Assiut University Journal of Multidisciplinary Scientific Research (AUNJMSR)
Faculty of Science, Assiut University, Assiut, Egypt.
Printed ISSN 2812-5029
Online ISSN 2812-5037
Vol. 53(2): 238- 254 (2024)
https://aunj.journals.ekb.eg

Measuring and Assessing the Effect of a Carbon Fiber Couch on Radiotherapy Dose Distribution

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ARTICLE INFO

Article History:
Received: 2023-12-03
Accepted: 2024-01-18
Online: 2024-04-29

Keywords:
Provide a maximum of 4-6 keywords, avoiding general and plural terms, **TNR 10 font**

ABSTRACT

A vital device for administering radiotherapy, especially intensity-modulated radiation treatment (IMRT) is the Central Opening Carbon-Fiber Couch. There doesn't seem to be any evidence in the literature about the impact of the thickest section (edge couch) on the dose distribution, even though multiple tests were conducted with the radiation field incident on the center of the couch. In this study, we evaluated and improved the computed beam profile doses for the under-couch fields for various field sizes for energy 6MV to reduce the skin surface dosage.

The beam profile dose was determined using OCTAVIUS detector 1500 with OCTAVIUS 4D modular phantom and Elekta's Monaco 5.11.03 Treatment Planning System (TPS) using three calculating algorithms: Collapsed Cone (CC), Monte Carlo (MC), and pencil beam (PB).

As the radiation treatment beam traverses through the treatment CONNEXION central opening couch, the radiation treatment beam passes through the central aperture couch to deliver the treatment. There are differences between the measured and calculated (using CC and MC) isodose profiles of about 8 % at angle 130^{o} and these errors decrease with increasing gantry angle until the couch effect disappears at angle 150^{o} on the left side and similarly on the right side. There are no doses calculated in the couch effect zone using the PB algorithm.

INTRODUCTION

Radiation therapy couches support the patient and assist with positioning, in addition, modern radiation has seen an increase in the use of treatment modalities such as intensity-modulated radiotherapy (IMRT) [1-3]. An essential tool for delivering these treatments is a carbon-fiber couch [4,5]. Couches must provide the least amount of beam attenuation possible for high-energy photon beams in posterior and oblique irradiation fields.

Carbon fiber couches for radiotherapy are made in a variety of ways to generate distinct qualities to meet certain treatment requirements. Even at high energies, couches still have an impact on X-ray properties despite being designed to be relatively X-ray translucent. [6-8]. Carbon-fiber insert couches were more suitable as couches than Polymethyl methacrylate (PMMA) and wooden hardboards [5]; Alternatively, the dosimetric effects of this couch include increased skin dose, reduced tumor dose, and altered dose profile. Besides, there is reduced distortion in dose distribution within the target volume [9].

The main function of medical linear accelerators is to provide homogeneous photon beams to various irradiation field sizes and shapes using a collimation system [10,11]. The dose profile is determined by the size of the irradiation field and the distance from the axis [12]. Different depths are needed for a good study of dosimetry with off-axis distance x from the central beam axis to the beam edge. For good interpretation of experimentation measurements, dose profiles are obtained by using Octavius®-4D phantom with high technical and clinical conditions of experiments.

The type investigated in this study is the CONNEXION central opening with couch insert. This couch design is intended to allow beam incident directly on the patient at normal incident gantry (0^0, and 180^0) and to reduce the loss of the delivered dose to the patient when posterior oblique beams are used. One of the major parameters affecting the dose distribution is the amount of material placed in the beam path which increases photon scatter. Varying the beam angle of incidence will inevitably change the beam profile dose delivered through the couch material.

Many researchers investigated various types of carbon fiber couches. Butson MJ [13] investigated the skin dose delivered through the Varian Exact™ couch at normal incidence and found significant variations in the dose distribution. He also investigated the skin dose delivered through the same carbon fiber couch top and its variability with an angle of beam incidence [14].

The treatment couch has been recommended by several researchers because it may increase the skin dose in the TPS [15]. Taking support structures into account reduced the difference between planned and delivered doses significantly, according to Munjal et al. [16]. The differences between planned and measured doses can be reduced to less than 2% by including the couch in the TPS, according to Myint et al. [17] and Mihaylov et al. [18].

