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Carbon Fiber Belly Board Quality Assurance in Radiotherapy

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Abstract

Background: Carbon fiber belly board is the newer immobilization device that has earned recognition in sparing small bowel during prone pelvic irradiation. It is characterized by mechanical strength, a smooth rigidity, and a low specific density. In this study, the beam attenuation for a 10x10 cm^2 field size was calculated for 6 and 18 MV photons beam.

Methods: A Farmer ion chamber of 0.6 cc volume, slabs of solid water phantom, and an electrometer were used to measure the relative exit dose with or without the carbon fiber belly board at variable gantry angles. The measurements were performed at 100 cm SSD, and 100 MU were delivered.

Results: The average beam attenuation amounted to $3.46 \pm 1.53\%$ and $2.22 \pm 0.89\%$ for 6 and 18 MV, respectively. The highest attenuation was obtained at 130^o and the lowest at 120^o gantry angle for both energies.

Conclusion: Irradiating through carbon fiber immobilization devices triggered a variation of the beam attenuation at different gantry angles. As a result, there is a loss of skin-sparing effect with megavoltage photon beam. Therefore, special attention is needed in the treatment planning system when using these carbon fiber immobilization devices.

Keywords: Carbon Fiber, Quality assurance, Beam attenuation

1. Introduction

Treatments setup and reproducibility are essential in radiotherapy. The use of immobilization devices ensures the stability of the patient's position during and subsequent treatments. Although these devices are important, they are made of material that attenuates the incident beam, thus interfering with the tumor dose coverage, and altering the dose distribution. Furthermore, there is ample evidence that using carbon fiber immobilization devices results in the loss of the skin-sparing effect.

Several authors [1-6] have investigated different aspects of the radiation beam attenuation and surface dose of the linear accelerator (linac) couch top, chiefly made of carbon fiber by assessing its characteristics. They do not cause any computed tomographic (CT) artifacts and exhibited a high mechanical strength. Further, they showed a high beam transmission and a low specific density, leading to its widespread application in immobilization devices.

The belly board considered in this study, is made of carbon fiber. It is primarily used to decrease the volume of the irradiated small bowel during prone pelvic radiotherapy. It allows for the small bowel to shift and constrict because of its configuration. Its impact has become paramount mainly in the volumetric modulated arc therapy (VMAT) treatments. However, it is patient-dependent due to the physical body load variability. Thus, patient position will be affected, leading to a trade-off with bowel toxicity. Allal et al., [7] revealed in previous studies, that a combination of a belly board with the prone position is susceptible to setup errors. They found an increased reproducibility displacement in the anterior-posterior direction with a belly board compared to no belly board in the prone position. In addition, several reports [8-9] have shown the carbon fiber immobilization devices to be another source of beam attenuation coupled with the couch top. They concluded that a failure to consider these inherent factors will result in skin or target dose change.

To date and our knowledge, no study was undertaken to investigate the carbon fiber belly board beam attenuation. The report aimed to elucidate the carbon fiber belly board attenuation at various gantry angles for a 10 × 10 cm^2 field size using 6 and 18MV photon beams.

2. Materials and Methods

All measurements were acquired through a Varian 21 EX (Varian Medical Systems, Palo Alto, CA) dual photons energies (6 and 18 MV) using a 30 × 30 × 30 cm^3 solid water phantom placed at a 100 cm source-to-surface distance (SSD). The data were collected via an Accredited Dosimetry Calibration Laboratory (ADCL) calibrated Farmer-type chamber Exradin A12 and an electrometer A MAX4000 (Standard Imaging, Madison, WI). The measurements were performed with and without the carbon fiber belly board (CIVCO, Orange City, IA, USA) at variable gantry angles starting at 180 degrees with 10 degrees increments to 120 degrees. The carbon fiber belly board components whose goal is to decrease the irradiated small bowel volume during prone pelvic radiotherapy are illustrated in Figure (1). It is composed of a caudal aperture for the pubic bone position while the central portion aid in the forward compression of the small bowel towards the major aperture. Also, the rooted fiducial crosshair is used as a secondary setup reference. Figures (2a, b) displays the experimental setup for the beam attenuation measurement through the carbon fiber belly board and solid water slabs. The ionization chamber was placed at the isocenter with 10x10 cm^2 field size and exposed to 100 MU. The resulting percentage attenuation was then calculated as:

$$\text{Attenuation} = (1-D_c/ D_{nc})*100\% \quad (1)$$

where Dc represents the charges measured with the beam passing through the carbon fiber belly board and Dnc represents the charges measured without the carbon fiber belly board.

