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Dosimetric Effect and Impact Caused by Carbon Fiber Table and its Accessories in Linear Accelerator

Haydar H. Alabedi[1,2]*, Mustafa S. Al Musawi[3], Nabaa Mohammed Ali[4]

[1]Department of Surgery, College of Medicine, Baghdad University, Baghdad, Iraq.
[2]College of Medicine, University of Warith Alanbiyaa, Karbala, Iraq.
[3]Department of Physiology and Medical Physics, College of Medicine, Al-Mustansiriya University, Baghdad, Iraq.
[4]Radiotherapy Department, Faculty Of Health Science, University Kebangsaan Malaysia, Bangi, Malaysia.
*Correspondence to: Haydar H. Alabedi (E-mail: haydar.h@comed.uobaghdad.edu.iq)
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Abstract

Objective: Most contemporary treatment planning systems (TPS) exclude the couch during treatment planning. The present investigation aimed to evaluate the impact of couches and accessories on radiation therapy planning by quantifying the degree of attenuation for two-photon beam energies, 6 MV and 10 MV, at two different field sizes, 5 cm x 5 cm and 10 cm x 10 cm.

Methods: An x-ray radiation beam at two energies (6 MV and 10 MV) generated by a linear accelerator (Elekta Synergy). The output dose was measured using a digital parallel plate ionization chamber of the IBA cc13 type (IBA Dosimetry, Germany), and the readings were recorded with a 2944 Farmer Type chamber. Different commercially available couch tops and accessories evaluated in this study.

Results: The results show that the highest attenuation values were observed at 130° gantry angles for both energies and field sizes. The lowest attenuation values were recorded at 100° gantry angles with 6 MV energy for 5 cm x 5 cm and 10 cm x 10 cm field sizes. The breast board with D level demonstrated the highest attenuation of 6.27% and 5.51% for 6 MV and 10 MV energies, respectively.

Conclusion: the findings indicate that the degree of attenuation is not uniform across all angles and may exceed tolerable limits, indicating the need for careful consideration during treatment planning to ensure optimal treatment outcomes.
Keywords: Carbon fiber, attenuation, couch Inserts, photon beam, treatment planning

Introduction

Carbon fibers are utilized in the manufacture of linear accelerator couches in accordance with established guidelines, owing to their radiotranslucent properties.[1] These materials are preferred due to their favorable properties, including high specific strength, low specific density, physical durability, and excellent beam transmission. However, the dosimetric effects of external devices on patients are multifaceted and may include increased skin dose, decreased tumor dose, and altered dose distribution, as first described by de Mooy.[2] The carbon fiber couch is an essential component of radiotherapy treatment, as it immobilizes and stabilizes the patient during therapy administration, thereby reducing motion artifacts and enhancing the accuracy and precision of radiation delivery.[3]

Posterior and posterior oblique beam orientations in radiotherapy treatments may give rise to two potential concerns. Firstly, the presence of the couch insert may lead to attenuation of high-energy photon beams, resulting in a dose to the treatment volume that is lower than the intended dose. Secondly, the skin-sparing effect of the build-up region may be diminished. The former is particularly important as it may directly impact the therapeutic outcome and necessitate corrective measures to ensure optimal dose delivery to the intended treatment volume. The latter concern may also have significant implications for patient comfort and satisfaction. Therefore, carefully considering and evaluating these factors are essential when devising and administering radiotherapy treatments.[4]

Numerous studies used a gantry angle of 180° and therefore offer little information on the amount of attenuation during oblique treatments for esophageal cancer and posterior lung lesions.[5] In another study by Vieira et al.,[6] a 15% attenuation was found when head and neck IMRT treatments using six MV posterior oblique photon beams were repeated and evaluated using electronic portal imaging device (EPID) dosimetry. The amount of the observed beam attenuation may be ascribed to attenuation caused by the treatment couch and immobilization devices rather than by the carbon fiber insert alone.

