Australasian Physical & Engineering Sciences in Medicine Volume 20 Number 2, 1997

Skin Dose Reduction by a Clinically Viable Magnetic Deflector

M.J. Butson[1,2], P. Yu[3], M. Kan[3,4], M. Carolan[1,2], E. Young[3], J.N. Mathur[2], P.E. Metcalfe[1,2]

1. *Illawarra Cancer Care Centre, Department of Radiotherapy, Wollongong NSW, Australia*
2. *University of Wollongong, Dept of Physics, Wollongong, Australia*
3. *City University of Hong Kong, Dept of Physics, Kowloon Tong, Hong Kong*
4. *Hong Kong Polytechnic University, Department of Optometry and Radiography, Hung Hom, Kowloon, Hong Kong*

Abstract

A variable magnetic deflector which attaches onto the treatment head of a linear accelerator has reduced skin dose by as much as 65% for 6MV x-rays. The magnetic deflector is constructed from Neodymium Iron Boron (NdFeB) rare earth magnets. It weighs approximately 15 kg and is designed to easily fit onto the accessory mount of a clinical linear accelerator. All field sizes are attainable up to 35cm x 35cm at 100cm SSD. The gap between the magnetic poles can be adjusted, providing the highest field strength for each field size. Magnetic field strengths up to 0.55 Tesla are attainable. For a 6MV x-ray beam with a 10 mm perspex block tray, surface dose is reduced from 29% to 14% and from 59% to 37% for a 20cm × 20cm and 35cm × 35cm field size, respectively. Results at varying SSD's have shown at least 10cm of space must be allowed between the magnets and patient for adequate reduction of skin dose through removal of electron contaminants.

Key words

Electron contamination, Neodymium Iron Boron, surface dose, skin sparing.

Introduction

Removal of electron contamination from a clinical linear accelerator or cobalt-60 machine by magnetic sweeping has yet to produce a clinically useful device[1-4]. This has been due to the use of electromagnets to remove electron contamination from the beam. Large heavy devices were needed to produce a high enough field strength. The introduction of Neodymium Iron Boron rare earth magnets has reduced the weight to field strength ratio dramatically to clinically usable weights. Our initial prototype[5] showed that significant reductions in the superficial dose were achievable with such a device. The prototype however was limited by its fixed pole separation which limited any clinical applications to a fixed field size. We have now constructed a device which can vary the pole separations of two NdFeB magnet banks to allow field sizes up to 35cm × 35cm to be used without compromising the magnetic field strength at any field size. This paper examines the skin sparing properties of this device at varying SSD and SAD treatments. The advantage of magnetically sweeping electrons over the insertion of a mechanical filter is two fold. Firstly, no correction factor is required to account for beam attenuation and secondly, all contamination from the treatment head can be removed without the production of extra contaminants as with an electron filtering device.

The layers of skin which are radiation sensitive lie at the following depths. The epidermal layer of the skin is approximately 0.07 mm thick[6]. The basal layer lies at this depth and is the origin of new skin growth. Below the epidermis lies the dermis which can extend to a depth of 1 to 4 mm. The dermis contains the capillaries which supply the skin with blood and thus nutrients. Late skin reactions such as hypoxia and telangiectasia occur when the dermis is exposed to a large dose[7] whereas early reactions such as erythema can occur when the epidermis or basal layer is exposed to high doses thus removal of the dose due to contaminant electrons up to a depth of 4mm is clinically desirable.