Several different methods have been used to investigate the inclusion of a treatment couch in a TPS by Spezi et al. [19, 20] and Mihaylov et al. [18]. With the couch included in the plan, both researchers find that the planned and measured doses are in good agreement. According to Spezi et al. [21], adding the couch dramatically and in an unanticipated way alters the IMRT beam characteristics. Because of its great homogeneity, the Varian IGRT couch's precise location was determined to be irrelevant in this instance; nonetheless, by including the couch in the TPS, clinically significant dosimetric differences were prevented [22]. Numerous other papers have demonstrated couch-affected surface dose and depth-dose curves by beam intensity [23-25]. However, there appears to be no evidence in the literature of the effect of the CONNEXION Central Opening Module on the isodose curve.

Therefore, it is crucial to thoroughly investigate the impact of a CONNEXION central carbon fiber treatment couch on dose distribution in practical practice. Consequently, the current study aims to evaluate and improve the calculated dose distribution for the under-couch fields to reduce the skin surface dose .This work utilizes the difference between measured and computed isodose curves obtained with an ionization chamber and the treatment planning system (TPS) algorithm. Using three different algorithms, the pencil-beam algorithm (PB), the collapsed cone algorithm (CC), and the Monte Carlo algorithm (MC). We measured the isodose curve caused by the CONNEXION carbon fiber couch and then computed the treatment planning system (TPS). By assessing the impact of carbon fiber couches on dose distribution, we were able to improve the calculations of the couches using TPS to provide patients with better therapeutic dose distribution.

MATERIALS AND METHODS

To determine the effect of the CONNEXION Central Opening couch on the dose distribution and dose profile measurements were performed for 6MV produced by Elekta Synergy Platform Linear accelerator, at South Egypt Cancer Institute on Assiut University to the procedure illustrated in Fig. 1. Elekta Oncology Systems, Crawley, UK, has unveiled the Elekta Synergy Platform Linear Accelerator.

In our institute CONNEXION central opening model is available in Fig.2. Which is a Carbon fiber sandwich with a foam core, 7.2 kg (15.9 lb) Weight, 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), 200 cm length and has CF 1.2 g/cm^3 and Foam density is 0.02 g/cm^3 electron density. CF thickness increases to 0.45 cm toward the edges of the couch.

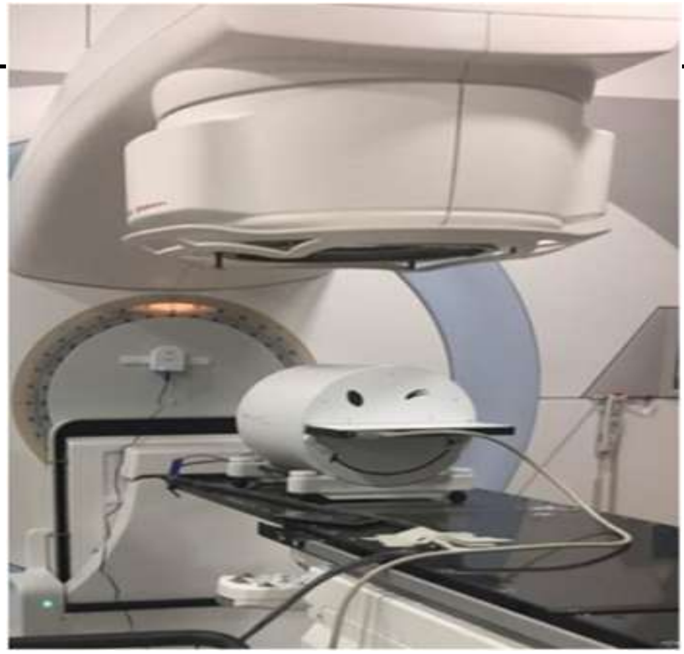

Fig. 1: Experimental setup for off-axis dose measurements. 2D array inserted inside the Octavius phantom for different gantry angles, photon energies, field size, and SSD 100 cm.

