Improving MVCBCT image quality using a Cu target with flattening filter-free LINAC

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Abstract: Megavoltage Cone Beam Computed Tomography MVCBCT is an image guided radiotherapy imaging tool used for everyday patient repositioning. Present work studies the effect on MVCBCT image quality in using a copper target in place of the original target. Monte Carlo (MC) simulations using FLUKA were carried out for the original target with flattened and unflattened 6 MV beams for different target materials and thicknesses, calculating the photon spectra incident on the phantom surface. MC simulations were also performed for the original and copper targets to calculate the local contrast (LC) in a simple phantom. Reduction is observed in the mean energy of the photon spectrum and a large increase is obtained in the low energy photons ratio when the copper and carbon targets are used in place of the original target, leading to an improvement in the quality of MVCBCT images. Further, the LC was improved by 31% when the copper target was used. The reduction in mean energy and the increase in low energy photons ratio for the carbon target was found to be higher than that for the copper target, noting that the copper target is already available in the head of most Varian LINACs for treatments requiring a higher photon energy mode (> 6MV). It can be concluded that with simple modification, using a copper target with an unflattened beam will improve the MVCBCT image quality.
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1. Introduction

Megavoltage cone beam CT (MVCBCT) is one of a number of image guided modalities that are used to reduce the physical uncertainties occurring during the course of a radiotherapy treatment, related to patient position on the couch of a linear accelerator from fraction to fraction, including organ movements and deformation of tissues (Sharpe *et al*, 2007). Although the introduction of kilovoltage cone beam CT (kVCBCT) provides the opportunity to acquire images of much improved quality, interest in MVCBCT images still exists due to the simplicity of dose modelling in the treatment planning system (Gayou 2012). Several studies have been conducted to improve the quality of MVCBCT images by changing acquisition parameters such as number of projections, dose exposure and the scan arc length or by changing image reconstruction parameters such as the reconstruction filter, image thickness and pixel size (Gayou 2012). Improvements in image quality were obtained by changing the material and thickness of the target and by removal of the flattening filter from the LINAC head. Tsechanski*et al.* (1998) introduced a thin target approach for portal imaging, simulating several targets with different materials and thicknesses, finding the production of sharper images in using a 4 MV unflattened beam with a 1.5 mm copper or 5 mm aluminum target and a new Kodak mammographic film. They concluded that using lower atomic number Z materials did not produce significant improvement. Flampouri*et al.* (2002) found the optimum imaging arrangement for a 6 MV beam to be a 6 mm aluminum target, improving the contrast by 19% for a 1.4 cm slab of bone inside 5 cm of water. Roberts *et al.* (2008) carried out a MC simulation and experiment to study the effect of using a low Z target with an X-ray Volume Imaging-panel (XVI-panel) detector (Elekta, Stockhholm)(the panel being based on AmSi technology) instead of the conventional imaging technique. They found that by using this setup, the contrast for a 1.6 cm slab of bone inside 5.8 cm of water was improved by a factor of 4.62 while it reduced to a factor of 1.3 if the same slab of bone was placed inside 25.8 cm of water. Faddegon*et al.* (2008; 2010) developed a new image beam line (IBL) to be used with Siemens LINACs. They used a carbon target instead of electron foils and irradiated it with a 4.2 MeV electron beam, obtaining an improvement in contrast and spatial resolution of a factor of 3 and 2 respectively, with the same dose to patient or in acquiring an image with same quality but at lower dose. Connell and Robar (2009) performed several MC simulations to study three target materials (beryllium, aluminum and tungsten) with different thicknesses, irradiating them with 4.5 and 7.0 MeV electron energies. They found that the thinner target with the higher electron energy produced images with better modulation transfer function MTF. Sawkey*et al.* (2010) used a diamond target with 4 and 6 MV beams instead of the carbon target, allowing treatment beams that simplify the commissioning and the quality assurance. They found that the image quality is the same as the carbon target at 4 MV. In addition, Bretbach*et al.* (2011) developed a sintered pixelated array detector made of Gd_2O_2S ceramic scintillator to be used with the imaging beam line (IBL). They found that the contrast-to-noise ratio (CNR) was improved by a factor of 2.66. Furthermore, Parsons and Robar (2012) studied the effect of the presence of a 1 mm copper plate placed on electronic portal imaging devices (EPIDs) on the quality of MVCBCT images. They found that the copper plate reduced the number of diagnostic photons by 20%.