Materials and Methods

Neodymium Iron Boron variable magnetic deflector

Two banks of NdFeB ceramic magnets[8], dimensions 30 cm × 5 cm × 5 cm, were placed in a custom made holder to fit directly under the block tray holder on

---

Corresponding Author: M.Butson
Department of Radiotherapy, Illawarra Cancer Care Centre, P.O. Box 1798, Wollongong NSW 2500
Received 22nd January 1997; accepted in final form 8th May, 1997.

the accessory mount of the machines head as shown in figure 1. Thus the magnets were 70 cm from the x-ray source. Neodymium Iron Boron alloy rare earth permanent magnets have a magnetic field strength approximately 16 times greater than iron ferromagnetic devices. The supporting structure was designed from welded aluminium to reduce weight without compromising strength to a great extent. The magnetic poles were positioned on a large screw thread which could be wound in or out to produce a pole separation from 5 cm to 26 cm. In future the screw threads would be motorised. This allowed the production of x-ray field sizes up to 35 cm × 35 cm without mechanical interference from the mounting device. The magnetic deflectors weight including the frame and attachment bracket is approximately 15 kg. Field strengths measured by a Hall effect probe of up to 0.55 Tesla are attainable with the device. The lowest field strength of 0.05 Tesla is produced at the centre of the field when the poles are separated to the maximum amount, ie 26 cm.

Treatment machine

Measurements were performed under a Varian 2100C linear accelerator. Photon beam measurements were made using an Attix Model 449 parallel plate ionisation chamber, in a solid water[9] stack phantom. The chamber was connected via a triaxial cable to a Keithley model 2540 electrometer at 300V bias voltage. Results were obtained with various field sizes, using block trays and at varying SSD's.

Results

Figure 2 shows the magnetic flux density attainable across the poles for the NdFeB magnet. The x-axis defines the distance in cm from the centre of the magnetic deflector / x-ray field. Flux densities up to 0.55 Tesla were recorded near the magnet faces. For the small 6 cm separation which correlates to a 10 cm × 10 cm field size the field strength varies from 0.55 to 0.34 Tesla. At the larger setting of 26 cm separation which correlates to a 35 cm × 35 cm field size, the field strength varies from 0.45 Tesla down to 0.05 Tesla.

Figure 3 shows build up curves for 6MV X-rays at 10 cm, 20 cm, 30 cm, 35 cm square field sizes using the magnetic deflector. The contamination removed also shown on the figure was calculated by subtracting the shown build up curve data from % build up dose data for the same field size without the magnetic field.

Figure 4 shows build up curves for 6MV X-rays at 10 cm, 20 cm, 30 cm, 35 cm square field sizes with a 10 mm perspex block tray located 65 cm from the source with the magnet in place. The dose due to contaminant electrons is obtained by subtraction of the measured depth dose curves with and without the magnet in place.

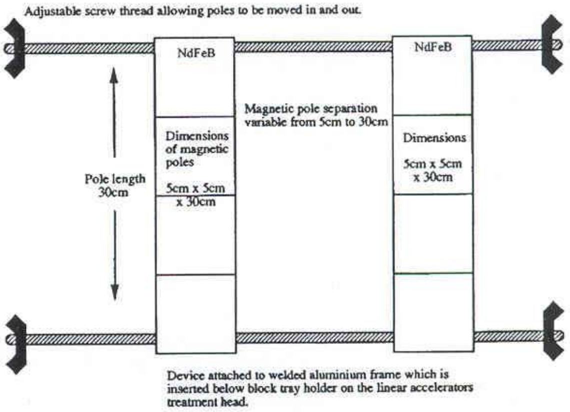

Figure 1. *Beams eye view of the Neodymium Iron Boron variable magnetic deflector. The device attaches onto the treatment head of the linear accelerator below the block tray slot. The magnetic pole separation is variable due to a thread winding through both sides of the poles. Pole separations ranging from 5 cm to 30 cm are achievable producing field strengths as large as 0.55 Tesla.*

