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Implementation of carbon fibre treatment couches in the XiO® and Monaco® Treatment Planning Systems

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Abstract

Purpose: Carbon fibre treatment couches on linear accelerators provide a strong, rigid framework for patient support. Patient safety is a priority, therefore the dosimetric properties of treatment couches need to be accurately incorporated in treatment plans, to minimize differences between planned and delivered dose. This study aims to determine the attenuation effect of treatment couches for 3-D Conformal Radiotherapy (3-D CRT) and to validate the implementation thereof in the XiO and Monaco treatment planning systems (TPS).

Material and methods: Attenuation measurements were performed on the ELEKTA Connexion couches of the ELEKTA Precise and Synergy-Agility linear accelerators. Measurements were made at 10° intervals in RMI-457 Solid water (30 cm x 30 cm x 30 cm) using a PTW Farmer-type ionization chamber (TW30013) positioned at the accelerator's isocentre. The percentage attenuation was calculated as the ratio of the electrometer readings for parallel-opposed fields. The Computed Tomography (CT) data sets of the set-ups were obtained on a Philips Big Bore 16-slice CT scanner and exported to the TPS. The individual couch structures were delineated and electron density (ED) values were assigned using the commissioned CT-to-ED curve. Test treatment plans were generated with 100MU per field at 10° gantry intervals.

Results: The percentage attenuation was determined to be within 2% and 3% for beams perpendicular to the couch surface for XiO and Monaco, respectively. The maximum attenuation was observed for oblique fields which was significantly higher than the manufacturer specified values. TPS validation showed an agreement to 1% for XiO and Monaco. At extreme oblique angles, both planning systems overestimated this effect up to a maximum of 4%.

Conclusions: Couch attenuation differs significantly with gantry angle and beam energy. As a result, the treatment couch models should be included in all treatment planning calculations.

Key words: treatment planning; carbon fibre couches; attenuation.

Introduction

The treatment of cancer has undergone major progress in the past decades with many previously untreatable malignancies being successfully treated by a combination of various treatment modalities.[1] External Beam Radiotherapy (EBRT) plays an important role in this treatment regimen. Radiation treatment planning is a complex process and it involves a number of processes and technologies. These include, but are not limited to, the acquisition of patient data for tumour localization and organ at risk identification, and determining the dose distribution due to incident beams using the Treatment Planning System (TPS).[2]

The International Commission on Radiological Protection (ICRP) produced publication 112 (ICRP 112) on Preventing Accidental Exposures from New External Beam Radiation Therapy Technologies.[3] This report which focuses on lessons learnt from accidental exposures is intended to be a valuable resource for radiation oncologists, medical physicists, dosimetrists and regulators. It concluded that one of the important factors that need to be taken into account when the TPS is used to calculate dose distributions due to incident beams of radiation is to quantify the attenuation of the beam due to the treatment couch (and other auxiliary devices used for patient immobilisation).[3]

Carbon fibre couch tops on modern linear accelerators provide a number of advantages which include a strong, rigid framework providing patient support with minimal sagging, artefact-free cone-beam CT, and planar kV imaging capabilities.[4]

A study conducted by Meara and Langmack concluded that attention must be paid to irradiating through the couch at oblique angles.[5] A similar study carried out by Vieira et al yielded a 15 % beam attenuation for a posterior oblique 6 MV beam.[6] These findings lead McCormack et al to implement a change in attenuation with gantry angles for their TPS.[7]

In a report titled "Dosimetric effects caused by couch tops and immobilization devices", the AAPM Task Group 176 reported consensus between researchers that a significant increase in surface dose can be measured when beams first transit carbon fibre couch tops at normal or oblique incidence.[8] Modern day carbon fibre couches exhibit up to 15% beam attenuation at oblique angles with 2-5 % being typical values.[8,9]

This range of values reported in the literature is mostly due to the individual couch manufacturing processes and designs employed by different vendors.[8] As a result the dosimetric properties of treatment couches need to be carefully examined by users and be taken into account when dose distributions are calculated on the TPS. Failure to do so leads to an observed bolus effect where the couch tops act as a bolus material, i.e. increasing skin dose and decreasing dose at depth. The clinical manifestation of this effect is most commonly reported by researchers as reduced Planning Target Volume (PTV) coverage.[9,10]

In summary, the inclusion of couch structures in the clinical environment requires stringent commissioning and validation before it is implemented in TPS calculations.