Fig. 2: Connexion Central Opening couch model

All dose calculations with a TPS, and all IMRT plans in this study were calculated using MONACO Treatment Planning System TPS (version 5.11 .03). Elekta AB (Sweden) provides the Monaco option for treatment planning [26]. The beam model in Monaco is based on the virtual flounce model for photons that Fippel created, and it uses the Sikora and Alber [27] technique for electron contamination. Monaco currently uses the voxel-based MC algorithm (VMC) for electron beams and has a clinical MC engine for photons dubbed XVMC [28].

Monaco TPS is a computing program based on a mathematical calculation algorithm. It uses Modals to calculate the absolute dose and iso-dose distribution on a patient's CT, the available three algorithms are Collapsed Cone (CC) and Monte Carlo algorithm (MC) models (model–based) for photon and electron beam data [29], and Pencil Beam (PB)model (correction- based) for photon energies only.

MEPHISTO mc² software (version 3.4) was used for therapy data acquisition and data analysis with the TBA therapy beam analyzer. An Octavius Detector 4D -1500 (PTW, Freiburg, Germany) was used for the IMRT Quality Assurance (QA) plan. The 2D-Array together with Octavius®-4D is widely described in the literature [30, 31].

In this experiment, we performed a series of measurements to determine the beam profile dosage. The experiment's dosimetric setup is depicted in Fig. 1. An Octavius Detector 4D -1500 was utilized to evaluate the impact of a carbon fiber couch on the dose distribution. With fields sizes of 5 × 5, 10 × 10, 15 × 15, and 20 × 20 cm^2 and photon beam energy of 6MV, the detector was exposed to gantry angles of 0°, 180°, 130°, 140°, 150°, and 160°. For IMRT verification, the source-to-phantom surface distance (SSD) was configured by our normal setup configuration, which is 100 cm. On the center axis, beam profiles are normalized at a depth of 10 cm. Following the sets of CT images were transferred to the TPS. After that, 3D-CT datasets were rebuilt, and dosimetry's intended spots were identified. Following the TPS calculation of the absorbed dosage, the outcomes were compared to the experimental dosimetry results using the following formula:

$$\%D_E = \frac{D_M - D_C}{D_M} \times 100 \qquad (1)$$

DE is the difference dos, DM is the measured dose, and DC is the calculated dose.

RESULTS

In Fig. 3, the agreement between measurement and computation beam profile doses becomes better with increasing field size. At which the difference beam profile dose for 5 × 5 cm^2, 10 ×10 cm^2, 15 × 15 cm^2, and 20 × 20 cm^2 was ±38.54 %, ±26.35 %, ±20.99 %, and ±8.40 % respectively with 6MV photon beam, and gantry angle 130^0 by using the collapsed cone as algorithm calculation with couch insert.

