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Effect of Carbon Fiber Couch Density on Best Agreement between Monaco Treatment Planning System Calculated and Measured Doses

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We investigate the impact of the table's electronic density on the calculated and received dose for the energy 6MV. And we determine the density of the carbon fiber and foam with the best agreement between the measured and Monaco treatment planning system calculated dose.

1. Introduction

The devices close to the patient act like bolus when the beams pass through them, by increasing the skin dose and shifting the depth dose curve toward the patient surface, consequently reducing the target dose [1-4]. The medical physicist can have measured the correction factors of the perpendicular beams and apply it manually to the monitor units (MU) calculation unfortunately, it was not the case for the beams passing obliquely through non uniform portions of the devices. Furthermore, a greater fraction of the dose delivers from posterior angles using the Arc techniques. The intensity modulated radiation therapy techniques (IMRT, VMAT) allows for highly conformal dose distribution and the possibility to increase the target’s dose, while reducing the dose to adjacent organs at risk [5], and decreasing the treatment margins to limit the normal tissue toxicity [6,7].

In order to determine accurately the location of the target during the treatment, many imaging techniques have recently been introduced called Image Guided Radiation Therapy (IGRT) [8]. The intersection of the couch and the X-ray projections during the treatment and the images acquisition show the importance of the material making up the couch. The carbon fiber is the material of choice for the modern radiotherapy couches, with high tensile strength and rigidity and extremely light with low density [9].

The attenuation of high energy photon beams by carbon fiber is less than the hardboard, copolyester and polymethylmetha-crylate (PMMA) [3,10,11]. The available carbon fiber couches are as follows: Ibeam Evo Couch top EP (Medical Intelligence, Germany) [12], Sinmed Mastercouch (Sinmed, Recuwijk, the Netherlands) [13], MED-TEC (USA) couch, BrainLAB imaging couch top [14], contesse tabletop (Candor Aps, Denmark) [15], Kvue IGRT Couch top (Qfix Avondale, PA, USA) and Dignity Airplate (Oncolog Medical AB, Uppsala, Sweden). The attenuation of some of them have already been evaluated [13, 14, 16,17]. To avoid the under-dose of the target and the increase skin dose, some correction has to be applied for patient treatment planning [18-23].

The photon attenuation through the headrest and frameless extension has been shown to be insignificant [14]. The modern treatment planning systems (TPSs) generally allow contouring and naming any pixel as part of the body contour and will then the dose calculated accordingly. Hence, they are not included in this study. The objective of our study was to investigate the impact of the Ibeam Evo couch top on the treatment planning using the Monaco TPS version 5.11.02 and to determine the densities of the carbon fiber (CF) and the foam (F) with excellent agreement between measured and calculated dose. However, clinically relevant skin toxicity due to the passage of beams through the couch top and immobilization services has been reported in the literature [24-26].

2. Methods and Materials

Hexapod Ibeam Evo-couch top (HIECT) is a carbon fiber radiation therapy table. It has CF plates sandwiched with a plastic foam cone. Its carbon fiber construction ensures that no metal parts are used in the entire treatment area.

The HIECT is 53cm width, 200.00cm length and has a 5.00cm (1.2 Cm water equivalent) thickness of which 0.2cm per plate is made up of CF. CF thickness increases to 0.45 Cm toward the edges of the couch [27]. It weighs 11.9kg (just couch top) and can hold a maximum load of 185kg. There are also couch extension (headrest) 53.00cm x 65.00cm x 2.00cm. The thickness of the CF extension is 2 x 0.75cm. The entire HIECT is designed for remote robotic control capability with 6 degrees of movements including pitch, roll and yaw. The Elekta Versa-HD is equipped with collimator having 160 leaves each with 0.5cm thickness.