This study investigates the ELEKTA Connexion modular patient support devices in two different configurations, i.e. Connexion with Central Opening Module and Connexion with Imaging Module suitable for Image-guided Radiotherapy techniques. The treatment couches consist of a low-density foam interior surrounded by a thin carbon fibre layer. This paper reports on the beam attenuation of Connexion modular patient support devices for different beam energies, and different gantry angles. The accuracy of CMS XiO v5.10.01 (CMS Inc., Saint Louis, MO, USA) and ELEKTA Monaco v5.11.02 (ELEKTA CMS, Maryland Heights, MO, USA) for calculating the beam attenuation due to the presence of the treatment couch is also reported.

Materials and Methods

Couches

The Connexion carbon fibre treatment couches are constructed from a foam material sandwiched between two thin layers of carbon fibre. The thickness of the carbon fibre increases towards the edges of the treatment couch. **Figures 1a-b** indicate the computed tomography acquired cross-sections of the two different configurations in use in the department.

Water-equivalent phantoms

Attenuation and TPS measurements were performed in a cubic phantom constructed by combining RMI-457 Solid Water® slabs of 30 cm x 30 cm x 30 cm. The central slab has a bore-hole running along the center to allow the insertion of a PTW 0.6 cm^3 Farmer-Type ionisation chamber (PTW, Freiburg, Germany).

Point dose measurements

Point dose measurements were performed by using an ELEKTA Synergy Platform combined with Agility treatment head and Precise linear accelerators (ELEKTA Oncology Systems, Crawley, U.K.) capable of generating 6, 10, 18 MV, and 6 MV photon beams, respectively. The cubic phantom was fitted with a PTW Farmer-type 0.6 cm^3 ionisation chamber paired with a PTW Unidos E electrometer (PTW, Freiburg, Germany). The phantom was positioned such that the center of the ionisation chamber was at the radiation isocentre (**Figure 2**)

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Figure 1. Cross-sections of the (a) ELEKTA Connexion Solid Inlay and (b) ELEKTA Connexion IGRT treatment couches with contoured couch structures.

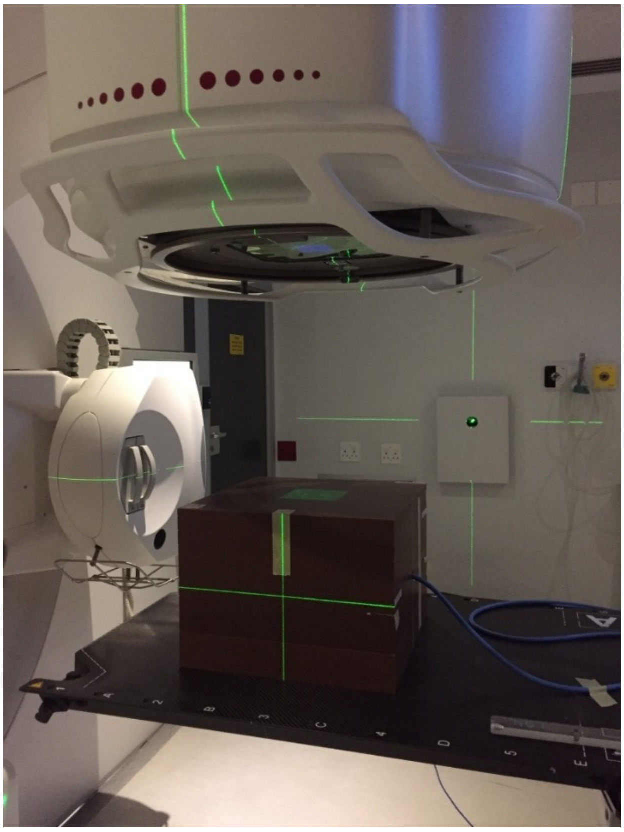

Figure 2. Phantom setup and positioning for the ionisation chamber measurements.

For gantry angles ranging from 0° to 350°, 100 MU exposures were made in 10° increments for energies ranging between 6 – 18 MV. The corresponding open beam angle was used to calculate the percentage attenuation according to **Equation 1**:

$$Attenuation = \frac{R_{open} - R_{couch}}{R_{open}} \times 100\ \% \qquad \text{Eq. 1}$$

Where R_{open} and R_{couch} are the electrometer readings without and with the couch in the beam, respectively.