All studies above suggest modification of LINACs by adding a thick low Z or thin medium Z target and/or the design of a new imaging line. Such changes would present a number of developmental issues, not least in developing countries in which LINACs in many cases lack an on-board imager and have not yet established an IGRT protocol. In addition, some of these suggestions have either not been accompanied by studies of the effect of reducing the thickness of the target on the electron contamination or have added a plate of Perspex to reduce the electron contamination in the imaging beam leading to absorption of a fraction of the low energy photons. In this work use has been suggested of the use of a copper target for the imaging mode using a 6MV beam since the former is already present inside the head of most Varian LINACs to be used with treatments requiring higher photon energy mode (> 6 MV).

2.0 Materials and methods

2. 1MC parameters

The 6 MV Varian Clinac 2100C was simulated using the FLUKA Monte Carlo (MC) code (Ferrari *et al*, 2005); see Figure 1.

The actual geometry of this LINAC head was obtained from the Varian manufacturer. Five different targets were simulated without a flattening filter (FF). All configurations are listed in Table 1.

Table1: Target configurations used in this simulation

Targets material used in this simulation	
with FF	*Varian 6 MV original target*
Without FF	*Varian 6 MV original target*
	Varian copper target (~0.5 cm)
	Copper target (0.25 cm)
	Carbon (1 cm)
	Carbon (2 cm)

The incident electron beam hitting the target was simulated as a pencil beam of energy 6 MeV and a diameter 3 mm. A 40 × 40 × 40 cm^3 water phantom was simulated at a source surface distance (SSD) of 100 cm. The water phantom was divided into voxels in order to calculate the percentage depth dose as well as the entrance dose along the central axis (CA). The voxel size was set to 0.5 × 0.5 × 0.25 cm^3. The photons and electrons cut-off energies were set to 10 keV and 511 keV respectively. The number of histories was set to 1×10^9 primary electrons to reduce the statistical uncertainty to an acceptable level. Each simulation was run on a laptop (Intel 8 Core, 2.4 GHz CPU, 8 GB RAM) with a Linux operating system.

2.2 MC validation

To validate the simulation, the calculated percentage depth doses (PDDs) of the FF beam in the CA of the water phantom were compared with percentage depth dose (PDD) data in BJR-supplement 25. Figure 2 shows the PDD curves of the simulated 6 MV FF beam and that obtained from BJR-supplement 25 (BJR 1996). The difference between them was less than 2% at all points.

2.3 Photon spectra, electron contamination and entrance dose

The photon spectra for all configurations were calculated in air at the isocentre. The ratio of low energy photons (10-150 keV) in each spectrum was compared with that for the conventional beam. The photon average energies for all setups were calculated. The electron contamination on the patient plane in each setup was obtained by calculating the ratio of the total number of electrons to photons at the isocentre. In addition, the entrance dose was calculated by averaging the dose within the first 1cm inside the water phantom on the CA.

2.4 Image quality

In order to calculate the improvement in image quality by using Varian copper target, two simple simulations for the conventional and the copper target beams were performed. Both beams with 20×20 cm^2 field-size were simulated to irradiate two cylindrical bones with 2 cm diameter placed inside water phantom with 5 cm thickness at 100 cm from the target; see Figure 3. The images were obtained by scoring the photon fluence 10 cm below the phantom. Since changing the target and removing the FF will affect the dose rate, the number of incident electrons for the new setup was reduced to obtain an image with same dose as in the conventional setup. The LC for both images was calculated using the following equation (Flampouri*et al*, 2002):

$$LC = 2|I_b - I_w| / (I_b + I_w)$$

Where$I_b$and$I_w$are the photon fluence in the region of interest in bone and water respectively.

