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Modelling the x-ray source for the Australian MRI-Linac

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Abstract

MRI-guided radiotherapy allows real-time imaging during treatment however the magnetic field influences the dose distribution in the patient. An accurate model of the radiation beam and the encompassing magnetic field is important to predict dosimetry changes. The purpose of this work is to develop a Monte Carlo model of the Australian MRI-Linac to be used as input into a dose calculation tool for treatment planning. The Australian MRI-Linac is a 1 T inline system with a 6MV flattening filter free photon beam. Commissioning measurements were undertaken both with and without the magnetic field present, PDDs and profiles were used to develop a model with the Geant4 toolkit. To date the model at 0 T matches within ± 2% of measured data. Ongoing work involves measurements at 1 T at various linac to MRI isocentre distances, the magnetic field model at each configuration is also under development.

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Modelling the x-ray source for the Australian MRI-Linac

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Abstract. MRI-guided radiotherapy allows real-time imaging during treatment however the magnetic field influences the dose distribution in the patient. An accurate model of the radiation beam and the encompassing magnetic field is important to predict dosimetry changes. The purpose of this work is to develop a Monte Carlo model of the Australian MRI-Linac to be used as input into a dose calculation tool for treatment planning. The Australian MRI-Linac is a 1 T inline system with a 6MV flattening filter free photon beam. Commissioning measurements were undertaken both with and without the magnetic field present, PDDs and profiles were used to develop a model with the Geant4 toolkit. To date the model at 0 T matches within ±2% of measured data. Ongoing work involves measurements at 1 T at various linac to MRI isocentre distances, the magnetic field model at each configuration is also under development.

1. Introduction

MR-guided radiotherapy offers superior soft tissue contrast and the potential to reduce current treatment margins while escalating dose to the tumour [1]. The radiotherapy beam can be adapted to deliver a more precise treatment by utilising knowledge of tumour position and shape obtained from the MRI in real time. While there are many potential advantages to this treatment technique, there are still many engineering and physical challenges which must be resolved. Understanding how the magnetic field produced by the MRI impacts dose distributions inside the patient is something which can be modelled using Monte Carlo methods. For the Australian MRI-linac [2] it is important to include the fringe field of the MRI in calculations due to the increased electron hot spot at the surface caused by this particular field [3,4]. Since current commercial treatment planning systems are not capable of modelling the complete magnetic field, including the fringe field, we have proposed a Monte Carlo dose verification system to calculate dose with and without the magnetic field. The focus of this work is to develop a model of the x-ray beam for such a system for the Australian MRI-linac.

2. Materials and Method

The current Australian MRI-linac prototype is a 1 T split-bore MRI (Agilent Technologies, Oxford UK) with a 6MV FFF horizontal photon beam (Varian Linatron-MP), and MLC system (Varian Millennium 120-leaf). The linac and MLC are mounted on a rail system so that source to imaging isocentre distance can be varied between 1.8-3.3 m.

Initial commissioning of the linear accelerator was performed prior to installation of the MRI. These measurements were acquired under 0 T conditions, and used to assist in developing an accurate model of electron beam parameters for the linear accelerator. The Monte Carlo toolkit, Geant4 [5] version 10.2.p01 was used to model the beam to obtain a close match to experiments. PDDs and profiles for the 6MV beam were taken in a water tank with a CC13 ion chamber and in solid water with Gafchromic EBT3 film. The model includes the linear accelerator treatment head, MLC and phantoms used during measurements as shown in figure 1a. Mean energy, FWHM of the energy distribution and focal spot size of the incident electron beam were optimized in the simulation to match experimental results. Measurements were taken at extended source to isocentre distances (SIDs), corresponding to the adjustable SIDs following installation of the MRI. This variation in source position means the field sizes are also variable, to keep consistent all field sizes are quoted as input into the MLC controller defined as the field size at 1 m from the source.

Commissioning measurements after installation of the MRI were performed with EBT3 film in solid water, profile shapes were cross checked with the STARCHECK$^{maxi\ MR}$ (PTW, Freiburg, Germany), all measurements were taken at an SID of 2.869 m. The Agilent MRI magnet was modelled in COMSOL Multiphysics (Stockholm, Sweden) to produce a 3D magnetic field map. Figure 1b shows simulation geometry with the MRI model displaying its cross section to visualise the coils.