TPS Modelling

The cubic solid water phantom was placed on the dedicated treatment planning couch of the Philips Brilliance Big Bore 16-slice CT scanner (Koninklijke Philips N.V., Amsterdam, NL). The phantom was aligned with the external lasers and CT scanned using a standard planning protocol (3 mm slices, 120 kVp, and 512 x 512 matrix size). The data was then transferred to the CMS XiO v5.10.01 (CMS Inc., Saint Louis, MO, USA) and ELEKTA Monaco v5.11.02 (ELEKTA CMS, Maryland Heights, MO, USA) treatment planning systems. The external surfaces of the phantom were contoured on both planning systems. The external surfaces of the couches consist of a foam core surrounded by the rigid carbon fibre couch material. Two non-overlapping regions of interest were taken over multiple slices for each couch structure to obtain their respective average Hounsfield units (HU). The commissioned Computed Tomography HU to Relative Electron density calibration curve was used to assign relative electron densities to the Hounsfield units of the different couch structures. The relative electron densities assigned to the foam core and carbon fibre were 0.100 and 0.520, respectively (**Table 1**). This was identical to the findings reported by Zhang et al.[11]

For CMS XiO, care was taken to include the couch in the external contour for treatment planning. Treatment plans were generated by adding 10 x 10 cm^2 beams for all available photon energy, couch and gantry angle combinations in 10° increments. The treatment isocentre was set to the center of the cubic phantom. A dose calculation grid size of 4 mm x 4 mm x 4 mm was selected for the Superposition algorithm available on CMS XiO and 2.5 mm x 2.5 mm x 2.5 mm for Monaco's Collapsed Cone algorithm. A total of 100 MUs was delivered for each energy, couch, and gantry angle combination. The attenuation was then calculated according to **Equation 2**:

$$Attenuation = \frac{D_{open} - D_{couch}}{D_{open}} \times 100\ \% \qquad \text{Eq. 2}$$

Where D_{open} and D_{couch} are the interest point doses without and with the couch in the beam, respectively.

Results

Figures 3 and **4a-c** compare the measurements of attenuation in the cubic solid water phantom with the calculated attenuation performed in XiO and Monaco, for the two linear accelerator couch combinations, respectively.

The phantom measurements for the Connexion Solid Inlay couch show that for a 6MV beam at normal incidence the attenuation is 0.79%, increasing to a maximum of 7.14% at gantry angles of 120° and 240°. As the gantry angle is varied from normal incidence, the path length is increased, causing an increase in attenuation. Attenuation values from the planning systems show a wide range depending on the algorithm used. The XiO Superposition algorithm provides more accurate results than the Monaco Collapsed Cone algorithm. The maximum absolute difference between calculated and measured values for beam angles between 140° and 220° is 1.51 %. The accuracy of the Superposition algorithm is reduced at 130° and 230° showing an agreement of 2.37% between calculated and measured values. The Monaco Collapsed Cone algorithm produced more inaccurate results with a maximum absolute difference of 2.97% at gantry angles between 140° and 220°. The accuracy of the algorithm at gantry angles of 130° and 230° continues the trend of overestimating couch attenuation up to a maximum of 3.69%.

The phantom measurements for the Connexion IGRT couch show that attenuation at normal incidence is 2.13%, 1.38%, and 0.96% for 6 MV, 10 MV, and 18 MV respectively. Unsurprisingly the attenuation at gantry angles of 120° and 240° increases up to 4.62%, 3.58%, and 2.79% for 6 MV, 10 MV, and 18 MV respectively. The attenuation values from the planning systems show a close correlation between the XiO Superposition algorithm and Monaco Collapsed Cone algorithms. Both algorithms exhibit overestimations of couch attenuation up to a maximum absolute difference of 1.14%.

The accuracy of the calculation has been shown to strongly depend on the beam obliquity and the complexity of couch structures. The decision to include the couch in treatment planning calculations does not only depend on the ability of the treatment planning system to accurately take it into account but also depends on the practicability and the added benefit of importing the couch in treatment planning calculations. Monaco allows the user to intuitively import couch structures into treatment plans, whereas XiO requires a more detailed process as couch structure inclusion is not a standard feature. In the case of benefit associated with importing treatment couches, it is more compelling to include couch structures in complex treatment plans with multiple beams traversing through the treatment couch.

Table 1. Relative electron densities assigned to the couch structures for the ELEKTA Connexion Solid Inlay and IGRT treatment couches.

Structure	Connexion Solid Inlay Treatment Couch	Connexion IGRT Treatment Couch
Foam Core	0.100	0.100
Carbon Fibre	0.520	0.520

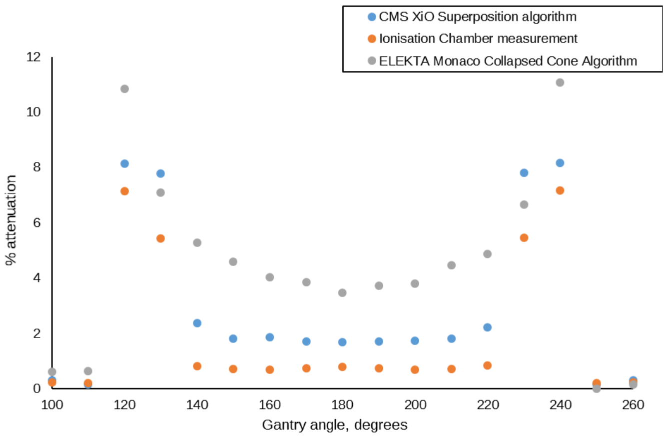

Figure 3. Connexion Solid Inlay treatment couch attenuation measurements (6MV) for CMS XiO and ELEKTA Monaco TPS compared to ionisation chamber measurements.