3.0 Results and discussion

3.1 Photon spectra, electron contamination and entrance dose

The average energy for copper targets is between the average energy obtained using the original Varian targets and the carbon targets; see Figure 4. In addition, the low photons ratio increased in using the copper target compared with use of the original target. It was further found that by using a thin target (0.25 cm copper or 1 cm carbon) the number of primary electrons at the isocentre increased sharply.

The entrance dose also increased when the FF was removed and also increased as the thickness or Z of the target decreased. Table 2 summarises the calculated parameters for each configuration.

3.2 Image quality

The acquired images obtained by the conventional and the copper target beams are shown in Figure 5. It can be noticed that the image acquired by the copper target beam has the better quality compared to that acquired by the conventional beam. The LC has improved by 31%. Clearly, this value will reduce if a thicker phantom is used.

This modification is suggested to be useful for repositioning patients who undergo radiotherapy treatment for lung or head and neck cancers. This modification points to provision of a simple and low cost technique for acquiring MVCBCT images with better quality, being perhaps most important for developing countries.

4.0 Conclusion

The effect of using a copper target to acquire MVCBCT images was studied using the MC method. It was found that the low energy photon ratio was increased by a factor of 7.2 when the copper target was used as a replacement for the conventional target. The image quality for a simple phantom made of two cylindrical bones with 2 cm diameter placed inside 5 cm thickness water phantom was improved by 31%. It can be concluded that the quality of MVCBCT images can improved with a simple and low cost modification of the Varian copper target.

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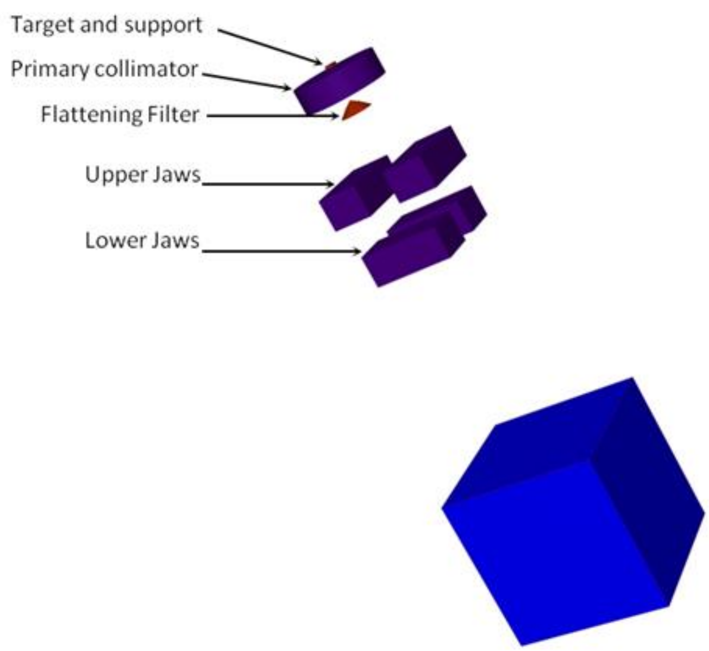


Figure 1: The simulated geometry of the conventional 6 MV Varian Clinac 2100C.

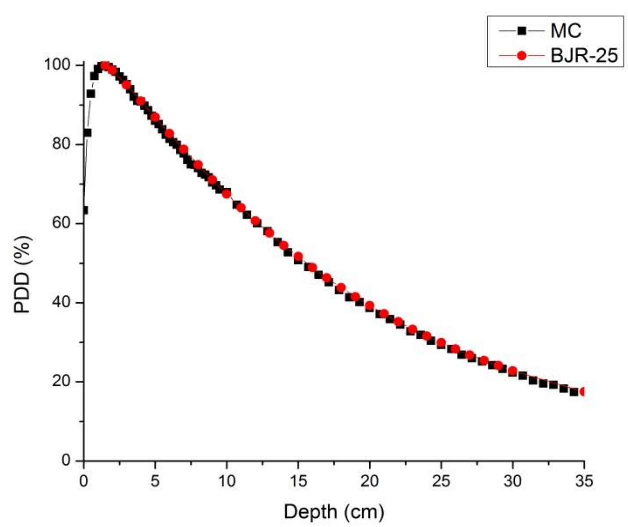


Figure 2: The PDD curves of the conventional 6 MV Varian linac beam simulated (squares) and obtained from BJR-suplement-25 (circles) for a 10×10 cm^2 field-size in a water phantom.