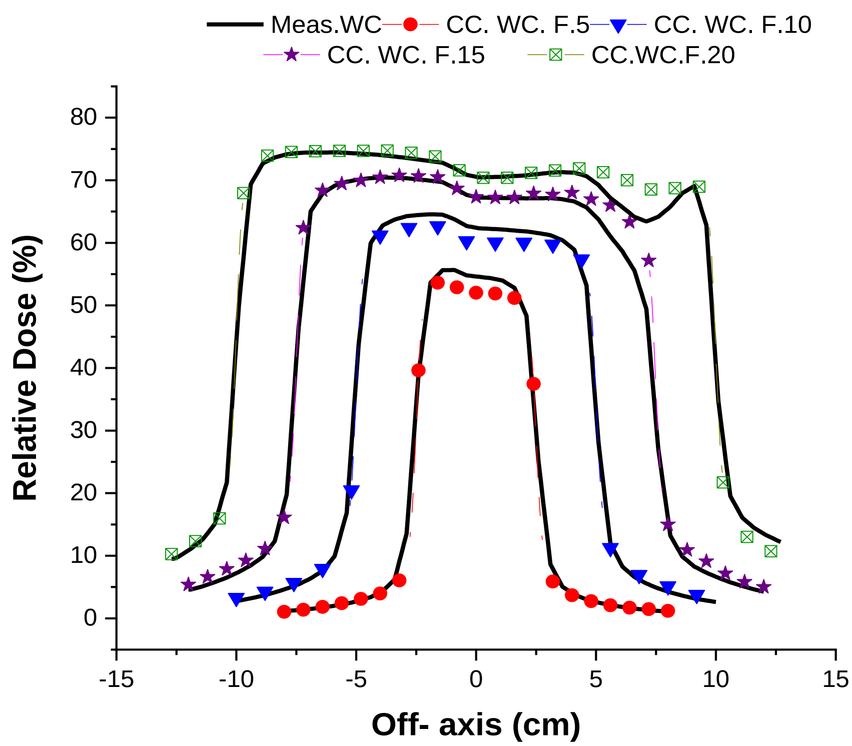

Fig. 3: Calculated and experimental dose profiles (WC) with 6MV photon beam, gantry angle 130^0 by using the collapsed cone as algorithm calculation with field sizes 5 × 5 cm^2, 10 ×10 cm^2, 15 × 15 cm^2, and 20 × 20 cm^2.

The calculations difference beam profile dose with and without CONNEXION central opening couch with treatment planning system (TPS) algorithm from various angles (160^0, 150^0, 140^0 and 130^0), the field sizes 20 × 20 cm^2, and 6M energy were conducted, and the results are presented in Table 1. The highest difference beam profile dose values were observed at 130^0 gantry angle with Monte Carlo algorithm which were ±8.06%. On the other hand, the lowest difference beam profile values were recorded at 160^0 gantry angle with Collapsed cone algorithm, which were ±0.19%.