Higgins and colleagues[7] conducted a study to evaluate the effect of carbon fiber couch inserts on surface dosage with different beam sizes. Their study revealed that incorporating a carbon fiber insert panel did not cause significant attenuation of the primary radiation; however, it significantly reduced the skin-sparing effect, particularly for smaller beam sizes. When carbon was added, the surface dose was approximately four times higher for a 10 cm × 10 cm beam and almost twice as high for a 40 cm × 40 cm beam.

The CT simulation couch top is utilized in patient imaging but has not been a part of CT-based planning until recently due to technical difficulties. Before 2008, it was not incorporated into the Treatment Planning System (TPS) for dose calculations. The recently released TPS software does not provide an option to replace the CT couch top with the treatment couch. Nevertheless, the TomoTherapy planning software (Accuray, Sunnyvale, CA) has incorporated this feature.[8–10]

Several Treatment Planning Systems (TPSs) have provided options to account for the modified CT datasets, and some have allowed for the inclusion of the treatment couch top in the planning CT. It is crucial to measure the impact of intervening devices on photon beams and include them in TPS dose calculations to determine whether the skin receives a safe dose. However, correcting the couch attenuation by increasing the monitoring units (MU) can increase the absolute skin dose. Additionally, patient support and immobilization devices also attenuate the photon beam, and therefore, their effects on dose delivery should also be considered.[11–14]

This study aimed to quantify the amount of radiation beam attenuation caused by the couch inserts and their associated accessories, as well as to develop a correction factor for the delivered dose to the patient.

Materials and Method

The present study was conducted at the Baghdad Radiotherapy and Nuclear Medicine Center in Baghdad Medical City. This study aimed to evaluate the beam attenuation of various commercially available couch tops and accessories and to correct the administered radiation dose to the patient. To achieve this, measurements were taken for the X-ray radiation beam at two energies (6 MV and 10 MV) generated by a linear accelerator (Elekta Synergy). The output dose was measured using a digital parallel plate ionization chamber of the IBA cc13 type (IBA Dosimetry, Germany), and the readings were recorded with a 2944 Farmer Type chamber.

Measurements were taken at a reference dose for gantry angles ranging from 0° to 180° at a fixed source-to-surface distance (SSD) of 100 cm and for two field sizes (5 cm × 5 cm and 10 cm x 10 cm) by keeping the SSD constant for the couch top, and only at 0° for the other accessories. All measurements were taken at a dose rate of 100 MU. The isocenter of the treatment table was set with the center of the chamber and phantom and was placed on the surface of either the tabletop or the table combi board combination. The entrance window of the chamber was directed toward the radiation source Figures 2–5.

The attenuation of the main couch top was measured at a gantry angle of 0° (and for every 10° at the beam gantry angles between 0° and 180°). The attenuation of the insert couches was measured at a gantry angle of 0° with and without the insert at 5 cm depth and for a field size of 10 cm × 10 cm only. The measurement point was taken from the area with the large grid.

The commercially available couch tops and accessories evaluated in this study included 1) System Breast STEP Conv (Beast STEP, Schwabmu ňchen, Germany) with four levels A, B, C, and D, 2) Beam evo couch top Ep (Schwabmu ňchen, Germany), 3) Qfix PortraitTM Intracranial. Head and Neck (USA), 4) System HS iBeam evo, Head STEP (Schwabmu ňchen, Germany), 5) Mask, 6) Vac. Lock, 7) Polystyrene foam, and 8) Belly Board (Schwabmu ňchen, Germany). The settings used in this study are illustrated in Figure 1.

