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Dosimetric studies of cadmium free alloy used in compensator based intensity modulated radiotherapy

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ABSTRACT

Aim of this study was to investigate dosimetric properties of cadmium free alloy which is used in compensator based intensity modulated radiotherapy (cIMRT). A mixture of lead, bismuth and tin was used to prepare the alloy whose melting point is 90–95 °C. Slabs of different thicknesses ranging from 0.71 cm to 6.14 cm were prepared. Density of alloy was measured by Archimedes' principle using water. For six megavolt (6 MV) photon beam energy transmission, linear effective attenuation coefficient (μ_{eff}), tissue phantom ratio (TPR_{10}^{20}), beam hardening, surface dose (D_s), percentage depth dose (PDD) and effect of scatter has been measured and analyzed for different field sizes and different thickness of compensator. Effect of extended source to detector distance (SDD) on transmissions and μ_{eff} was measured. The density of alloy was found to be 9.5456 g/cm^3. At SDD of 100 cm, μ_{eff} was observed 0.4253 cm^{-1} for a field size of 10 × 10 cm^2. Calculated TPR_{10}^{20} was found to be within 3% of experimental TPR_{10}^{20}. It was found to be increasing with increasing thickness of compensator. D_s was found to decrease with thickness of compensator and increase with wider collimator opening due to increased scattered dose. Compensator slabs of 1 cm, 1.98 cm and 4.16 cm decreased surface dose by 4.2%, 6.1% and 9.5% respectively for a field size of 10 × 10 cm^2 at 100 cm SDD. For small field size of 3 × 3 cm^2 and 5 × 5 cm^2 PDDs are increased from 3.0% to 5.5% of open beam PDDs as compensator thickness increased from 1 cm to 6.14 cm at a depth of 10 cm in water while variation in PDD is insignificant in for larger field sizes 10 × 10 cm^2 to 20 × 20 cm^2. A high degree of intensity modulation is essential in cIMRT and it can be achieved with this compensator material. Dosimetric properties analyzed in this study establish this alloy as a reliable, reusable, optimally dense and cost effective compensator material.

1. Introduction

Study of compensator material has always been an area of interest in field of radiotherapy physics (JPCV et al., 1995; Weeks et al., 1988; Thomsen and Ulso, 2002). Investigation of its attenuation property is useful for estimation of intensity modulation of radiotherapy beams (Huang et al., 1986; Paliwal et al., 1998). Various compensator materials with wide range of densities have been studied so far viz. copper with mass effective attenuation coefficient = 0.0504 cm^2 g^{-1} for 4 MV (MV) photon beam (Huang et al., 1986), Thermo-shield with linear effective attenuation coefficient (μ_{eff}) = 0.205 cm^{-1} for 6 MV photon beam (Paliwal et al., 1998), gypsum having μ_{eff} ranges from 0.101 to 0.063 cm^{-1} for photon beam of energy 4 MV to 15 MV (Arora and Weeks, 1994), lipowitz alloy (PbSnBiCd mixture) with μ_{eff} = 0.4031 cm^{-1} for 6 MV photon beam (El-Khatib et al., 1987). All these have advantages and disadvantages. Lipowitz alloy is the mostly used compensator material because of its high μ_{eff}. However, heavy metals fumes are hazardous to health but intensity of high energy radiotherapy x-ray beam can only be modulated better in materials with high atomic number (Z). In lipowitz alloy cadmium (Cd) is very toxic (Godt et al., 2006; Sethi et al., 2006; Anthony et al., 1978; Hengstler et al., 2003), therefore cadmium free alloy may be used to stay away from bio hazard effect of cadmium fumes produced while preparing compensator. Heavy metals like lead (Pb), bismuth (Bi), tin (Sn) alone itself cannot be used as compensator because of higher melting point which makes it difficult for reusability. Therefore eutectic mixture of bismuth, lead and tin lower the melting point and it become hard and dense enough to be use as a compensator. So, an alloy of Pb-Sn-Bi termed now onward PSB alloy may be used as a compensator for high energy beams. Tyagi et al. (2009) and Nangia et al. (2006) have used one such alloy to treat head

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and neck cancer patients successfully by compensator based intensity modulated radiotherapy (cIMRT). However, they did not report the dosimetric properties of that compensator.

In relevant to clinical use in cIMRT, the μ_{eff} is an important factor which determines the thickness profile of the compensator. Therefore, dosimetric study of PBS alloy is of great importance. Present study is aimed to investigate the dosimetric characteristics Cd free PSB alloy for 6 MV photon beam.