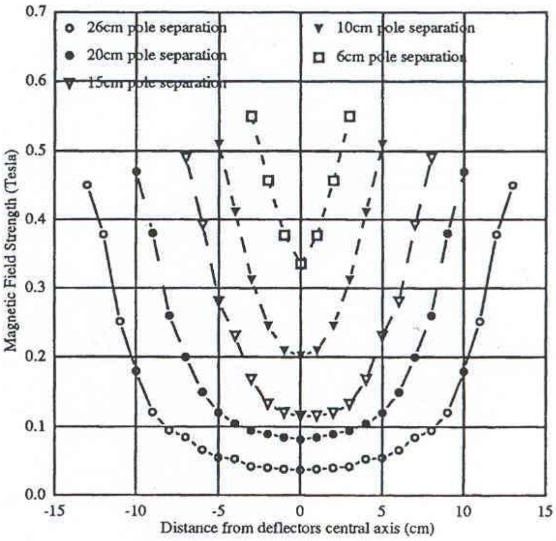

Figure 2. *Magnetic field strength as a function of position for varying pole separations. As the poles are widened, the magnetic field reduces accordingly. However this approach allows the maximum field strength to be applied for various field sizes.*

Figure 5 shows the first 4 mm of build up for a 20 cm × 20 cm field size using the magnet at various source surface distances. Results show an increase in build up dose as the SSD is decreased. This increase is

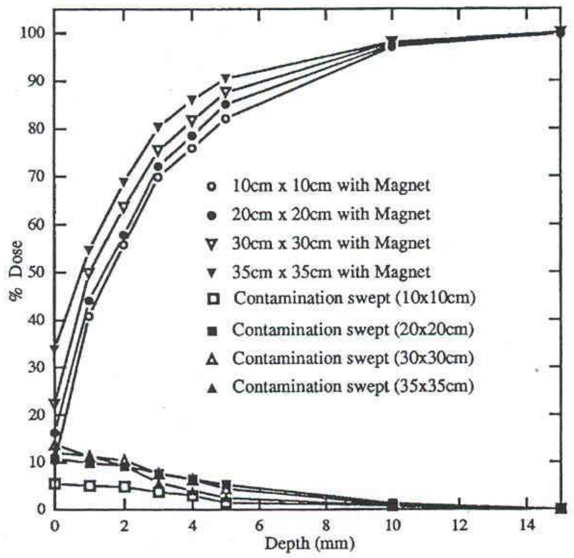

Figure 3. *Build up curves for 6MV x-rays with the magnetic deflector. Also shown is the electron contamination removed from the beam by the magnetic field. Up to 15% of applied dose can be removed from the surface by the magnetic deflector for open field beams at 6MV.*

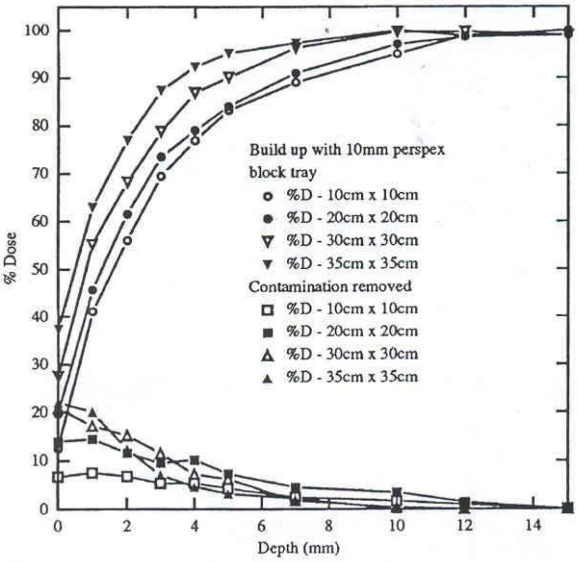

Figure 4. *Build up curves for 6MV x-rays with block trays are shown with the magnetic deflector attached. Again, electron contamination removed is shown and percentage dose reductions as large as 22% are seen at the surface with 6MV x-rays.*

