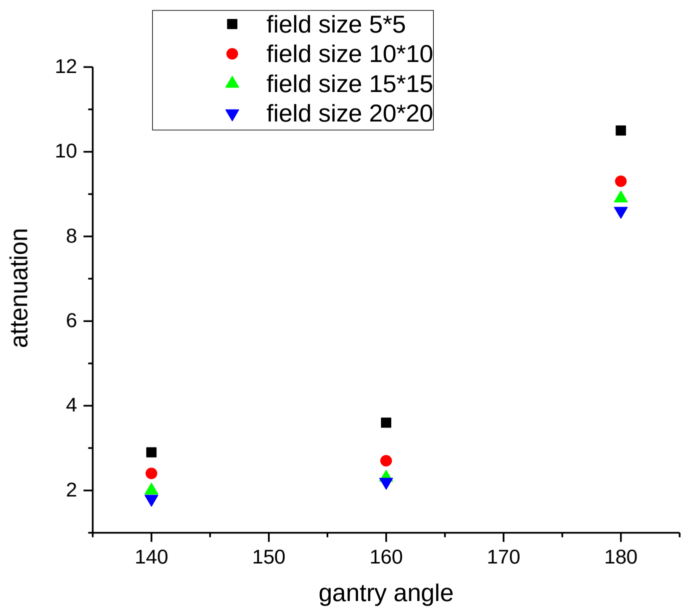

Figure 4. Gantry dependence of the transmission of 6 MV photon beam to the CCO couch for 5 × 5 cm^2, 10 × 10 cm^2, 15 × 15 cm^2, and 20 × 20 cm^2 field sizes.

Table 1. 6 MV, 10 MV, and 15 MV photon beam attenuation by the Connexion central opening couch**.**

F. size cm²	***Energy***	***180⁰***	***160⁰***	***140⁰***
5 × 5	***6MV***	10.50%	3.50%	2.90%
	10MV	8.60%	2.80%	2.50%
	15MV	7.40%	2.50%	2.10%
10 × 10	***6MV***	9.30%	2.70%	2.40%
	10MV	7.70%	2.20%	2.00%
	15MV	6.70%	2.00%	1.80%
15 × 15	***6MV***	8.90%	2.30%	2.00%
	10MV	7.30%	2.00%	1.80%
	15MV	6.50%	0.90%	1.60%
20 ×20	***6MV***	8.60%	2.20%	1.80%
	10MV	7.30%	1.90%	1.70%
	15MV	6.40%	1.80%	1.50%

Additionally, we investigated the beam attenuation of the studied couch based on gantry angle with energies of 6, 10, and 15 MV (Table 2 and Figure 5). The attenuation for 6 MV was 9.3 %, 7.7 % for 10 MV, and 6.7 MV for 15 MV. Similarity for 160 and 140 gantry angels' attenuation varied as a function of the energy. As a result, the attenuation values increase as the gantry angle increases and decrease as the beam energy and field size increase.

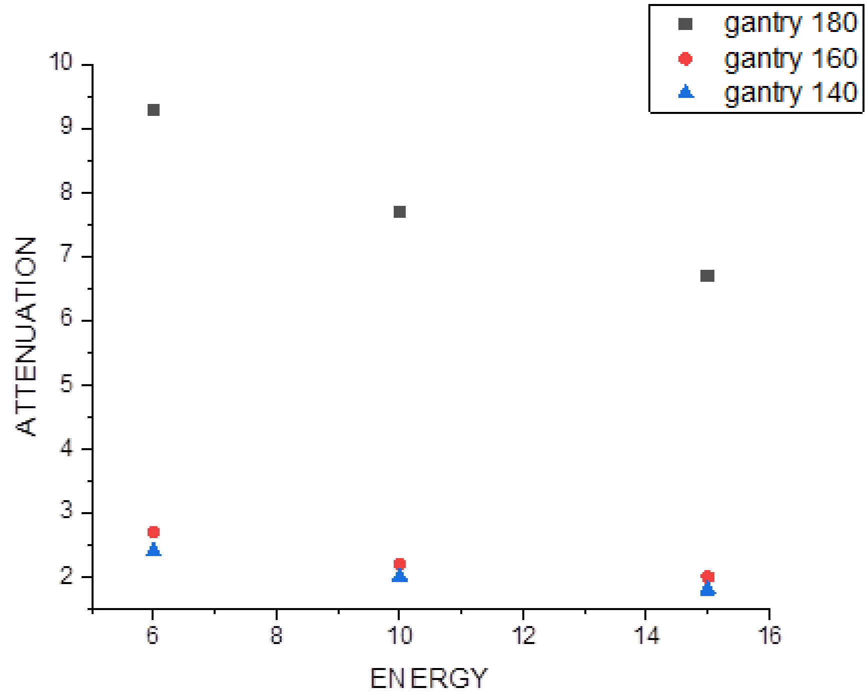

Figure 5. Energy dependence of the transmission for field size 10 × 10 cm^2 to the CCO couch for 180^0, 160^0, and 140^0 gantry angles