3. Results

A beam attenuation of carbon fiber belly board was measured for 18 and 6MV photon energy at 10x10 cm2 field size. A graphical representation of the frontal and sagittal view of a patient undergoing volumetric modulated arc therapy (VMAT) pelvis irradiation using the carbon fiber belly board is shown in Figures (3a, b). The data were enabled by using an ionization chamber through a combination of belly board and water slabs. The magnitude of the beam attenuation measured by the ionization chamber through the couch and the combination of the couch and belly board is expressed in Figure (4), depicting the charges collected as the gantry angle varies. Table 1 summarized the calculated attenuation for both energies. The magnitude attenuation of 18 MV photons beams was lower compared to 6 MV. In fact, it was 3.467 ± 1.538% and 2.225 ± 0.894% for 6 and 18 MV, respectively at 10×10 cm^2 field size.

Figures (5a, b, and c) showed the angular distribution of the carbon fiber belly board attenuation for both energies. As estimated, all measurements show higher attenuation values as the gantry angles increases. This is in part due to the beam obliquity as the path length through the couch, belly board and water slabs increases. The highest beam attenuation was detected at 130° gantry angle for both energies yielding an attenuation of 5.77% and 3.67% for 6 and 18 MV, respectively. The least attenuation was observed at 120° gantry angle with 1.15%, 1.41 % for 6 and 18 MV, respectively.

4. Discussion

The objective of this study was to perform quality assurance for a new immobilization device. Due to their abundance and widespread application, it is incumbent to check for the material integrity, strength, durability, and beam attenuation for the treatment planning system (TPS) where different materials densities have been configured. One of the most vital benefits of the megavoltage beam in radiotherapy is its skin-sparing effect. Couch attenuation coupled with immobilization devices made of carbon fiber supplants the buildup region and lessens the skin-sparing effect resulting in an increased skin reaction. [10]

In this report, the calculated beam attenuation is in agreement with that of the manufacturer: 2.8% vs. 3.467±1.538%, (our measurement) for 6 MV photon beams. The results revealed higher attenuation at 6 MV compared to 18 MV due to beam hardening and emphasized the bolus effect. Besides, the results demonstrated that the attenuation rises with increasing beam obliquity and is angular dependent [11]. Anjanappa et al., [12] reported on the benefits of using the belly board in terms of reducing the setup error and acute small bowel toxicity. Mok et al., [13] echoed the same sentiment by highlighting the improvement in the clinically relevant doses to the small bowel in the treatment of rectal carcinoma. Indeed, several reports supported prone position using belly board for pelvic radiation. [14-16]

While these events may influence the dose distribution, they are not presently taken into account in some commercially available TPSs nor the full impact of these immobilization devices have been elucidated. The reliance on manufacturer account should be examined by a quality assurance. It is reasonable to apply the characteristics of well-discussed carbon fiber couch tops to the carbon fiber belly board.

5. Conclusion

We have investigated the beam attenuation through the carbon fiber belly board as a function of photon energy and gantry rotation. The obtained results showed a more pronounced beam attenuation at 130° angle incidence for both energies regardless of belly board or not. These attenuation measurements might be a valuable verification tool to substantiate the manufacturer's claims to be considered in the treatment planning system.