Phantom solid water was used for the dose verification measurement. Three slabs of solid water (30x30)cm^2 was used, 2 outer slabs were 4.5 cm thick and the middle slab was 2cm thick, and had a hole which allowed for the insertion of the ionization chamber. The depth of the center of the ionization chamber (Farmer 0.65 cc) was 5.5cm (4.5cm + 1cm). The solid water phantom was scanned with a Siemens Scanner then its data was brought into the planning system Monaco. The dose was calculated using the Collapse Cone Algorithm. The body of the phantom was generated automatically then verified on each slice. The simple Elekta couch (the couch model) was imported and placed accurately such that the TPS takes on consideration of the couch for the dose calculation and should be placed the couch removal plane below the couch model. The dose was calculated at the center of the ionization chamber (which was the isocenter of the plan i.e., at the depth of 5.5cm in the phantom) for 10x10cm^2 field size for 100 MU for different gantry angles from 180° to 100° counter clockwise in 10 degree increments. And different values of the CF and F densities to find the correct densities for the couch model.

The CF and F densities were varied from 0.4 g/cm^3 to 0.7 g/cm^3 and 0.02 g/cm^3 to 0.1 g/cm^3, respectively (Table 1). For the measurement dose, the phantom was centered on the couch left to right and replicating the planning setup. The ionization chamber Farmer was connected to the PTW Freiburg Unidos 1002 Electrometer and placed at the isocenter of the linear accelerator which was calibrated to deliver 1 CGy per MU at Dmax. Then the dose was measured at the depth of 5.5cm in the phantom for different gantry angles as in the TPS and no measurement were carried out from 180° to 270°, since Spezi and Ferri [28], had previously demonstrated that any angular dependence would be symmetric. For each setup, three repeated measurements were recorded for a dose of 100 MU delivered at 400 MU/min and an average value computed.

Concerning the data analysis, we computed the average and the sum of the deviations (Δcm) between the calculated dose (Dc) and the measured one (Dm), where:

$$\Delta cm = (Dc - Dm) / Dm \times 100 \qquad (1)$$

The best model was the one with the least average and sum of the deviation from zero. Furthermore, we also used the student t-test, where the difference between, calculated and measured is significant if the p-value is less than 0.05. On the other hand, the attenuation of the beam through the couch was also estimated from the TPS for different angles by using the following equation:

$$\text{Attenuation TPS} = ((\text{Dose without Couch} - \text{Dose with Couch})/\text{Dose without couch}) \times 100 \qquad (2)$$

3. Results

The Hexapod Ibeam Evo Couch Top's modeling in the Monaco TPS using different combinations of CF and F densities are presented in Table 1 for the X-ray 6 MV and the field size (10x10) Cm^2.

The mean deviation of the TPS dose from the measured dose was calculated for different Gantry Angles and densities combinations of CF and F using the equation (1), see the (Table 2). Since the combination which had the least deviation from zero provided the least agreement between the predicted Monaco TPS and measured dose, the combination of the CF density 0.55g/cm^3 and the F density 0.03 g/cm^3 provided an excellent agreement between the Monaco TPS and the measured dose, with an Average = +0.203% and Sum = +1.818%, as shown in Table 2. The worst agreement measured/calculated was for the Average =-1.515% and Sum =-13.634%, which corresponds to the density 0.7 g/Cm^3 and 0.1 g/Cm^3 of the CF and the F, respectively.

Angle	*Measured Dose (CGy)*	*Monaco treatment planning system predicted dose (CGy)*							
		Without Couch	*CF 0.46 F 0.05*	*CF 0.55 F 0.03*	*CF 0.5 F 0.03*	*CF 0.46 F 0.1*	*CF 0.6 F 0.1*	*CF 0.6 F 0.02*	*CF 0.7 F 0.1*
180	112.49	113.9	111.3	111.2	111.4	110.5	110.0	111.5	109.6
170	112.8	113.5	110.9	110.8	111.0	110.1	109.6	111.3	109.2
160	110.81	112.5	109.7	109.6	109.8	108.9	108.3	109.9	107.9
150	108.48	110.7	107.7	107.6	107.8	106.8	106.1	107.9	105.7
140	104.32	107.6	104.2	104.1	104.3	103.2	102.5	104.2	102.0
130	98.029	102.5	98.7	98.7	98.9	95.5	96.8	98.8	96.3
120	88.554	92.9	89.00	89.7	89.3	87.5	86.9	89.3	86.4
110	69.551	77.1	74.1	73.9	74.1	72.6	72.7	73.8	72.2
100	65.155	64.8	64.7	64.7	64.7	64.7	64.7	64.7	64.7