Table 2. 10 × 10 Field size attenuation by the CCO couch

Energy	***Gantry Angle***		
	180	***160***	***140***
6MV	**9.30%**	**2.70%**	**2.40%**
10MV	**7.70%**	**2.20%**	**2%**
15MV	**6.70%**	**2.00%**	**1.80%**

The measurement results in the ionization chamber, TPS of the effective couch density (1.2 g/cm^3), show that the measured and calculated values have the greatest attenuation in the area which more thickness where the largest differences occurred for beams with a direct posterior beam (180°) through the more thickness areas of the couch. Where the difference with (MC) algorithm was 4 %, and 3.7 % for the 5 × 5 cm^2, and 10 × 10 cm^2 field sizes respectively, 3.5 % for both 15×15, cm^2, and 20×20 cm^2 field sizes, furthermore, the difference with (CC) algorithm was 3 %, 3.6 %, 2.6 %, and 3.3% for 5 × 5 cm^2, 10 × 10 cm^2, 15×15 cm^2 and 20×20 cm^2 field sizes, respectively. While the differences at 160^0 and 140^0 was less where the greatest difference was recorded at 140^0 for 15×15 cm^2 field size, and 10 MV energy with CC algorithm which was ±1.9 (Table 3). As a result, the difference values increase as the gantry angle increases (Figure 6) (for all field sizes, for all energies, Table 3)

The Monte- Carlo calculation algorithm is more accurate than Collapsed Cone, and this result is consistent with other published results. According to Souris et al. [17], the Monte-Carlo method provides high accuracy for measurements in heterogeneous geometries, where it is routinely used as the 'gold standard' for comparing analytical methods.

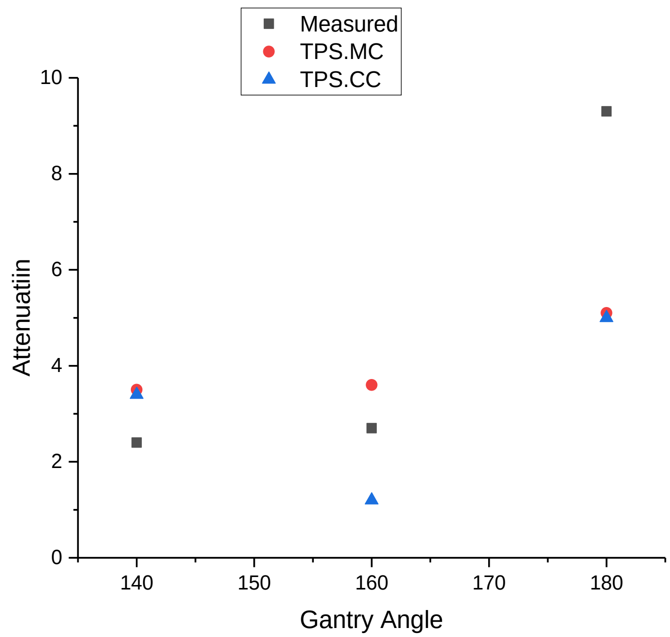

Figure 6. Attenuation comparisons of TPS and LINAC measurements for Connexion central opening couch at 6 MV and field size 10 × 10 cm^2

Table 3. Attenuation comparisons of TPS and LINAC measurements for Connexion central opening couch at 10MV with different field sizes, and 180,160 and 140 angles

Gantry angle	*Field size cm^2*	*Measured attenuation (%)*	*TPS algorithm attenuation (%)*		*Difference (%)*	
			CC	*MC*	*CC*	*MC*
180	***5×5***	8.6	5.6	4.6	3	4
	10×10	7.7	4.1	4	3.6	3.7
	15×15	7.3	4.7	3.8	2.6	3.5
	20×20	7.3	4	3.8	3.3	3.5
160	***5×5***	2.8	3.1	2.6	-0.3	0.2
	10×10	2.2	2.4	2.1	-0.2	0.1
	15×15	2	1.7	2	0.3	0
	20×20	1.9	1.6	1.9	0.3	0
140	***5×5***	2.5	3.7	3.2	-1.2	-0.7
	10×10	2	2.4	2.8	-0.4	-0.8
	15×15	1.8	3.7	2.6	-1.9	-0.8
	20×20	1.7	2.3	2.6	-0.6	-0.9
Mean		***3.9***	***3.3***	***3***	***2.3***	***1.5***

DISCUSSION

In Table 1 at the gantry angle of 160^0, two separate layers of carbon fibers were in a horizontal position with a foam gap between them, which caused the attenuation dose to decrease. At angle 140, the two layers of carbon fibers were in a horizontal position as well, but they were in an adjacent position without a foam gap. which caused a slight decrease in attenuation over angle 160°. But when the gantry was at angle 180^0, the two layers of carbon fiber were vertical, increasing the thickness of the carbon fiber and, as a result. Radiation attenuation has increased significantly for all energies.