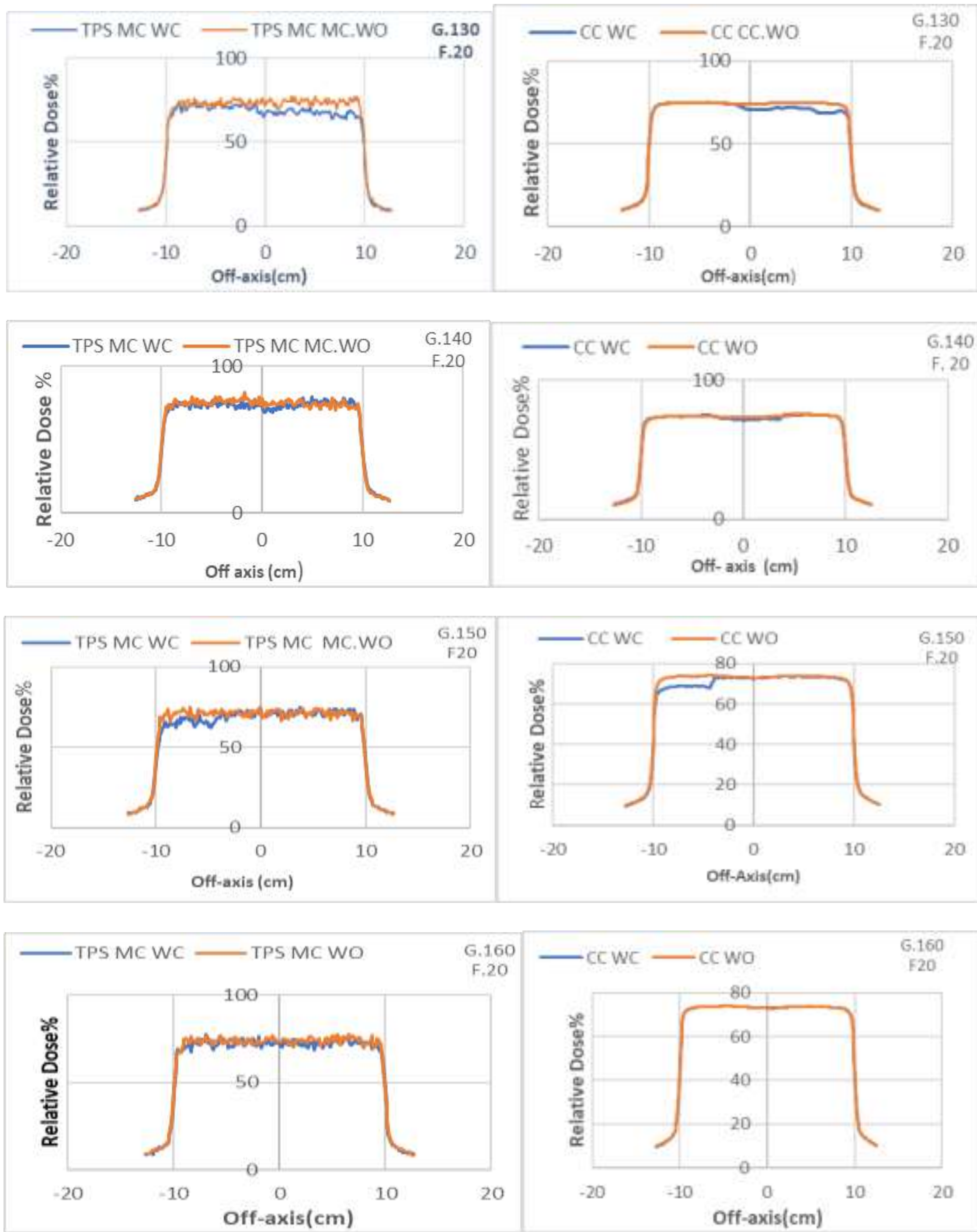

Fig. 4: beam profile dose by Monaco treatment planning system (TPS) under two algorithms, Monte Carlo (MC), and collapsed cone algorithm (CC), with and without CONNEXION central opening couch as a function of off-axis distance for field size 20×20 cm² at depth of 10 cm, SSD of 100 cm, 6MV photon energy and gantry angles 130^0, 140^0, 150^0, and 160^0.

Table 1: Percentage Difference beam profile dose for TPS (Monte Carlo, and Collapsed Cone algorithms) with and without CONNEXION central opening couch with 6MV photon beam, gantry angles 130^0, 140^0, 150^0, and 160^0 with 20×20 cm^2 field size.

Gantry Angle	TPS Algorithm		Relative Dose%	difference%
130	*MC*	WC	67.1	±8.06
		WO	72.99	
	CC	WC	68.52	±7.8
		WO	74.33	
140	*MC*	WC	72.17	±1.99
		WO	73.64	
	CC	WC	71.97	±2.41
		WO	73.77	
150	*MC*	WC	65.55	±6.71
		WO	70.72	
	CC	WC	67.08	±7.24
		WO	72.32	
160	*MC*	WC	72.32	±0.88
		WO	73.21	
	CC	WC	73.81	±0.19
		WO	73.62	

Table 2: Percentage Difference between TPS (Monte Carlo, Collapsed Cone, and Pencil Beam algorithm) and experimental dose profiles with CONNEXION couch insert for 6MV photon beam, gantry angles, 130^0, 140^0, 150^0, and 160^0 with 20×20 cm^2 field size.

Gantry Angle	*Measured Dose (WC)*	*TPS Algorithm*	*Calculated Dose (WC)*	*Difference (%)*
130^0	63.71	***MC***	67.1	5.32
		CC	68.52	±7.54
140^0	69.81	***MC***	73.64	±4.50

		CC	73.77	±3.0
150^0	64.38	***MC***	70.72	±1.81
		CC	72.05	±4.1
160^0	74.55	***MC***	72.41	±2.9
		CC	73.62	±0.99

Furthermore, the Percentage Difference between TPS (Monte Carlo, Collapsed Cone, and Pencil Beam algorithm) and experimental dose profiles with CONNEXION couch insert for 6MV photon beam, gantry angles, 130^0, 140^0, 150^0, and 160^0 with 20 × 20 cm^2 field size were conducted, and the results are presented in Table 3. At 160^0, we observed good agreement between the measured and planned doses when the plan takes into account the CONNEXION central opening couch.

