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Use of Beam Spoiler to Improve Build-up of Photon Beam Using Low Strength Magnetic Field

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The purpose of this study is to propose the use of a beam spoiler for improving the build-up region of photon beam by using external magnetic field with a low strength of 0.5 T (Tesla) outside the human body. A home-made magnet device which can apply a transverse magnetic field to photon beam was developed. The effect of dose enhancement on build-up region was investigated by the beam spoiler-to-magnet distance (BMD), the magnet-to-magnet distance (MMD), and the magnet-to-surface distance (MSD). Build-up regions of 6 MV photon beam with and without the magnetic field were measured for the field size to 5 × 5 cm^2. When applying the low magnetic field with MMD of 10 cm, D_{0mm}, D_{2mm}, D_{5mm} and D_{10mm} at BSD of 13 cm and MSD of 5 cm were increased by approximately 3.2 %, 3.9 %, 1.7 % and 0.4 %, respectively, compared to the build-up of the existing 6 MV photon beam without the magnetic field. The dose reduction was 5.1 % compared to skin dose for 4 MV photon beam without the magnetic field. It is expected that use of a beam spoiler in the magnet device designed in this study could provide improved dose distributions in build-up regions while maintain similar surface dose to the existing 6 MV photon beam without the magnetic field.

Keywords : magnetic field, 6 MV photon beam, build-up region, beam spoiler

1. Introduction

The effect of an external magnetic field on dose distributions produced by high-energy electron and photon beams have been investigated by several researchers. Bostick [1] proposed the use of a strong magnetic field longitudinal to electron beams for the enhancement of dose deposition. Wienhous *et al*. [2] performed Monte Carlo simulation in order to evaluate the enhancement of electron beam dose deposited by a strong longitudinal magnetic field and to optimize the design of a single-coil superconducting magnet with a magnetic field of 6 T. Bielajew [3] proved that a strong longitudinal magnetic field of 20 T shows an ideal penumbral due to significant reduction of lateral spread of scattered and secondary electrons. The possibility of a longitudinal magnetic field was investigated for overcoming underdosing phenomenon in the region of tissue-air interface using Monte Carlo simulation [4, 5]. The experimental study by Litzenberg *et al*. [6] demonstrated that a strong longitudinal magnetic field of 3.5 T focused the high-energy electron beams, leading to increased dose deposition near the magnetic axis, especially near the surface of the phantom.

The application of a strong transverse magnetic field to control the dose profiles of high-energy photon beams (24 MV and 50 MV) also has been investigated using Monte Carlo simulation [7, 8]. They showed that a strong transverse magnetic field can be used to enhance the dose in the tumor region and reduce the dose to adjacent normal tissues. For most of existing studies, the use of a strong longitudinal or transverse magnetic field on high-energy photon and electron beams shows appreciable dose effects in depth. However, they were not practical for clinical application because it is very difficult to realistically apply a locally strong magnetic field inside human body.

In previous study, we presented a preliminary result for build-up modulation of photon beam using a low strength

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magnetic field [9]. When the magnetic field was directly applied to the photon beam, the effect of dose build-up was insufficient. Therefore, the purpose of this study is to propose the use of a beam spoiler for improved build-up of 6 MV photon beam by using external magnetic field with a low strength of 0.5 T outside the human body. In addition the possibility of a transverse magnetic field to provide sufficient build-up in regions close to the skin such as glottic cancer is investigated for clinical application.

2. Materials and Methods

To investigate the effect of a beam spoiler on dose enhancement of build-up region of 6 MV photon beams, a