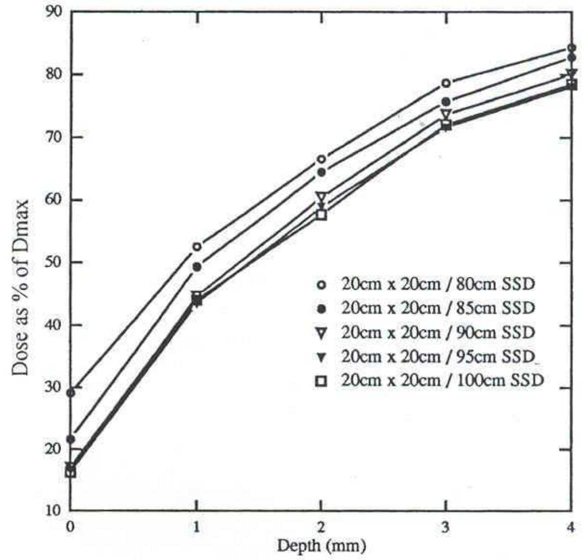

Figure 5. *The first few millimetres of build up percentage dose at various SSD's. Decreasing the SSD down from 100cm to 80cm increases % dose in the build up region. This is due to insufficient space between the magnet and ionisation chamber to sweep the electrons away.*

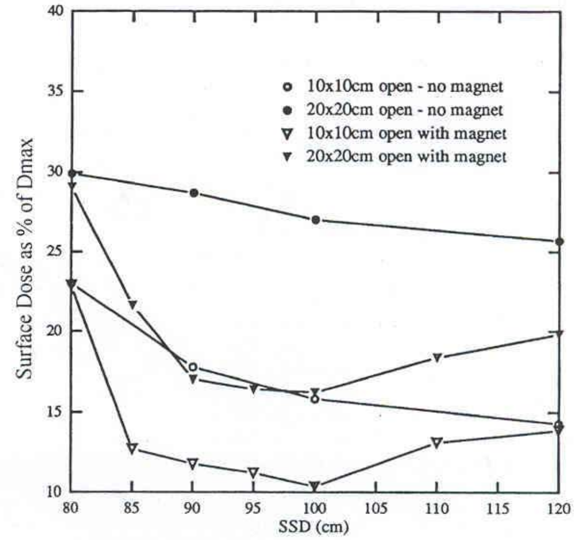

Figure 6. *Graph showing percentage surface dose at varying SSD to highlight the importance of the magnet-phantom distance.*

dramatically enhanced at 85 cm SSD or closer. This relates to a distance of 10 cm between the phantom surface and the magnetic assembly. This distance is insufficient to allow the swept electrons to be removed from the beam path due to the larger radius of curvature of the electrons trajectory.

Figure 6 shows the change in surface dose with SSD variations from 80 cm to 120 cm. Results are shown for two field sizes with and without the magnetic field. 100 cm SSD is found to be the optimum SSD for skin dose reduction with this device. Also note that skin dose reductions are seen at all SSD's to varying degrees. At some SSD's there is minimal benefit but definitely no adverse effects.

Discussion

Experiments involving the quantification of electron contamination in clinical radiotherapy megavoltage beams in the past have shown that the majority of dose deposited at the surface is due to electron contamination[10-14]. In this work, a magnet with an adjustable gap between the pole pieces has been used to produce a suitable field strength for a variety of field sizes. This produces considerable reduction in the skin and subcutaneous doses. The device however does not remove all contamination at the larger field sizes eg 20 cm × 20 cm or greater. Electrons passing through the magnetic field experience a force perpendicular to their direction of travel (Lorentz force). This produces a helical path of travel due to the increase and then decrease in field strength as the electrons pass by the magnet poles. For small field size, the deflection angle is larger as the maximum field strength is high. The combination of small field and large mean angular deflection allows the majority of electrons to be removed from the beam. As field size increases, magnetic field decreases. This causes a reduction in mean deflection angle producing a sweeping pattern which does not completely remove all electrons. However, dose in all regions is less than original field without the magnet. The dose results quoted in this note are measured along the central axis. We have found at larger field sizes that a dose variation occurs at the surface due to this swept electron contamination. Percentage surface doses slightly less than quoted are recorded on the side opposite the sweeping direction and vice-versa. These variations are of the order of a few percent of Dmax.

