Monte Carlo simulation of the SIEMENS IGRT carbon fibre tabletop

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Abstract. Carbon fibre materials can provide rigid and lightweight patient support materials with low radiation beam attenuation properties. The dosimetric properties of some of these devices have been already investigated. However, the possibility to incorporate their geometrical and physical characteristics in the treatment planning process has not been yet fully investigated. This work deals with the Monte Carlo characterization and simulation of the effects of a new commercial carbon fibre tabletop on the relevant parameters of a clinical 6MV photon beam. Calculations were validated against measurements in two different experimental conditions. The agreement between experiments and calculations showed that the tabletop attenuation properties were well described with the developed MC model. The technique described in this investigation can contribute to increase the calculation accuracy provided by MCTP in the clinical practice.

1. Introduction
Intensity Modulated Radiotherapy (IMRT) provides more degrees of freedom compared to conformal techniques with a greater chance that multiple beam axis intersect the treatment table. Hence, there is an increased interest in carbon fibre (CF) materials for IMRT and Image Guided Radiotherapy (IGRT) as they can provide rigid and lightweight patient support devices with low radiation beam attenuation properties. The study of the effect on relevant beam parameters of some CF patient positioning systems have been already investigated (Vieira et al 2003, McCormack et al 2005, Spezi and Ferri 2007). However, a Monte Carlo (MC) characterization and simulation in radiotherapy clinical conditions of such materials has not yet been reported. In this work we provide a method to incorporate geometrical and physical characteristics of a commercial CF tabletop especially designed for IMRT and IGRT into the treatment planning process. We also build a MC model for this device validating our simulations versus experimental data in two different experimental conditions.

2. Materials and Methods
The Siemens IGRT tabletop (Siemens Medical Solutions, Concord, CA) is a 100% CF treatment table. The table uses a hollow slab construction design: a CF shell of \( \approx 0.2 \) cm thickness wrap a layer of foam. The tabletop is 230 cm long and 50 cm wide and has a wedged cross section design as shown in Figure 1. Some relevant technical specifications for this device are reported in Figure 2. The material specifications needed for the MC modelling of the tabletop were provided
by the manufacturer (Siemens Medical Solutions, Concord, CA). In this work the carbon fibre shell was simulated as graphite with density 2.0 g/cm$^3$. The MC code used throughout this work was BEAMnrc (Rogers et al. 1995).

In order to import both geometrical and physical characteristics of the IGRT tabletop in the MC system we CT scanned the device using a SIEMENS Emotion CT scanner and built a CT-based MC phantom (Walters et al. 2005). CT image was converted into materials and density using a dedicated CT conversion ramp. Materials conversion parameters for the CT to materials and density conversion ramp are shown in Table 1. For the simulation of the carbon fibre material we used graphite with density 2.0 g/cm$^3$ as from the PEGS4 based ICRU database (Nelson et al. 1985). For the simulation of the foam layer inside we used epoxy foam with density 0.075 g/cm$^3$. The numerical representation of the device was also saved to file for further use.

**Figure 1.** This is an image of the SIEMENS IGRT tabletop.

| Material     | CT upper bound | Density lower bound | Density upper bound |
|--------------|----------------|---------------------|---------------------|
| Air          | 35             | 0.001               | 0.010               |
| Foam         | 450            | 0.075               | 0.075               |
| Graphite     | 700            | 1.800               | 1.800               |
| Polystyrene  | 1200           | 1.060               | 1.060               |

**Figure 2.** Tabletop characteristics: longitudinal view (a) and transverse view (b) (from Spezi and Ferri 2007).

The MC model characterization and verification was carried out through two different experiments: (a) the irradiation of a RW3 cubic polystyrene phantom and (b) the 360$^\circ$ irradiation of a RW3 cylindrical polystyrene phantom (PTW, Freiburg Germany). In both cases a pinpoint chamber (type 31014: PTW, Freiburg, Germany) inserted in a special polystyrene plate. In the first experiment a percentage depth dose (PDD) was acquired by moving the pinpoint insert along the CAX and by repeating the irradiation with the same MU at each step. This was repeated for both anterior-posterior (AP) and posterior-anterior (PA) beam directions as depicted in Figure 3a. In the second experiment a 360$^\circ$ irradiation of the cylindrical phantom.
was performed, in steps of 10°, for a complete characterization of the tabletop’s attenuation properties and an accurate validation of our MC model. The experimental setup is shown in Figure 3b. A fuller description of both experimental configurations can be found elsewhere (Spezi and Ferri 2007). The clinical photon beam used in this work was a (10×10) cm² field provided by a Siemens Oncor IMRT Impression + linear accelerator operating at 6MV. Both phantoms where also CT scanned so that the experimental conditions could be replicated in the MC environment.

One of the issues arising when trying to include the dosimetric properties of linacs treatment tables in the radiotherapy planning process is that the densitometric information of the device is normally not included in the patient’s CT dataset. This is because CT patient’s bed and linac treatment tables are usually different. In order to replicate with the MC simulations the experimental conditions described above we merged the original CT scan dataset of the RW3 phantoms with the tabletop CT scan dataset already acquired. Two MC phantoms corresponding to the experiments described above were then built. This operation was performed within the Matlab¹ environment (The MathWorks Inc., Natick USA). Figure 4 depicts both original (a) and postprocessed dataset (b) for the RW3 cubic phantom. The color differences between Figure 4a and 4b are only due to an automatic rescale of the colormap and not to any change in the underlying CT data. The results of the comparison between calculations and measurements is given in the next section.

¹ http://www.mathworks.com/matlab/
Figure 4. CT scan of the experimental equipment (a) and postprocessed CT dataset showing the attached IGRT tabletop volume (cf. Figure 3a).

3. Results

Figure 5 shows a comparison between experimental data and MC calculations for the irradiation of the RW3 polystyrene cubic phantom (cf. Figure 3a). PDD for both AP and PA irradiations are reported. As expected, the MC dataset fits very well the measurements for the AP irradiation. In this case the entrance dose is 82% of the dose at depth of maximum.

In the case of the PA irradiation it can be noticed that a good agreement between MC and experiments is found below the buildup region. However in the buildup region the agreement between MC and experiments is less satisfactory (3-5%). In this case the beam entrance dose is 97% of the dose at depth of maximum and MC calculations predict a higher beam entrance dose than recorded with the ion chamber. The reason of this discrepancy is being investigated.

As shown in Figure 6 the beam attenuation of the Siemens IGRT CF tabletop varies from a minimum of $\approx 2\%$ (central axis) to a maximum of almost 5% (120 and 240 beam incidence) with respect to central axis data. In this case the comparison between MC calculations and experiments is very good for all the considered irradiation arrangements with an agreement well within 2% with ion chamber measurements. Overall, the MC model characterization of the SIEMENS IGRT tabletop can be considered very satisfactory.

4. Conclusions

We successfully modelled with the MC technique the effect produced by a new commercial carbon fibre tabletop on relevant parameters of a clinical 6MV photon beam. We devised a method to include the densitometric characteristics of the CF tabletop in the treatment planning procedure which involved the CT scan of the device. The introduction of such model in the treatment planning data can contribute to increase the calculation accuracy provided by MCTP in the clinical practice.

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Figure 5. Comparison between experimental data and MC calculations for the irradiation of the RW3 polystyrene cubic phantom (cf. Figure 3a).

Figure 6. Comparison between experimental data and MC calculations for the irradiation of the cylindrical RW3 polystyrene phantom (cf. Figure 3b)
fibre tabletop.

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