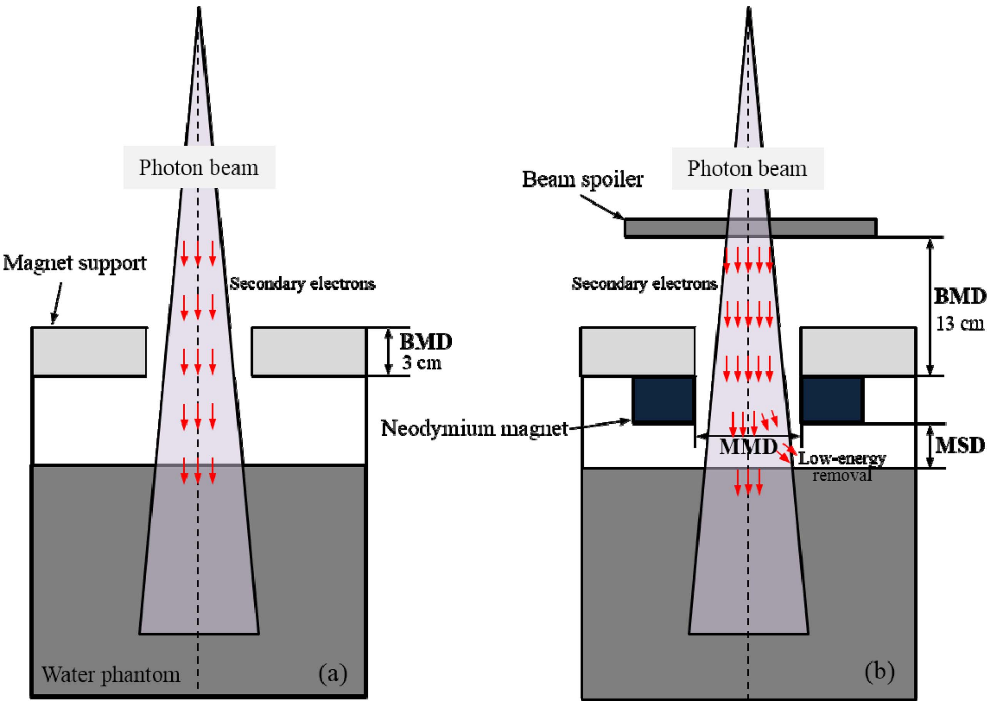

Fig. 1. (Color online) A schematic diagram of the use of a beam spoiler on build-up modulation of 6 MV photon beams by using low transverse magnetic fields; (a) open beam without magnetic field (b) with magnetic fields of 0.5 T.

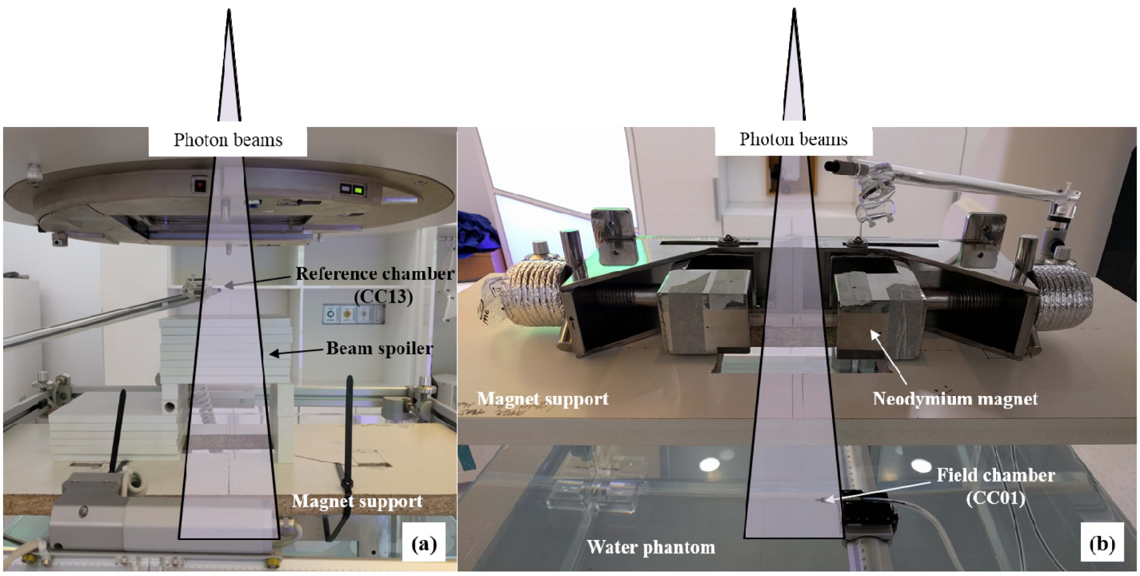

Fig. 2. (Color online) A home-made magnet device capable of applying the beam spoiler for dose enhancement in build-up regions of photon beams. Secondary electrons were produced by beam spoiler (a). The actual measurements were performed by placing magnet system under the magnet support (b).