Table 1: The measured and calculated dose for the photon 6MV and (10x10) Cm^2 with the seven CF and F densities combinations and different gantry angles

The student t-test showed that the difference between the calculated and the measured dose were statistically significant with a p-value of 0.008 and 0.021 for (10x10) Cm^2 without couch top and with couch (CF 0.7 g/Cm^3 and F 0.1 g/Cm^3), respectively and insignificant with the p-value > 0.05 for the other density combinations, see (Table 2).

Angle	*Measured Dose (CGy)*	*Percentage deviation of the Monaco calculated dose to measured dose*							
		Without Couch	*CF 0.46 F 0.05*	*CF 0.55 F 0.03*	*CF 0.5 F 0.03*	*CF 0.46 F 0.1*	*CF 0.6 F 0.1*	*CF 0.6 F 0.02*	*CF 0.7 F 0.1*
180	112.49	1,250	-1,057	-1,146	-0,968	-1,769	-2,213	-0,880	-2,569
170	112.8	1,266	-1,684	-1,773	-1,595	-1,766	-2,830	-1,329	-2,569
160	110.81	1,525	-1,001	-1,091	-0,911	-1,723	-2,265	-0,821	-2,626
150	108.48	2,046	-0,719	-0,811	-0,626	-1,548	-2,193	-0,534	-2,562
140	104.32	3,144	-0,115	-0,210	-0,019	-1,073	-1,744	-0,115	-2,223
130	98.029	4,560	0,684	0,684	0,888	-0,539	-1,253	0,786	-1,763
120	88.554	4,907	0,503	0,616	0,842	-1,190	-1,867	0,842	-2,432
110	69.551	10,853	6,540	6,252	6,396	4,383	4,527	6,109	3,808
100	65.155	0,544	-0,698	-0,698	-0,698	-0,698	-0,698	-0,698	-0,698
Sum %		30.095	2.453	1.823	3.309	-5.923	-10.536	3.360	-13.634
Average %		+3.344	+0.273	+0.203	+0.368	-0.658	-1.171	+0.373	-1.515
p-value		0.008	0.985	0.932	0.859	0.131	0.057	0.820	0.021

Table 2: The 6 MV Measured and calculated dose percentage deviation for the field size (10x10) Cm^2 with different CF and F densities' combinations and gantry angles

On the other hand, the attenuation of the HIECT was determined from the Monaco TPS calculated dose at the isocenter with and without HIECT using the equation (2). The TPS predicted attenuation range from 2.370% for the normal incident 180° to 4.15% at the oblique incident 110 degree, see (Table 3). These results are compared to the Ibeam Evo couch top measured attenuation (2.7% - 4.6%) reported by Smith et al [12]. They had as maximum difference between the collapsed cone predicted attenuation and the measured one 1.6% for 6MV and 0.8% for 10MV [12].

Angle	*TPS Without Couch*	*TPS with Couch (CF 0.55 F 0.03)*	*Attenuation TPS*
180	113.9	111.2	2.37 %
170	113.5	110.8	2.378 %
160	112.5	109.6	2.577 %
150	110.7	107.6	2.8 %
140	107.6	104.1	3.246 %
130	102.5	98.7	3.7 %
120	92.9	89.7	4.09 %
110	77.1	73.9	4.15 %
100	64.8	64.7	0.15 %
Sum			25.465
Average			2.829
p-value		0.002	

Table 3: Attenuation TPS of the photon 6MV and the field size (10x10) Cm^2 for different Gantry angles.