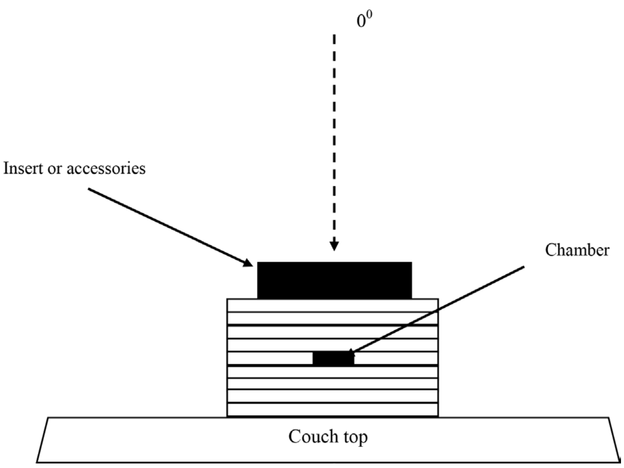

Fig. 1 **The measurement of the attenuation couch insert setup.**

The dose delivered by the linear accelerator (linac) is measured relatively with respect to air density and correction factor using a chamber with a sensitivity of 11.75 nC/Gy, a background radiation of 0.01 mGy/s, and a bias voltage of +299 V. However, to obtain the absolute dose, it is necessary to correct this measured dose using the equation provided by the manufacturer. This correction ensures that the delivered dose is accurate and can be used for safe and effective patient treatment. It is essential to follow the manufacturer's instructions and procedures to obtain reliable and precise dose measurements:

$$\text{Output Dose} = \text{KQ} \times \text{KTP} \times R_{\text{electrometer}} \quad (1)$$

The value of the quality constant (KQ) of radiation depends on the type of radiation (i.e., electron or photon) and the energy level. For instance, the KQ for 6 MV is 0.99, while for 10 MV, it is 0.98. Another constant that affects the measurement of radiation dose is the constant of temperature and pressure (KTP). This value can be obtained using the following equation:

$$KTP = \frac{(273 + T)P^{o}}{(273 + T^{o})P} \quad (2)$$

The absolute dose measurement of each output dose is corrected by considering the constant of temperature and pressure (KTP) and the quality constant of radiation (KQ). The KTP accounts for the differences in room temperature and pressure between the commissioning and study times. Specifically, it is calculated using the equation provided, where T° and P° are the temperature and pressure of the linac room at the time of commissioning, respectively, and T and P are the corresponding values at the time of the study. This study's values of T°, T, P°, and P were 20°C, 21.3°C, 1000 Pa, and 1004 Pa, respectively. The KQ, on the other hand, is the quality constant of the radiation, which depends on the type of radiation and its energy. In this study, the KQ values for 6 MV and 10 MV were 0.99 and 0.98, respectively. By taking into account these correction factors, each output dose is converted into an absolute dose measurement.

Results

The measurements of couch maximum attenuation from various angles were conducted, and the results are presented in Table 1. The highest attenuation values were observed at 130° gantry angles for both energies and field sizes. On the other hand, the lowest attenuation values were recorded at 100° gantry angles with 6 MV energy for 5 cm × 5 cm and 10 cm ×10 cm field sizes, which were 0.02% and 0.41%, respectively. Additionally, the measurements showed that the attenuation was 0.39% at 180° gantry angle and 0.11% at 80° gantry angles for a 10 cm × 10 cm field size.

The other couch inserts were adjusted to the field size of 10 cm × 10 cm for 6 MV and 10 MV energies with a slab thickness of 5 cm. The attenuation measurements were performed at a reference angle of 180°, and the reference distance of

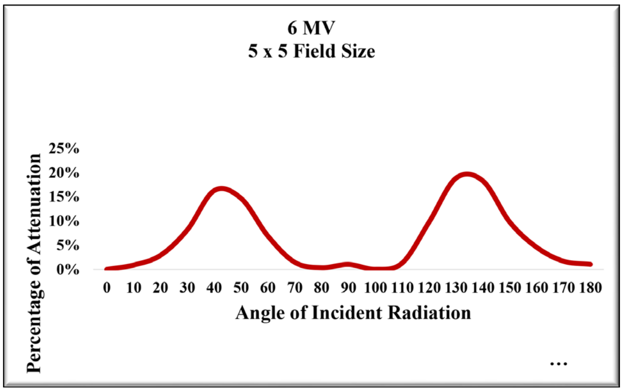

Fig. 2 **The attenuation percentage of the couch top using 6 MV x-ray photon beams at different angles for 5 cm x 5 cm.**