home-made magnet device which can apply a low strength magnetic fields of 0.5 T and additionally install a beam spoiler was designed (Fig. 1). A magnetic field was applied between two parallel neodymium magnets with dimensions of 5 × 5 × 5 cm^3. Source-to-surface distance (SSD) was positioned at 100 cm after fixing the home-made magnet device above the water phantom (48 × 48 × 41 cm^3). CC13 ion chamber (IBA Dosimetry GmbH, Germany), which has effective volume of 0.13 cm^3 and CC01 ion chamber with effective volume of 0.01 cm^3, which is excellent in spatial resolution were used as the reference detector and the field detector, respectively (Fig. 2).

A TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, CA, USA) was used in this study. Build-up regions of 6 MV photon beam with and without the magnetic field were measured for the field size to 5 × 5 cm^2. All measurements were repeated three times at the dose rate of 400 MU/min. The effects of magnetic field strengths were investigated at the distances of magnet-to-magnet distance (MMS) of 6 cm and 10 cm. The differences of dose build-up were evaluated with the distance between the permanent magnet and the water surface (Magnet-to-Surface Distance, MSD) and between the beam spoiler and the permanent magnet (Beam-spoiler-to-Magnet Distance, BMD), respectively.

For quantitative analysis of the measured dose build-up, the following dosimetric parameters were used in this study; dose to the water surface (D_{0mm}), dose at 2 mm depth (D_{2mm}), dose at 5 mm depth (D_{5mm}), and dose at 10 mm depth (D_{10mm}).

3. Results and Discussion

Build-up regions of 6 MV photon beam measured under various experimental conditions were compared with build-up curves measured without the magnetic field. The measured data were processed with a smoothing method provided by myQA Accept v7.5 software. For evaluating the effect of a beam spoiler on dose distribution in build-up regions, the measurements of percentage depth dose were normalized to the maximum dose (D_{max})