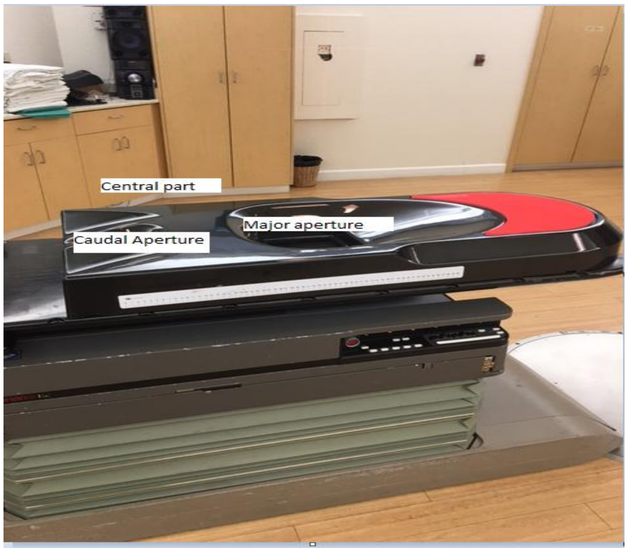


Figure 1: Illustration of the carbon fiber belly board used in prone pelvic irradiation

Figure 2a: Setup for the beam attenuation measurement as a function of photon energy and gantry rotation through 10 cm solid water slab

Figure 2b: Setup for Setup for the beam attenuation measurement as a function of photon energy and gantry rotation through 10 cm solid water slab and a carbon-fiber belly board

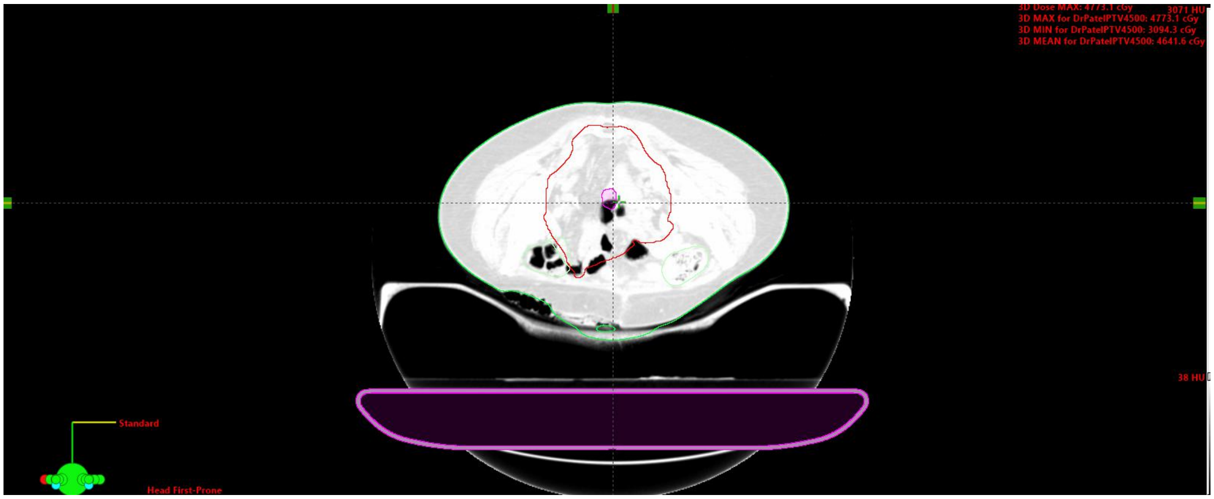


Figure 3a: Frontal view of a patient undergoing VMAT pelvis irradiation using Carbon Fiber belly board (180x25 = 4500cGy)