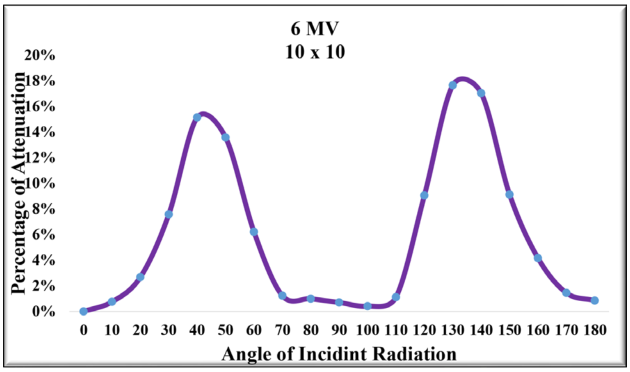

Fig. 3 **The attenuation percentage of the couch top using 6 MV x-ray photon beams at different angles for 10 cm x 10 cm.**

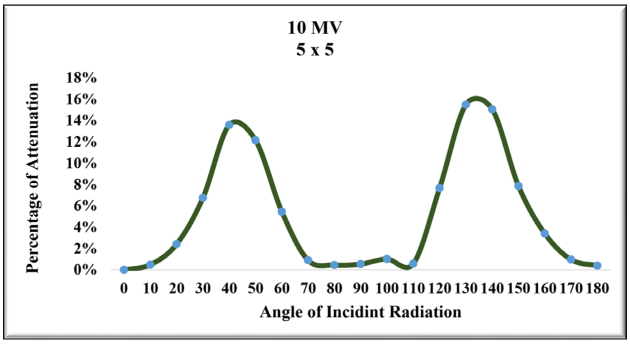

Fig. 4 **The attenuation percentage of the couch top using 10 MV x-ray photon beams at different angles for 5 cm x 5 cm.**

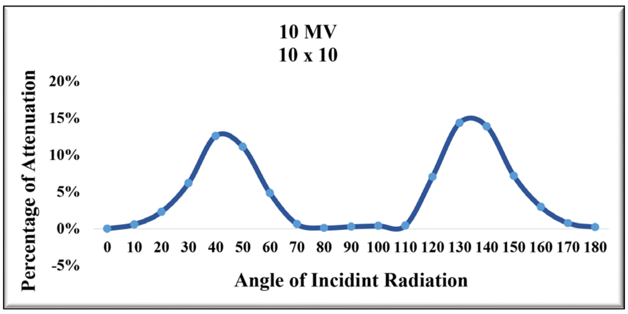

Fig. 5 **The attenuation percentage of the couch top using 10 MV x-ray photon beams at different angles for 10 cm x 10 cm.**

SSD = 95, SAD = 100, and MU = 100. The attenuation values for other couch inserts and their accessories are summarized in Table 1. Among the inserts, the breast board with D level demonstrated the highest attenuation of 6.27% and 5.51% for 6 MV and 10 MV energies, respectively. On the other hand, the foam insert showed a minimum attenuation of 0.75% and 0.80% for 6 MV and 10 MV energies, respectively.

Discussion

Our study findings indicate that carbon fiber material situated in the path of posterior oblique beams can considerably attenuate the radiation beam. Specifically, as the angle of incidence becomes increasingly oblique, the distance that the radiation beam must traverse through the carbon fiber insert increases, thereby exacerbating the attenuation effect. This finding underscores the importance of carefully accounting for carbon fiber couches and other supporting materials in treatment planning for external-beam radiotherapy, particularly when using posterior oblique beams. Failure to accurately account for attenuation effects could result in inadequate dosing of the target tissue, potentially compromising the treatment's efficacy and the patient's health outcomes.

In accordance with the principles of radiation physics, the attenuation of carbon fiber can be explained as follows: As the radiation beam passes through the thickness (t) of the carbon fiber insert, the distance that it must traverse increases proportionally with the angle, following a factor of 1/cosθ, assuming that all other factors remain constant. This attenuation effect can be further understood in the context of the intensity attenuation law of radiation, which describes the decrease in intensity of a radiation beam as it passes through an absorbing medium such as carbon fiber. The precise magnitude of this attenuation effect can vary depending on a range of factors, including the energy of the radiation beam, the thickness of the carbon fiber insert, and the angle of incidence. Our study aimed to investigate the impact of these factors on the attenuation of radiation in carbon fiber couches and patient supports, intending to inform more accurate and effective treatment planning strategies for external-beam radiotherapy:[3,15]

$$I = I_0 e^{-\lambda(t/\cos\theta)} \quad (3)$$

In the context of our investigation, we utilized the parameters I, I_0, and λ to represent the intensity of the radiation dose, the original intensity radiation dose without the couch, and the attenuation coefficient, respectively. These values were normalized at the incident angle of 0°, making λt a constant. Theoretically, the correction factor of attenuation (A) was calculated for each angle using the following equation:

$$A = \left(\frac{I}{I_0}\right) = e^{\left(\frac{\lambda t}{\cos\theta}\right)} \quad (4)$$