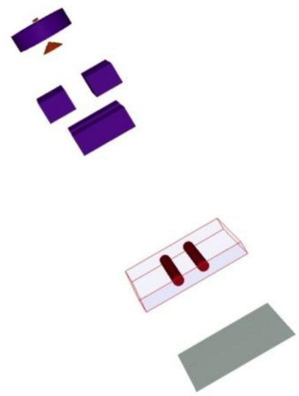


Figure 3: Conventional LINAC irradiating two cylindrical bones with 2 cm diameter placed inside a water phantom with 5 cm thickness at 100 cm from the target.

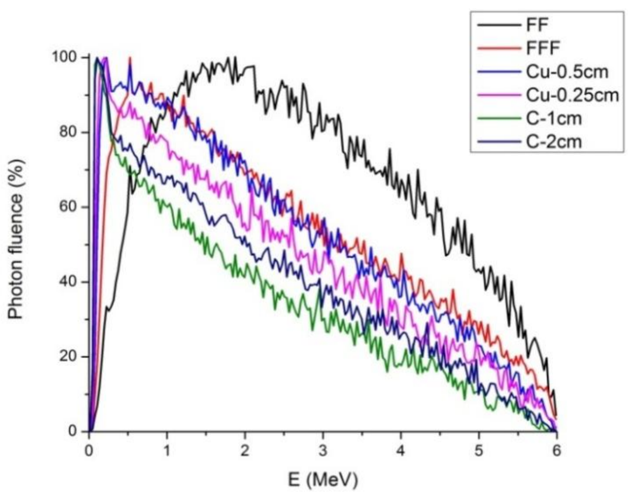
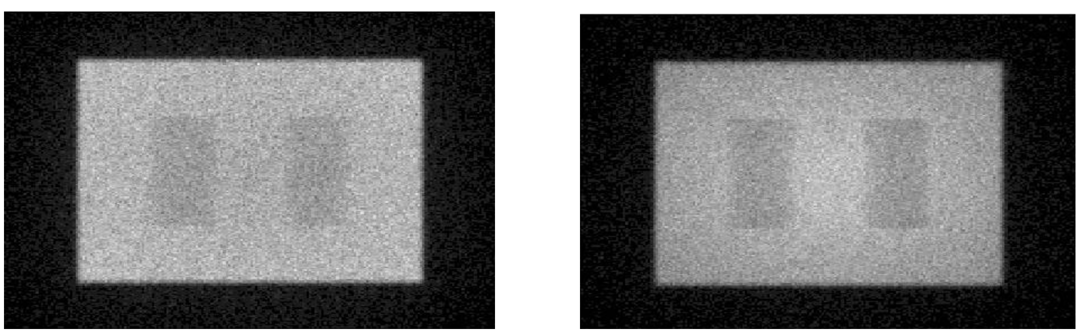


Figure 4: The photon spectra in air for all configurations at the isocentre.

Table 2: The average photon energy, low energy photon ratio, electron contamination ratio and the entrance dose for all configurations.

	FF	FFF	Cu(0.5 cm)	Cu(0.25 cm)	C(1 cm)	C(2 cm)
Average photon energy (MeV)	2.5	2.1	1.9	1.8	1.6	1.2
10-150keV photons ratio(%)	0.33	1.03	2.39	3.55	6.06	5.16
Electron contamination ratio (%)	0.09	0.25	0.06	6.17	41.07	0.03
Entrance dose (%)	65.7	84.4	72.6	90.2	84.4	72.9



(a) (b)

Figure 5: The acquired images of two cylindrical bones with 2 cm diameter placed inside water phantom with 5 cm thickness at 100 cm from the target by (a) the conventional beam and (b) the copper target beam.