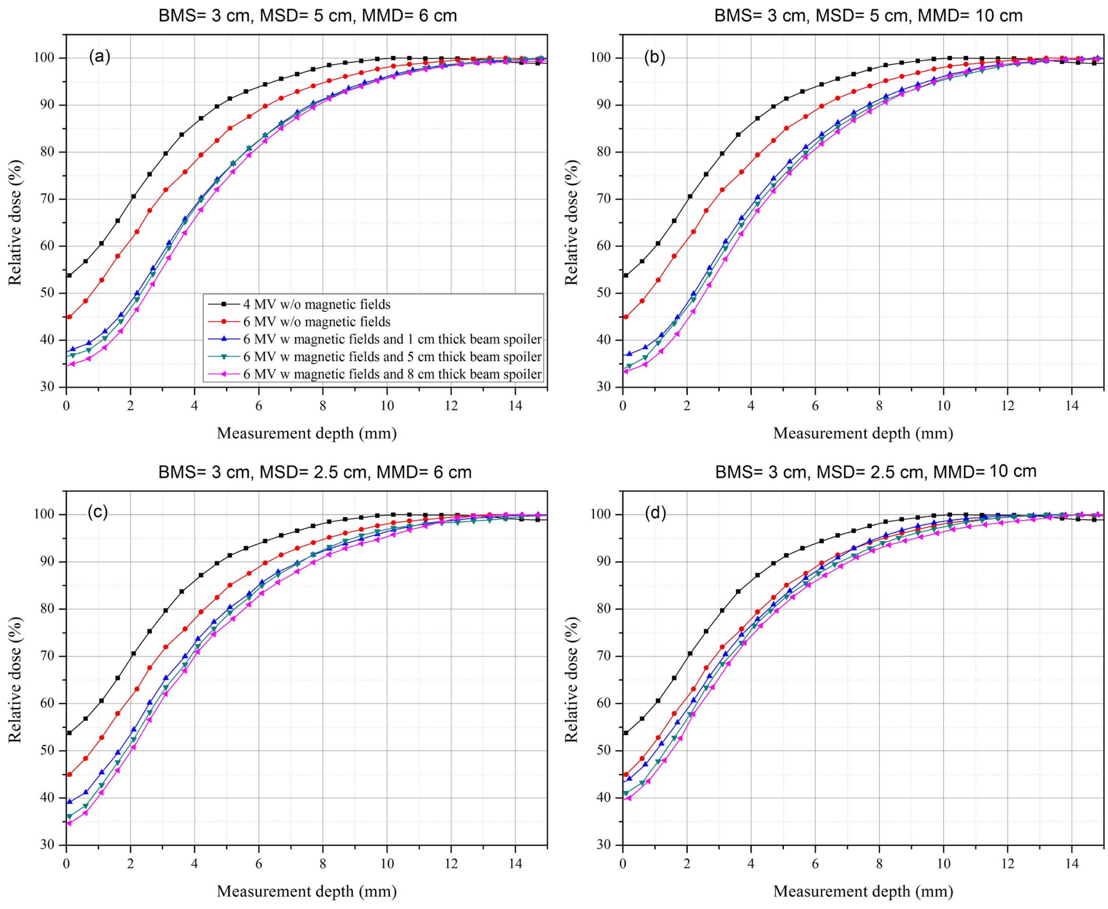

Fig. 3. (Color online) Measurements of build-up region of 6 MV photon beams with a strength magnetic field of 0.5T at the beam spoiler-to-magnet distance of 3 cm.