The methodological approach described above appears to oversimplify the connection between the angle of incidence and the absorbed dosage observed empirically. Our findings indicate that the attenuation of the radiation beam is higher than expected when the angle of incidence increases. This phenomenon was initially attributed to the non-homogeneous composition of the panel, which features a sandwich-like structure consisting of a polystyrene core surrounded by a layer of carbon fiber.

Table 1. **The attenuation of couch inserts and accessories for two types of energies, 6 MV and 10 MV, at 10 cm x 10 cm field size**

Material	6 MV	10 MV
Back A	2.66%	2.40%
Back B	3.12%	2.84%
Head STEP	3.51%	3.15%
C pad	1.23%	1.19%
Belly STEP	3.95%	3.51%
Vac. Lock	2.54%	2.27%
Vac. Lock + Foam	2.82%	2.53%
Foam	0.76%	0.80%
Breast Board 0 level	5.57%	4.87%
Breast Board D level	6.27%	5.51%
Breast Board C Level	6.04%	5.35%
Breast Board B Level	5.95%	5.31%
Breast Board A Level	5.87%	5.19%
New Board	2.00%	1.95%
Head Mask	1.09%	1.01%
Belly Board	2.11%	1.88%

Our study highlights the need to incorporate the effect of attenuation observed in this investigation, which resulted in a 6.27% difference in the absorbed dose at the breast board level with 6MV energy, into the MU calculations. By doing so, the dose attenuated by the carbon fiber can be effectively eliminated, particularly when dealing with posterior oblique beams during treatment planning. Calibration may also be applied to the MU calculations to refine the accuracy of the predicted treatment outcomes.

The importance of patient support in external-beam radiotherapy cannot be understated. Therefore, incorporating new materials into this field necessitates thoroughly investigating their effects on significant beam characteristics. This is especially relevant when such materials are positioned between the radiation source and the patient, as seen in the evaluation of carbon fiber-based couches and patient supports in this research. It is crucial to consider the potential impact of these novel materials on radiation dose distribution and patient outcomes and evaluate their safety and efficacy in clinical settings. Therefore, it is important to conduct comprehensive studies on the effects of these materials on the radiation beam and patient treatment.

Muhtarom et al.[16] conducted a study to investigate the effects of using three different carbon fiber plates on the properties of Cobalt 60, 6- and 23-MV beams at various field sizes. The authors aimed to demonstrate how these plates impact the surface dose and the magnitude of this effect. Similarly, Popple et al.[17] conducted a study where they found up to a 5.8% underdose at the isocenter for rapidArc treatment plans when the couch was not considered in the planning process. These studies highlight the importance of considering the effects of couch inserts and the treatment couch in dose calculations and planning to ensure accurate and safe treatment delivery.

Our research suggests that the displacement of the attenuating and scattering carbon fiber mass away from the phantom surface as the angle of incidence rises from 0° to 180° could potentially explain the observed differences. As the air gap increases, the contribution of scatter from the carbon fiber layer becomes less discernible near the isocenter, resulting in lower electrometer readings and, therefore, a perceived more significant attenuation. Further research is needed to develop a more precise theoretical model that accurately predicts the radiation beam's attenuation at oblique gantry angles.

Conclusion

In conclusion, our study suggests that the carbon fiber material employed in this investigation is not suitable for use as a supporting material during radiation therapy delivery, despite being well-suited for imaging purposes. As such, it is recommended that the attenuation differences resulting from using carbon fiber couches and supports be accounted for in the MU calculation during treatment planning. Alternatively, incorporating the supporting couches in the planning process may be a viable option to ensure optimal treatment outcomes. Further research may be required to explore the suitability of alternative materials for use as supportive couches, and patient supports during radiation therapy.