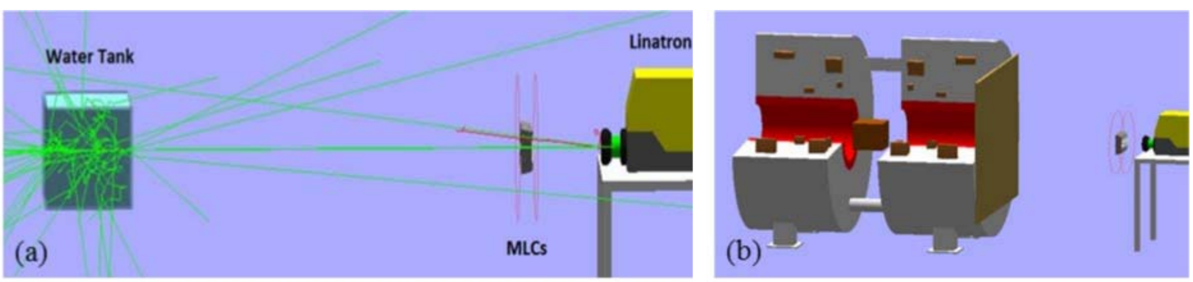

Figure 1. Geant4 model of Australian MRI-linac, 0 T setup which includes the linac, MLC and water tank (a) 1 T setup with MRI, RF panel, linac, MLC and solid water phantom at isocentre (b)

3. Results

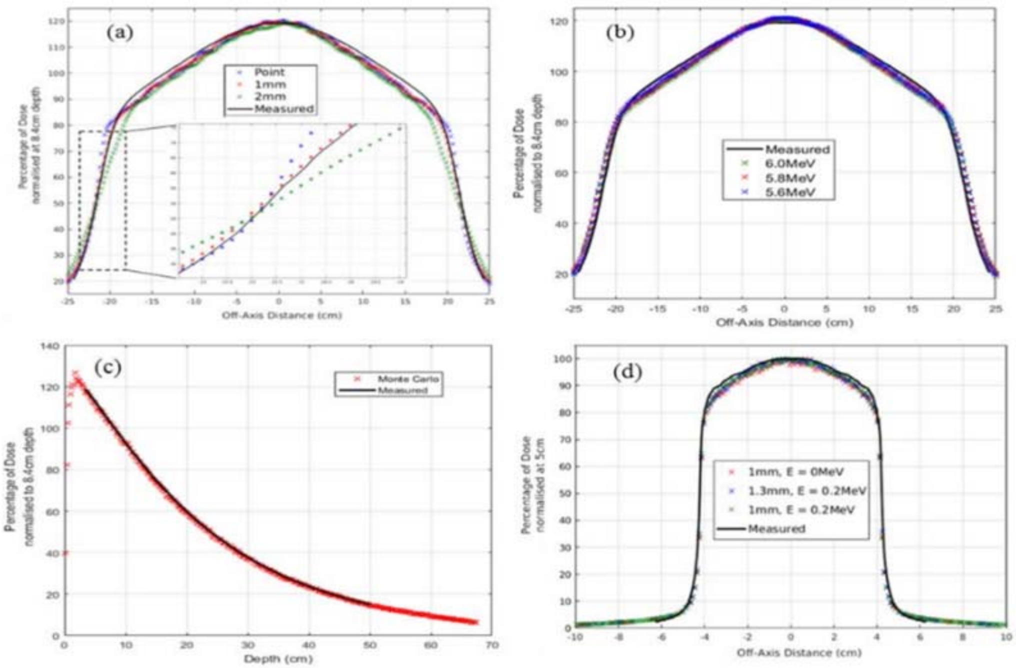

Figure 2. Comparison of measured (black) and simulated data (crosses). Open field at SID 1.9 m (a)-(c) variations in spot size of the incident electron beam (a) variations in energy of the incident electron beam (b) PDD for energy of 6 MeV and spot size of 1 mm (c). 10x10 cm^2 field at SSD 0.743 m, variation in energy spread and spot size (d)