4. Discussion

The presence of the carbon fiber couch top between the patient and the Beam source increases the surface dose in the buildup region [12, 20]. The carbon fiber couch attenuation ranges from 2% for normal incident through the central uniform portion to 6% for highly oblique beams and can reach 17% for more dense sections [29]. These values increase with the combination of the couch and immobilization device and skin doses can reach 100% of dose maximum [29]. This is important as it represents a clinically unacceptable difference between what dose we think a plan will deliver to a patient and the reality of what is being delivered. So the measurement should be made to verify the planning system calculation for each type of device. Gerig et al [20] reported that the effect of the Ibeam Evo carbon fiber couch on beam attenuation for a (10x10) Cm^2 field size was about 2.5% in its central region for 6MV. The study of Smith et al on dosimetric characterization of the Ibeam Evo carbon fiber couch,[12] showed that the 6MV measured attenuation (10x10) Cm^2 varied from 2.7% (normal incident) to 4.6% (oblique incident) and from 1.9% to 4.0% for a 10MV beam. Our calculated attenuation results from 2.37% to 4.15% for a 6MV beam (10x10) Cm^2 are similar to those reported by Smith et al since there is an absolute error of ±1.2% for 6MV between the calculated and the measured attenuation and some differences in attenuation were observed dependent on how the couch contoured [12].

Also, the measured performed on Elekta Synergy in Wurzburg, Germany [30], show that the attenuation at 6MV for the perpendicular incidence is 2.4%. In the study of Njeh et al [31], the predicted attenuation through the couch by Pinnacle TPS and iPlan RT dose TPS are (1.99% - 5.7%) and (3.4% - 9.8%), respectively. So, it has been suggested that to reduce the uncertainties introduced by the couch, the attenuation effects of the couch should be modeled in treatment planning systems such as Philips Pinnacle [23, 32, 33], Varian Eclipse TPS [21, 22], CMS XIO [12, 20], Theraplan Plus [19]. The Smith et al [12], measured carbon fiber and foam densities are $0.07 g/Cm^3$ and ($0.41 g/Cm^3$ – $0.64 g/Cm^3$), respectively. And the Elekta quote densities of (0.0750 ± 0.0005) g/Cm^3 for the foam and (1.7 ± 0.1) g/Cm^3 for the carbon fiber. Because of this discrepancy between the quoted and the Smith measured densities, it is better to determine the carbon fiber and foam densities with the best agreement between measured and predicted TPS doses. In this study the CF density of $0.55 g/Cm^3$ and the F density of $0.03 g/Cm^3$ show the best agreement between the measured and the calculated doses. Our results are similar to those reported by Njeh et al [31], and lower than the Mihaylor value $0.7 g/Cm^3$ for the FC and $0.1 g/Cm^3$ for the F [23]. The $0.7 g/Cm^3$ and the $0.1 g/Cm^3$ represent the worst for us with significant difference between the measured and the predicted TPS doses. All the studies showed that the beam attenuation and the agreement between the measured and the calculated dose depend on the energy, field size, the incident angle and the couch top densities. We further found attenuation to be gantry angle dependent, with the highest attenuation recorded at 110°- at which the couch attenuated the 6MV photon beam by 4.15% for (10x10) Cm^2 field size. Njeh et al [31], found that the highest Pinnacle TPS attenuation at 110° (5.7%) and at 120° with the iPlan TPS (9.4%). A limitation of this investigation is that it does not address increased skin dose, which has been reported elsewhere [3, 33-35].

5. Conclusion

The results of this study provide accurate quantitative data on the attenuation of the couch top and the densities of the carbon fiber and the foam core when used on the Versa HD Lineac, which can be in treatment planning calculations. The carbon fiber couch top attenuates the radiation dose, depending on the beam energy, entry angle and field size. Due to the homogenous construction oblique beams have to pass through more carbon fiber material then the increase of the attenuation as shown in our investigation. The Monaco treatment planning system generated more accurate results when including the couch in the plan treatment and there is a good agreement between measured and calculated dose with the densities $0.55g/Cm^3$ and $0.03g/Cm^3$ of the carbon fiber and the foam core, respectively. The statistical analysis shows that the difference between the calculated dose without insertion of the couch and the measured one was very significant with an p value 0.008. So, our results indicate that, for all treatments involving the posterior beams is recommended to include the table in treatment planning.

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Conflict of interest

The Author declares that she has no competing interest associated with this manuscript.

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