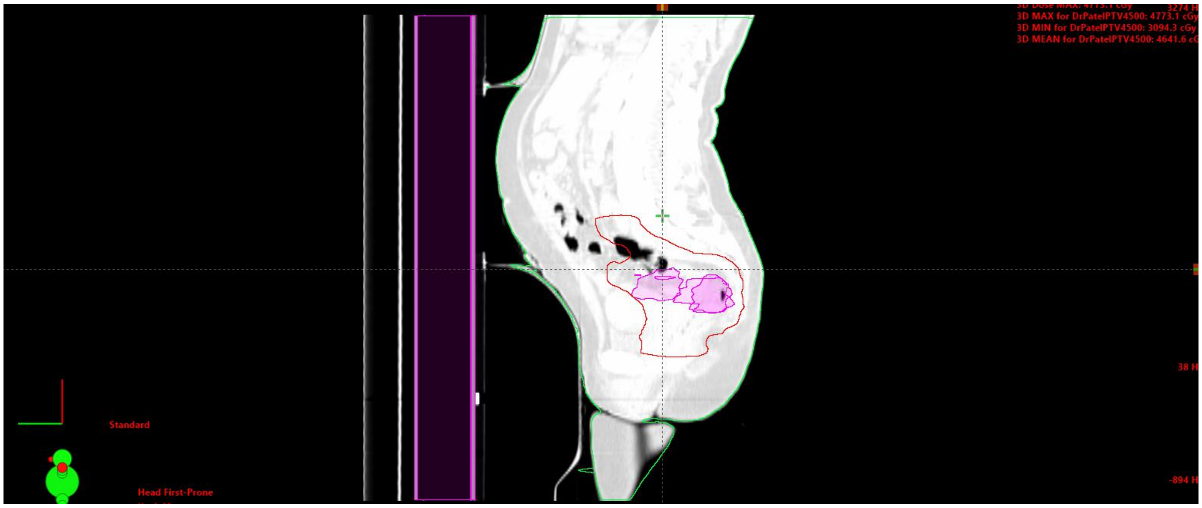


Figure 3b: Sagittal view of a patient undergoing VMAT pelvis irradiation using Carbon Fiber belly board (180x25 = 4500cGy)

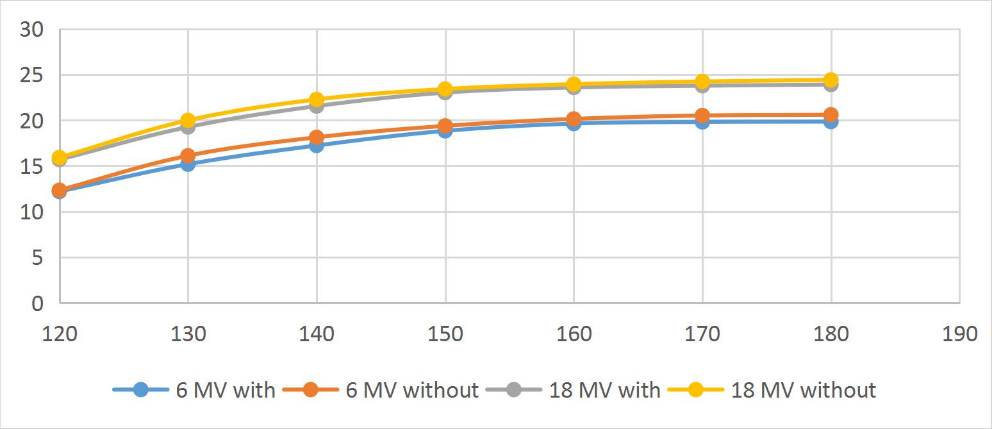
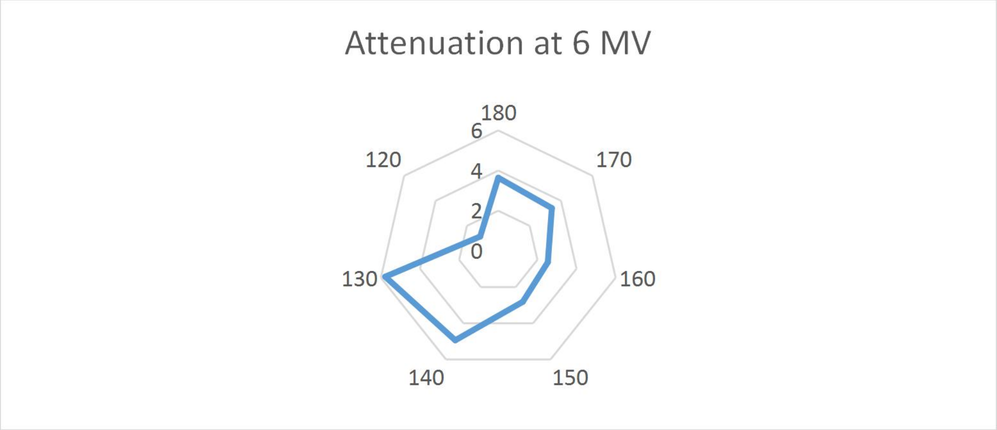
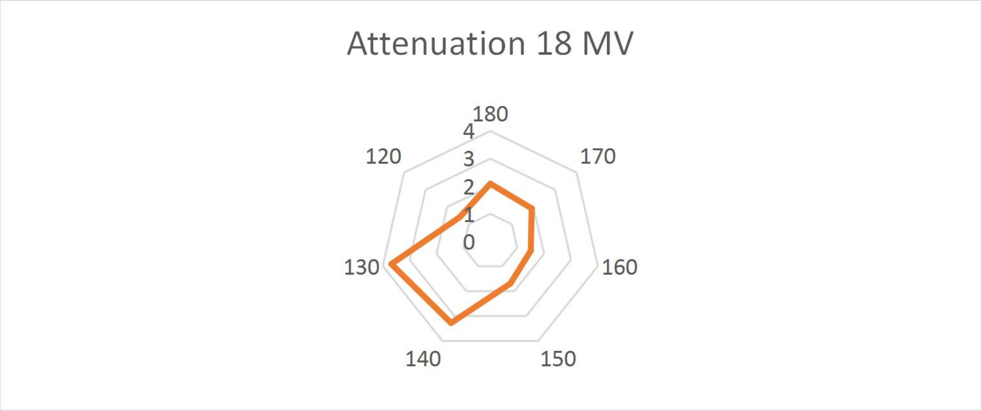