In Table 2 for all gantry angles, the probability of penetration increases with increased photon energy as it passes through the Connexion central opening couch with (1.2 g/cm^3) density, thus decreasing attenuation. Results showed that attenuation decreases as radiation field size increases (Table 1 and Figure 4). With larger fields, the attenuation decreases because more multileaf collimators (MLCs) are exposed to primary photon beams, resulting in more scattered radiation. In small fields, scattered radiation is associated primarily with the collimator (Sc). As the field size increases, however, more scattered radiation is produced on account of a larger surface area of the multileaf collimator (MLC).

Many studies have examined the attenuation of the photon beam by various couches. More recently, investigations have shown that as the oblique of the beam increases, there is increasing attenuation of the photon beam. McCormack showed that with a 6 MV beam, the transmission values for a Sinmed BV Posisert [10] carbon fiber sheet drop from 98 % at normal incidence to 91 % at 70° incidence. Therefore, it is crucial to thoroughly investigate the effect of a tabletop on dose distribution in practical practice. Njeh et al. [14]. conducted a study to measure beam attenuation from the top of the brain lab imaging table. They found a maximum attenuation of 8.3 % at a gantry angle of 120^0. In addition, an attenuation of 3.4 % was observed at a beam angle of 180° with 6 MV photons and a field size of 10×10 cm^2. The measurements of a 6 MV photon beam by Vanetti et al. [18]. The Varian Exact IGRT tabletop (thinnest part) suggests 2.3 % and 3.1 % attenuation for gantry angles of 180° and 135°. In addition, Sedaghatian et al. estimated attenuation of 6 MV was 5.95 % with a field size of 5 × 5 cm^2 and a beam angle of 130°.

The above results agreed with our measured beam attenuation values for different field sizes and different photon beam energies as the field size was smallest and the beam energy lowest established the highest beam attenuation for Connexion central opening treatment couch. The maximum attenuation was 10.5 % for field size 5 × 5 cm^2 and energy 6 MV vice versa the minimum attenuation was 0.9 % for 20 × 20 cm^2 and energy 15 MV.

In contrast, the above results were inconsistent with our measured beam attenuation values in terms of angular dependence where these studies have shown that attenuation increased with larger beams passing through the couch, considering that the table is uniform thickness. The maximum dose attenuation is expected to occur in the angular ranges of 180° to 160° as the beam travels greater distances within the couch in these ranges. But the results show otherwise, where the maximum dose attenuation occurred at $180^0$and become less with decreasing of gantry angle.

There appears to be no evidence in the literature of the effect of the Connexion Central Opening Module on the extent of beam attenuation and dose distribution but another type carbon fiber couch is investigated, fore stance for the BrainLABTM [19] couch, Del Nero et al. found that the greatest attenuation occurred for the 6 MVenergy, gantry at 120° in the 5x5 and 10x10 cm2 fields, with an attenuation of 8.03 % and 7.67 %, respectively. In our work, the highest attenuation for the same field sizes and energies was observed at 180^0, with an attenuation of 10.5 % and 9.3 %, respectively (Table 1). Another important point of this article is the evaluation of the calculated dose for the under-Connexion Central Opening couch fields using TPS under two algorithms, CC and MC algorithm to reduce the skin surface dose. Using the difference between the measured and computed attenuation doses. the measurements were performed in the LINAC Elekta for field sizes ranging between 5 x 5 and 20 x 20 cm² with increments 5 with 180^0,$160^{0,}$ and 140^0 gantry angles for 6 MV,10 MV, and 15 MV.

The measured data were compared to the values calculated using the Monaco treatment planning system, calculated with the algorithms MC and CC to identify the influence of couch attenuation on patient dose verification to deliver better therapeutic dose distribution for patients. The least agreement observed at an angle of 180 between calculated and measured attenuation for the field size of 5 x 5 cm² with 6 MV and 10 MV photon beam energy was 5.3 % and 4 % for the MC and CC, respectively. Excellent agreement was observed at an angle of 160 between calculated and measured attenuation with the field sizes of 10 x 10 cm² for 6 MV which the difference (lose dose) was ±1.5 %.

CONCLUSION

The Connexion central opening has demonstrated significant attenuation at an angle of 180 for all energies and attenuation decreases as the posterior angle decreases (at140, and 160). As a result, the least agreement was observed at an angle of 180 between calculated and measured attenuation for photon beam energies. It is imperative to exercise extreme caution, therefore, in the usage of direct posterior oriented as angle 180 for treatment using Connexion central opening at the edges of the couch. However, we observed excellent agreement between calculated and measured attenuation at an angle of 160 where the radiation beam avoided the thickest area of the couch.

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