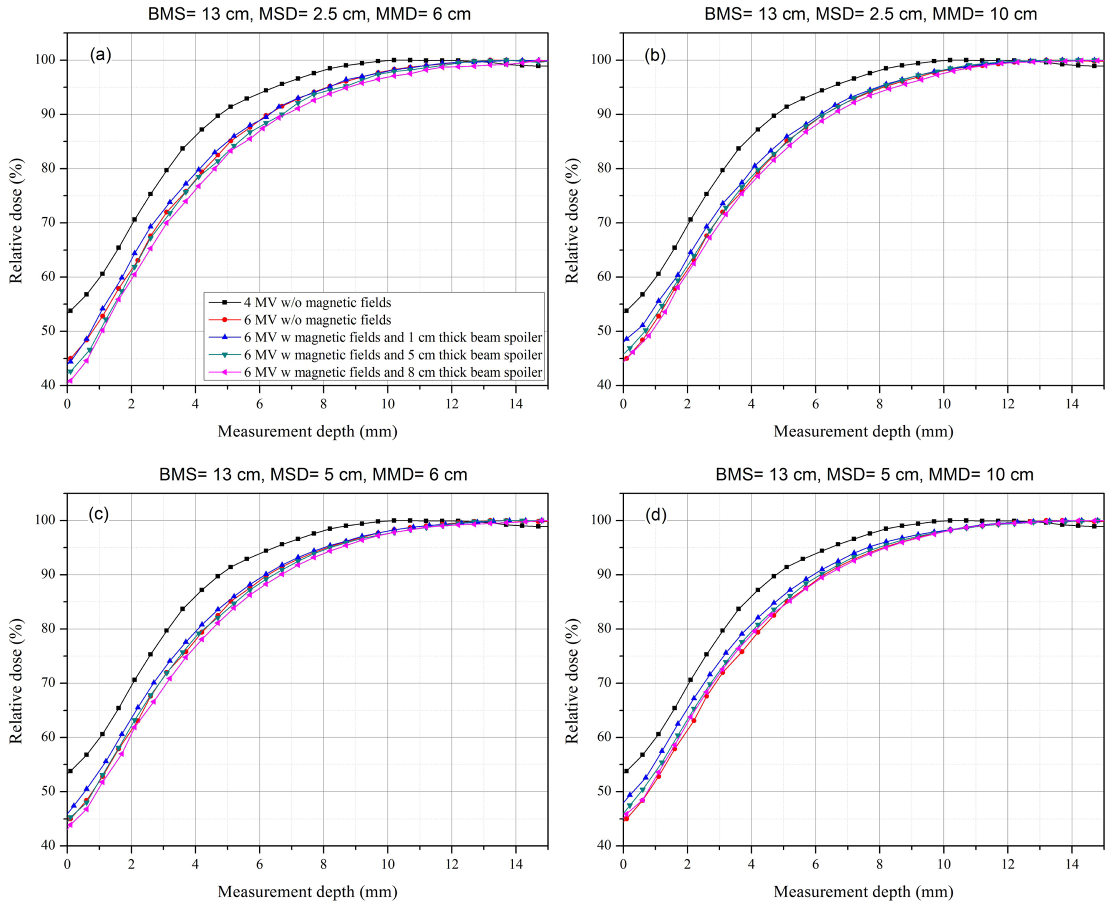

Fig. 4. (Color online) Measurements of build-up region of 6 MV photon beams with a strength magnetic field of 0.5T at the beam spoiler-to-magnet distance of 13 cm.

in depth. Figure 3 and 4 shows dose distributions within the build-up region of photon beam when applying transverse magnetic field to incidence photon beam of 5 × 5 cm^2.

For BMS of 3 cm, dose distributions in build-up region at MSD = 2.5 cm and 5.0 cm showed lower surface dose and the doses in build-up region than 6 MV photon beam as shown in Fig. 3. As the thickness of the beam spoiler increased, the attenuation effect on the build-up regions was prominent. Although the dose differences of build-up region at MSD of 2.5 cm were significantly reduced at low magnetic fields with MMD of 10 cm, the dose enhancement could not occur in compare with 6 MV photon beam at non-magnetic condition (Fig. 3(d)). However, for BMS of 13 cm, curves similar to the build-up of 6 MV photon beam were obtained at MSD of 2.5 cm as shown in Fig. 4(a) and 4(b). Fig. 4(c) and (d) showed that the surface dose and the dose in build-up region were slightly increased. Especially, the effect of dose enhancement in build-up region for MMD = 10 cm was prominent by using the beam spoiler with the thickness of 1 cm.

In order to evaluate the effect of skin dose sparing and dose enhancement in build-up region, the dosimetric parameters such as D_{0mm}, D_{2mm}, D_{5mm} and D_{10mm} were evaluated.

When applying the low magnetic field with MMD of 10 cm, D_{0mm}, D_{2mm}, D_{5mm} and D_{10mm} at BSD of 13 cm and MSD of 5 cm were increased by approximately 3.2 %, 3.9 %, 1.7 % and 0.4 %, respectively, compared to the build-up of the existing 6 MV photon beam without the magnetic field (Table 1). The dose reduction was 5.1 % compared to skin dose for 4 MV photon beam without the magnetic field. The modulation of build-up of photon beam using the low strength magnetic field showed higher dose improvement in build-up regions and lower skin dose than that of 6 MV and 4 MV photon beam without the magnetic field, respectively. It is considered that low strength magnetic field effectively removed low energy secondary electrons generated by photon beam in air and higher energy secondary electrons only contributed to the build-up region.

Some researchers previously reported that dose effect

Table 1. Dosimetric parameters of build-up modulation for photon beam with and without the magnetic field.

Photon energy	Magnetic field	Thickness of beam spoiler	Dose (%)		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
				BMD[a)]	3 cm				13 cm			
				MMD[b)]	6 cm	10 cm	6 cm	10 cm	6 cm	10 cm	6 cm	10 cm
				MSD[c)]	5 cm	5 cm	2.5 cm	2.5 cm	2.5 cm	2.5 cm	5 cm	5 cm
4 MV	0 T	0 cm	D_0		53.0 %							
			D_{2mm}		69.7 %							
			D_{5mm}		91.1 %							
			D_{10mm}		100.0 %							
6 MV	0 T	0 cm	D_0		44.7 %							
			D_{2mm}		61.4 %							
			D_{5mm}		84.5 %							
			D_{10mm}		98.1 %							
	0.5 T	1 cm	D_0		37.0 %	37.5 %	38.8 %	43.6 %	44.4 %	47.7 %	46.0 %	47.9 %
			D_{2mm}		47.9 %	48.2 %	53.5 %	58.8 %	63.3 %	63.6 %	63.5 %	65.3 %
			D_{5mm}		76.6 %	76.2 %	79.8 %	82.7 %	85.0 %	85.4 %	85.0 %	86.2 %
			D_{10mm}		96.2 %	96.1 %	96.4 %	98.6 %	98.0 %	98.2 %	98.1 %	98.5 %
		5 cm	D_0		34.0 %	36.7 %	36.0 %	40.8 %	42.6 %	45.9 %	44.1 %	46.0 %
			D_{2mm}		47.0 %	46.9 %	51.5 %	56.8 %	60.8 %	62.1 %	62.2 %	63.3 %
			D_{5mm}		75.1 %	76.1 %	78.6 %	82.1 %	83.1 %	84.3 %	83.7 %	85.1 %
			D_{10mm}		95.4 %	95.8 %	96.9 %	97.4 %	97.7 %	98.2 %	97.6 %	98.0 %
		8 cm	D_0		33.3 %	34.6 %	34.8 %	40.1 %	40.9 %	43.9 %	42.7 %	44.7 %
			D_{2mm}		44.3 %	44.8 %	49.8 %	55.3 %	59.6 %	61.5 %	60.7 %	62.8 %
			D_{5mm}		74.1 %	74.4 %	76.9 %	80.9 %	82.6 %	83.4 %	82.8 %	84.3 %
			D_{10mm}		95.7 %	95.7 %	95.4 %	96.4 %	96.9 %	97.7 %	97.6 %	97.9 %