References

1. Njeh CF, Parker J, Spurgin J, Rhoe E. A validation of carbon fiber imaging couch top modeling in two radiation therapy treatment planning systems: Philips Pinnacle3 and BrainLAB iPlan RT Dose. Radiation Oncology. 2012;7(1):1–11.
2. Lv R, Yang G, Huang Y, Wang Y. Dosimetric effects of supine immobilization devices on the skin in intensity-modulated radiation therapy for breast cancer: A retrospective study. BMC Cancer. 2021;21(1).
3. McCormack S, Diffey J, Morgan A. The effect of gantry angle on megavoltage photon beam attenuation by a carbon fiber couch insert. Med Phys. 2005;32(2):483–7.
4. Meydanci TP, Kemikler G. Effect of a carbon fiber tabletop on the surface dose and attenuation for high-energy photon beams. Radiation Medicine - Medical Imaging and Radiation Oncology. 2008;26(9).
5. Gergelis KR, Jethwa KR, Tryggestad EJ, Ashman JB, Haddock MG, Hallemeier CL. Proton beam radiotherapy for esophagus cancer: State of the art. Vol. 12, Journal of Thoracic Disease. 2020.
6. SC V, RS K, ML D, BJ H. Two-dimensional measurement of photon beam attenuation by the treatment couch and immobilization devices using an electronic portal imaging device. Med Phys. 2003;30(11):2981–7.
7. Higgins J, Bezjak A, Hope A, Panzarella T, Li W, Cho JBC, et al. Effect of image-guidance frequency on geometric accuracy and setup margins in radiotherapy for locally advanced lung cancer. Int J Radiat Oncol Biol Phys [Internet]. 2011 Aug 1 [cited 2021 May 18];80(5):1330–7. Available from: http://www.redjournal.org/article/S0360301610005109/fulltext.
8. E V, G N, A C, A F, L C. The impact of treatment couch modelling on RapidArc. Phys Med Biol. 2009;54(9).
9. KB P, RM H, D F, D L, RA W, SF K. The clinical impact of the couch top and rails on IMRT and arc therapy. Phys Med Biol. 2011 Nov 4;56(23):7435–47.
10. T T, B G, C D, IA P. A Monte Carlo model of the Varian IGRT couch top for RapidArc QA. Phys Med Biol. 2011 Dec 21;56(24).
11. Spezi E, Angelini AL, Romani F, Guido A, Bunkheila F, Ntreta M, et al. Evaluating the influence of the Siemens IGRT carbon fibre tabletop in head and neck IMRT. Radiotherapy and Oncology. 2008 Oct 1;89(1):114–22.

12. Z H, J D, L L, Y C, G F. Evaluating and modeling of photon beam attenuation by a standard treatment couch. J Appl Clin Med Phys. 2011 Jul 12;12(4):3561–3561.
13. LH G, M N, BJ N. Dose perturbations by two carbon fiber treatment couches and the ability of a commercial treatment planning system to predict these effects. Med Phys. 2010;37(1):322–8.
14. IB M, P C, Y Y, V R, EG M. Modeling of carbon fiber couch attenuation properties with a commercial treatment planning system. Med Phys. 2008;35(11):4982–8.
15. Khan FM, Gibbons JP, Sperduto PW. Khan's Treatment Planning in Radiation Oncology. 4th Editio. Lippincott Williams & Wilkins (Wolters Kluwer). Philadelphia, PA: Lippincott Williams & Wilkins (Wolters Kluwer); 2018.
16. Muhtarom, Hidayanto E, Sutanto H. Analysis of the Effect of carbon fiber utilization on Cobalt- 60 Teletherapy to the depth dose and the surface dose. International Journal of Innovative Research in Advanced Engineering. 2017;4(04):2015–8.
17. RA P, JB F, IA B, JA B. RapidArc radiation therapy: First year experience at the University of Alabama at Birmingham. Int J Radiat Oncol Biol Phys. 2010;77(3):932–41.