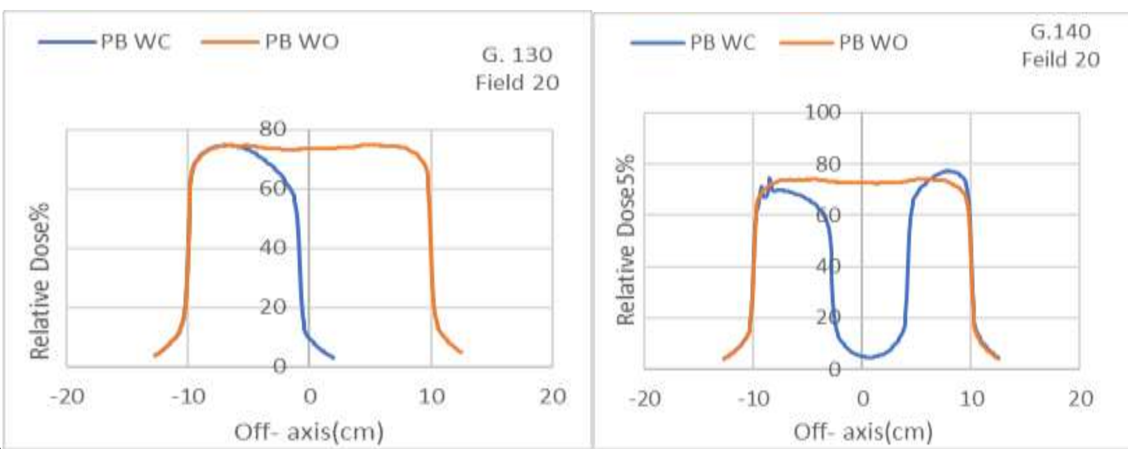

Fig. 5: Percentage Difference beam profile dose by Monaco treatment planning system (TPS) by Pencil Beam algorithm (PB), with and without CONNEXION central opening couch as a function of off axis distance for field size 20×20 cm² at depth of 10 cm, SSD of 100 cm, 6MV photon energy and gantry angles 130^0, and140^0

In Fig. 5 the blue dots refer to Pencil Beam computed beam profile with couch insert, and the orange dots refer to Pencil Beam computed beam profile without CONNEXION couch insert, as a function of Off-axis distance for field size 20×20 cm² at a depth of 10 cm, SSD of 100 cm, 6MV photon energy and gantry angles 130^0, and 140^0. With inserting the couch into the plan the pencil beam algorithm failed to calculate at 130^0, and 140^0 gantry angles.

DISCUSSION

Based on our study findings, CONNEXION central opening carbon fiber substance positioned in the posterior oblique rays' path attenuates radiation beams by a significant amount, which lead to deviation in beam profile dose. In particular, with an increasing angle of incidence, radiation beams must travel a greater distance through a carbon fiber insert, which increases attenuation consequently increase of the difference between the prescript and deliver dose. As a result of this finding, CONNEXION central opening carbon fiber couches should be carefully considered when planning external-beam radiotherapy, particularly when posterior oblique beams are used. If attenuation effects are not accurately accounted for, the dosage of the target tissue could be inadequate, potentially compromising the treatment's efficacy and the patient's health.

Several factors can affect the magnitude of this attenuation, which alteration the beam profile dose, for instance, the radiation beam field size, and the angle of incidence. To develop more accurate and effective treatment planning strategies for external-beam radiotherapy, we investigated how these factors impact radiation attenuation in CONNEXION central opening carbon fiber couches. Our goal was to better understand how these variables affected the radiation attenuation in carbon fiber couches to develop more precise and efficient treatment planning techniques for external beam radiation.

In Fig. 3 It is evident that as field sizes increased, so did the relative dose, the peak values also increased, and backscattering effects caused the increasing relative dose for large field sizes to increase with field sizes. We measured the backscattering effects in our investigation, and for a 20×20 cm^2 field size, the increasing relative dosage is 4.5. As a result, compared to the backscattering of 10×10 cm^2, the backscattering for the field size of 20×20 cm^2 was more the 4.5. and this is in agreement with other experimental results [32]. The incrassating in relative dose was produced by flattening filter design and geometry [33-35]. On the other hand, the agreement between measurement and computation beam profile doses becomes better with increasing field size. At which the difference beam profile dose for 5 × 5 cm^2, 10 ×10 cm^2, 15 × 15 cm^2, and 20 × 20 cm^2 was ±38.54 %, ±26.35 %, ±20.99 %, and ±8.40 % respectively with 6MV photon beam, and gantry angle 130^0 by using the collapsed cone as algorithm calculation with couch insert. As a result, the agreement between measurement and computation beam profile doses becomes better with increasing field size for all gantry angles, and all energies.