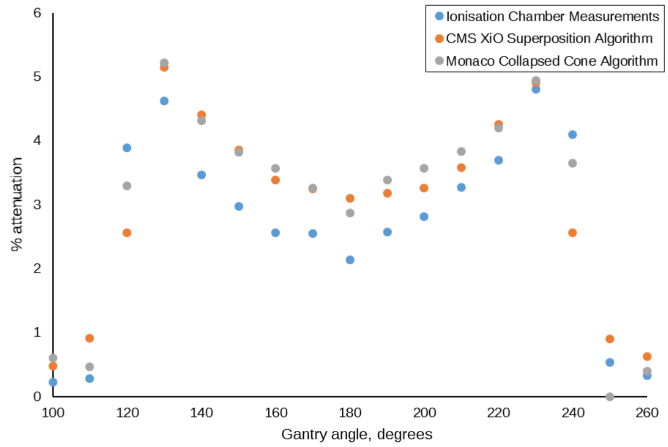

Figure 4a. Connexion IGRT treatment couch attenuation measurements for CMS XiO and ELEKTA Monaco TPS compared to ionisation chamber measurements for 6 MV.

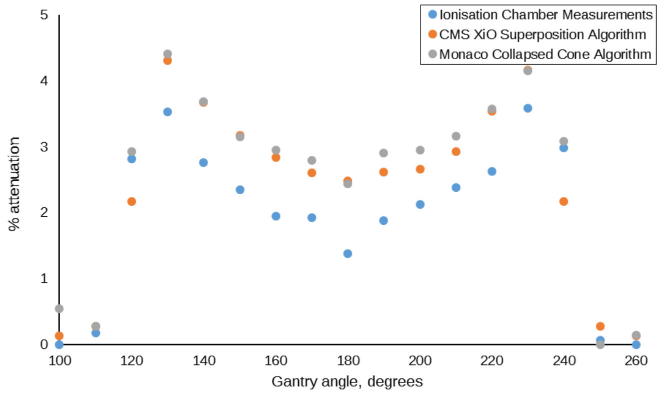

Figure 4b. Connexion IGRT treatment couch attenuation measurements for CMS XiO and ELEKTA Monaco TPS compared to ionisation chamber measurements for 10 MV.

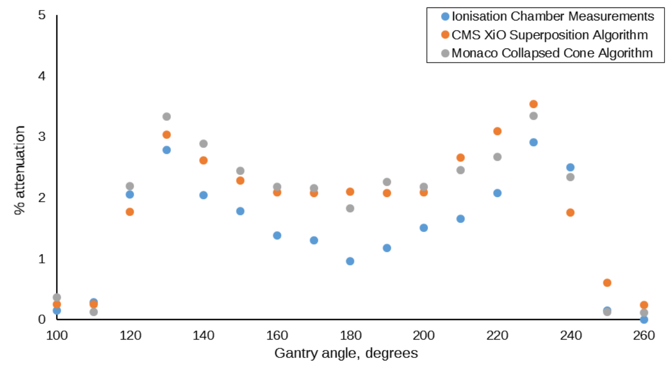

Figure 4c. Connexion IGRT treatment couch attenuation measurements for CMS XiO and ELEKTA Monaco TPS compared to ionisation chamber measurements for 18 MV.

Similarly, it might be more sensible to exclude the couch in treatment planning calculations where only one beam intersects the treatment couch as the effect on total dose error may be negligible.

Conclusions

This study investigated the dosimetric impact of the Connexion IGRT and Solid Inlay carbon fibre treatment couches and examined the accuracy of CMS XiO and ELEKTA-CMS Monaco treatment planning systems for calculating beam attenuation due to the couch structures. Ionisation chamber measurements showed that attenuation increased up to a maximum of 7.14% for oblique angles, which can have a detrimental effect on total dose errors. The accuracy of CMS XiO and ELEKTA-CMS Monaco was therefore investigated. In general, both treatment planning systems produced accurate results when using the Superposition and Collapsed Cone algorithms.

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