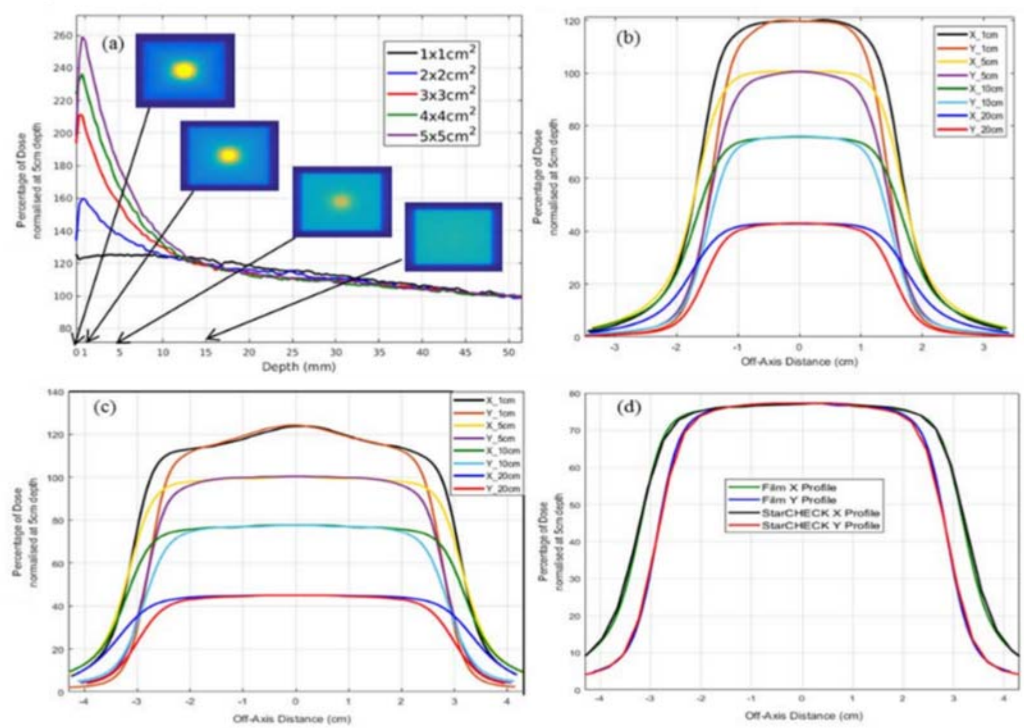

Figure 3. Measured data post MRI installation. PDDs for different field sizes, 2D dose distributions from 3x3 cm^2 field simulations overlaid (a), Profiles at different depths for 1x1cm^2 (b) and 2x2 cm^2 field (c), Comparison of film and STARCHECK$^{maxi\ MR}$ measurements at depth 10 cm for 2x2 cm^2 field (d)

4. Discussion

Open field data was collected for the initial 0 T commissioning measurements, comparing with simulations, with an incident electron beam of spot size 1mm the match of the beam penumbra is closest (figure 2a).

Energies from 5.6-6 MeV yielded similar PDDs and profiles for this SID (figure 2b, 2c). To investigate the spot size further, we took measurements at 0.743 m SSD. Varying the simulation spot size and energy spread at this SSD had minimal effects on the profiles (figure 2d). Since the SID will not be less than 1.8 m for the current system, the field sizes of interest would be 10x10 cm^2 (at 1m) or smaller, therefore the current match for 0 T data 10 cm off-axis at isocentre is sufficient.

The effects of the magnetic field on the dose distribution are dependent upon the orientation of B_0 field with respect to beam direction. In the current system the beam is parallel to the magnetic field; an advantage of this is reduced effects of the Lorentz force, however due to the magnet's fringe field we see an increased dose to the surface due to contaminant electrons being focused along the central axis [3,4]. This effect can be seen in measured data shown in figure 3a, the larger the field size the higher the percentage dose at the surface. Overlaid, on figure 3a, are 2D dose distributions from simulations where the electron hot spot can be seen through the first few millimetres of the phantom, these electrons have all been absorbed by 1.5 cm depth. Profiles taken with film for field sizes 1x1 cm^2 and 2x2 cm^2 are also shown (figure 3b, 3c). A comparison of the 2x2 cm^2 field profiles taken with film and the STARCHECK$^{maxi\ MR}$ (figure 3d) are in agreement, validating our film dosimetry methods.

5. Conclusion

A Monte Carlo model of the x-ray beam for the Australian MRI-linac system has been developed. Agreement within ±2% between modelled and measured PDDs and beam profiles was observed at 0 T. Commissioning measurements in the presence of the 1 T field have been performed and cross checked for a specific SID. Future work will involve similar measurements with the linac at shorter SIDs and further development on the magnetic field model at each SID.

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