Fig. 4 and Table 1, show the calculations of the difference beam profile dose with and without CONNEXION central opening couch by Monaco treatment planning system (MC, and CC) algorithms from angles (160^0, 150^0, 140^0, and 130^0) for the field size 20 × 20 cm^2, and 6MV energy, where this difference was the highest at 130° at which the couch angle caused a percentage difference in the 6MV photon beam with the (MC) by ±8.06 %, and it was ±1.99 %, ±6.71 %, and ±0.88 % at 140^0, 150^0, and 160^0 respectively as well as for (MC), where the percentage difference beam profile dose was ±7.8%, ±2.41 %, ±7.24 %, and ±0.19 % at 130^0, 140^0, 150^0, and 160^0 respectively. As a result, the couch angle has a significant effect on the percentage difference, especially at 130^0, 140^0, 150^0 gantry angles.

The results at 130^0, 150^0 gantry angles were inconsistent with the International Commission on Radiation Units and Measurements (ICRU), criteria for the dose calculation accuracy must be within +/-5 %**.** Mihaylov et al. [18] hypothesized that the couch's impact in multiple beam layouts is probably not clinically significant. Considering that standard IMRT methods employ seven or nine beams, this is not out of the ordinary.

Using a variety of techniques, Spezi et al. [19, 20] and Mihaylov et al. [18] have examined the incorporation of the treatment couch in a TPS. When the coach is part of the plan, both discover that there is good agreement between the measured and intended doses. According to Spezi et al. [21], adding the couch dramatically and in an unanticipated way alters the IMRT beam characteristics.

The above results agreed with our measured beam profile values for different field sizes and different photon beam energies as the CONNEXION central opening inclusion within TPS leading to good agreement between planned and measured doses.

In Fig. 5, the Pencil Beam failed to be calculated because its component of the model is used for stage 1 optimization only. It is not designed to achieve the accuracy necessary for stage 2 final dose calculation and QA plan dose calculation. Plans calculated with the Pencil Beam algorithm cannot be exported as DICOM plan objects from Monaco.

CONCLUSION

Radiation treatment beams traversing through the treatment CONNEXION central opening couch experience varying degrees of perturbation and thus can cause non-negligible beam difference dose with posterior oblique gantry angles. It was found that the highest difference between the calculated and measured dose was at gantry angles from 130^0 to 150^0, so avoid using these angles and their corresponding angles (from 210^0 to 230^0) in the plan. Clinically non-negligible dose and volume coverage losses could occur if the treatment couch is not considered. According to this study, the beam profile difference is largest when the beam traverses more material by going through the outer border of the couch. The CONNEXION couch will be necessary if posterior oblique beams are utilized in a treatment plan; therefore, care must be taken to avoid the couch's margins where a partial obstruction of the beam may not be precisely adjusted. Comparisons of the dosage data acquired in this study reveal that the CC algorithm calculations are closer to the measured dose, and the difference between the CC and MC algorithms was non-significant. The major difference due to dose calculation techniques by TPSs was observed with PB, Despite the owner company’s recommendation not to use PB in the final calculations for patients, it nevertheless used it in calculating the first stage of IMRT and VMAT techniques, causing fundamental differences between the first calculation stage that uses PB and the final calculation stage that uses MC, which forces us to modify the restrictions based on Results of the second stage calculations and recalculating the case again.

Recommendation

Dosimetric perturbations caused by the CONNEXION central opening couch should be included whenever possible in dose calculations. Additionally, it is important to choose the right treatment angle and steer radiation away from regions with high dose attenuation. It is essential to ensure dose accuracy by reducing the impact of the treatment couch on the planned dose. Comparisons of the dosage data acquired in this study reveal that the CC algorithm calculations are closer to the measured dose than the MC algorithm calculations. Elekta, the company that owns the MONACO program, must reconsider the PB algorithm, completely cancel it from the program, or at least remove it from 3D calculations, to avoid using it incorrectly in calculations, which leads to harm to patients.

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