Surface and skin dose reductions up to 22% of applied dose are achievable with the NdFeB magnet. In the case of an abdominal parallel opposed isocentric treatment to 50 Gy tumour dose, skin dose reductions above 10 Gy could be achieved with the magnet.

Percentage surface doses at varying SSD's has highlighted the deflection angle of electrons from the magnetic deflector. Figure 6 shows the % surface doses compared to Dmax(dose at depth of dmax) for open beams and for magnetically filtered beams. A sharp decrease in surface dose is seen with increasing SSD as more electrons are deflected away from the chambers active volume. A % dose minimum is seen at approximately 100 cm SSD and then % dose increases again. This increase is due to the relative increase in absorbed dose from air column produced electrons. These electrons are produced by interactions with air molecules and are normally low energy with a penetration depth of only 0-2mm in water. Consequently, the last 20cm of air above the phantom surface produces the majority of electrons incident on the phantom.

Conclusions

The NdFeB variable magnetic deflector has substantially reduced surface and skin dose of the linac x-ray beams by deflecting the electron contamination away from the field. Further reduction would be achievable by producing a larger active magnetic flux volume to deflect electrons to a larger degree. This could be achieved by another smaller separate magnetic field closer to the treatment head to start the deflection process. The magnetic deflector is a clinically manageable weight and would increase the skin sparing properties of high energy photon beams whilst retaining the tumour dose to existing levels.

Acknowledgments

This research was supported by grants from the Departmental Research Committee of the Department of Optometry and radiography, Hong Kong Polytechnic University.

References

1. Biggs PJ., Russell M., *An investigation into the presence of secondary electrons in mega voltage photon beams.* Phys. Med. Biol. 28(9), 1033-1043, 1983.

2. Parthasaradhi K., Prasad S., Rao B., Lee Y., Ruparel R., Garces R., *Investigation on the reduction of electron contamination with a 6MV X-ray beam*, Med. Phys. 16(1), 123-125, 1989.

3. Rao B., Prasad S., Parthasaradhi K., Lee Y., Ruparel R.,Garces R., *Investigations on the near surface dose for three 10MV X-ray beam accelerators with emphasis on the reduction of electron contamination*, Med. Phys. 15(2), 246-249, 1988.

4. Mackie, PhD Thesis volume 1, University of Alberta, Edmonton, Canada.

5. Butson M., Wong T., Law A., Law M., Mathur J., Metcalfe P., *Magnetic repulsion of linear accelerator contaminates*. Med. Phys. 23(6), pg 953-955, 1996.

6. Williams, Warwick, Dyson and Bannister. Gray's Anatomy 37th Edition. Churchill Livingston 1989.

7. Pointon, R.C.S. The Radiotherapy of Malignant Disease 2nd Edition. Springer-Verlag, 1991.

8. Wallace W.E. Rare Earth Intermetallics. Acedemic Press New York, 1973.

9. Constanitinou C., Attix F., Paliwal B., *A solid water phantom material for radiotherapy X-ray and gamma ray beam ray calculations,* Med. Phys. 9(3), 436-441, 1982.

10. Biggs P.J , Clifton Ling C., *Electrons as the cause of the observed shift with field size in high energy photon beams,* Med. Phys . 6(4), 291-295, 1979.

11. Butson M.J, Perez M., Mathur J., Metcalfe P., *6MV X-ray dose in the build up region : Empirical model and the incident angle effect.* Australas. Phys. Sci. Eng. Med., 1996.

12. Clifton Ling C., Biggs P., *Improving the build up and depth dose characteristics of high energy photon beams by using electron filters.* Med. Phys. 6(4), 296-301 1979.

13. Harper N. R., Metcalfe P., Hoban P., Round H., *Electron contamination in 4MV and 10MV radiotherapy X-ray beams,* Australa. Phys. Eng. Sci. Med. 14(3), 141-145, 1991.

14. Nilsson B. *Electron contamination from different materials in high energy photon beams. Phys.*Med.Biol. 30(2), 1985.