[a)]Beam spoiler-to-Magnet Distance (BMD). [b)]Magnet-to-Magnet Distance (MMD). [c)]Magnet-to-Surface Distance (MSD)

could be expected in control of secondary electrons generated by photon beam using magnetic field. The benefits of dose effect of human body depth were mostly evaluated, however, there were several limits to clinical application in practice. First of all, it is impossible to locally apply strong magnetic field to specific part of human bodies. Therefore the clinical application is highly unlikely in practice [10]. It is also essential to evaluate the effect of strong magnetic field on linear accelerator which generates electron and photon beam. Lastly, radiation treatment using the linear accelerator consists of diverse elements, such as beam direction, beam energy and field size [11]. Use of beam direction for the radiation treatment diversifies direction of magnetic field for beam modulation. Thus, special limitation between the linear accelerator and a patient hinders installation of magnetic field device according to beam direction.

It is considered that the magnetic field device designed in this study could be installed outside of the human body in order to overcome limitations in previous studies and could be easily applied to critical practice when the tumor is located close or adjacent to the skin and the target volume is not big, such as skin cancer or laryngeal cancer. The radiation treatment of early glottic cancer is commonly used to the field size of 5 × 5 cm^2 or 6 × 6 cm^2 [12-15]. This is consistent with the field size used in this study. Thus the dose effect in build-up region obtained from measurements could be directly expected. It is also easy to install the magnetic field device because one to two beam directions are traditionally used for the radiation treatment of glottic cancer. Furthermore, the use of low strength permanent magnet of 0.5 T could minimize physical effects of the linear accelerator when applying the existing strong magnetic field device such as previous studies.

The minimum energy of photon beam in the linear accelerators that are now used worldwide is mostly 6 MV. A low dose to the target volume located close or adjacent to the skin could be delivered. Due to such insufficient dose delivery, commercial tissue equivalent material such as bolus was conventionally used for the shift of build-up toward the skin [16]. Although the use of bolus could deliver sufficient dose to skin surface, it is difficult to expect the effect of skin sparing due to significant dose increase to skin. Therefore, it is considered that use of a beam spoiler designed in this study could provide improved dose distributions in build-up regions due to the sufficient production of secondary electron while maintain similar surface dose to the existing 6 MV photon beam without the magnetic field.

4. Conclusion

This study propose the use of a beam spoiler designed in magnetic device with low strength magnetic field capable of minimizing the physical effects of a linear accelerator while applying a magnetic field to the outside of the human body for clinical application. The feasibility of the use of beam spoiler on dose enhancement of build-up of 6 MV photon beam using the magnetic field was experimentally evaluated.

As the distance between the beam spoiler and the permanent magnet is increased, dose distributions in build-up regions were similar to that of 6 MV photon beam without the magnetic field. For MMD of 10 cm and MSD of 5 cm, the use of beam spoiler provide the dose enhancement in build-up regions while maintain similar surface dose on the dose distributions of the 6 MV photon beam.

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