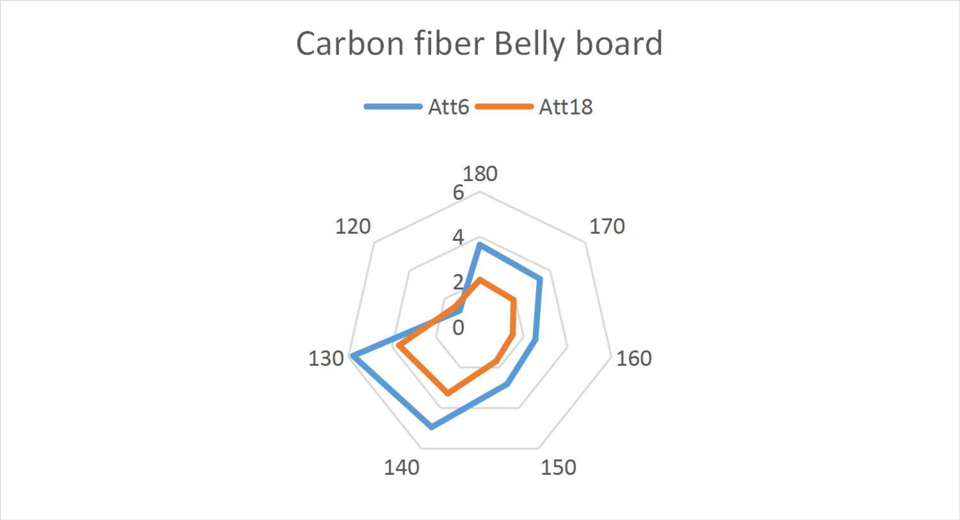
Figure 4: Charges collected during angular distribution for 6 MV and 18 MV for 10x10 cm^2 field size. The x-axis denote gantry angle in degree and y-axis charged collected in nC



Figures 5a: **Angular distribution of attenuation for 6 MV photon beam**



Figures 5b: **Angular distribution of attenuation for 18 MV photon beam**



Figures 5c: **Angular distribution of attenuation for both 6 MV and 18 MV photon beam**

Table 1: Calculated beam attenuation using an ionization chamber for 6 and 18 MV at variable gantry angles with 100 MU and a field size of 10X10 cm^2

Angle degrees	Attenuation (%)	
	6 MV	18 MV
180	3.643	2.090
170	3.414	1.919
160	2.533	1.540
150	2.814	1.688
140	4.940	3.279
130	5.776	3.679
120	1.151	1.414
Average	3.467	2.225
Std	1.538	0.894

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