2. Materials and methods

2.1. Sample (Compensator) preparation

Compensator slabs of PSB alloy were prepared with percentage by weight composition of 30% Pb, 18% Sn and 52% Bi. The weighted proper quantities of these heavy metals in exact proportions were properly mixed and then melted to mix thoroughly. It was then poured into the cast in molten state to form rectangular slabs of different thickness. The melting temperature of as prepared alloy is around 90–95 °C. After cooling down slabs, surfaces were made smooth by lapping to keep uniform thickness throughout the surface. Total six slabs of 0.71 cm, 1.0 cm, 1.98 cm, 3.02 cm, 4.16 cm, 5.0 cm and 6.14 cm were prepared. The thicknesses of as prepared slabs were measured using digital vernier caliper (Aerospace digital caliper). The assessment of presence of any air bubbles formed during slab preparation has been done by x-ray beam transmission profiles for all thicknesses and beam geometries at three depths 1.5 cm (depth of dose maximum, d_{max}), 5 cm and 10 cm and then normalized to 100% (Fig. 1).

2.2. Measurements performed

The measurements were carried out on Varian Trilogy Tx linear accelerator (LINAC) (Varian Medical Systems, Palo Alto, CA, USA) with 6 MV energy using PSB alloy as compensator of different thicknesses. Compensator slabs were placed on a perspex sheet at tray slot in accessory mount on LINAC head. Collimator opening effects on a number of parameters have been studied for narrow beam field sizes (A_n) 3 × 3 cm^2, 5 × 5 cm^2 and broad beam field sizes (A_b) 10 × 10 cm^2, 15 × 15 cm^2 and 20 × 20 cm^2.

2.2.1. Density (ρ)

Density of alloy was measured by Archimedes' principle using SI-234 physical balance (Denver instrument, Bohemia, NY, USA) (Repeatability = ± 0.0001 g) and water as buoyant liquid. The density of PSB alloy sample has been calculated using Archimedes' principle (Punia et al., 2011):

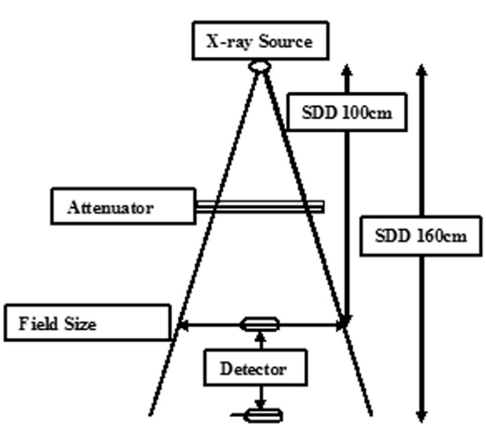

Fig. 1. Setup for in air measurements at SDD100 cm and 160 cm.

$$\rho_{sample} = \left(\frac{w_{air}}{w_{air} - w_{water}}\right)\rho_{water}$$

Where, w_{air} is weight of sample in air, w_{water} is weight of sample in water, ρ_{water} is density of water.

2.2.2. Transmission

For a mono energetic photon beam of intensity (I_0), the transmitted intensity (I) through an compensator of thickness, t is given by

$$I = I_0 e^{-\mu_{eff}.t} \quad (1)$$

$$\text{Log } I = \text{Log} I_0 - \frac{\mu_{eff}.t}{2.303} \quad (2)$$

Where, μ_{eff} depends on nature of material and energy of incident photon. Though x-rays are not discrete energy beam but in present study 6 MV photon beam is used, which may be treated as mono-energetic beam and intensity variation of these x-rays may behave according to Eq. (1) (Weeks et al., 1988; Khan, 2003).

The experimental setup for measurement of transmitted intensity of x-ray photon is as shown in Fig. 1.

In air measurements were carried out at source to detector distance (SDD) of 100 cm and for extended SDD of 160 cm (Fig. 4). Transmission was measured with farmers chamber FC-65 G (IBA Dosimetry, Germany) with effective volume of 0.65 cm^3. Measurements were performed with 1.5 cm buildup cap on ionization chamber placed in air on beams central axis with different slab thicknesses and for a number of square field sizes ranges from 3 × 3 cm^2 to 20 × 20 cm^2.

2.2.3. Tissue phantom ratio ($\mathbf{TPR_{10}^{20}}$)

TPR_{10}^{20} was measured by placing CC13 thimble chamber (IBA Dosimetry, Germany) at a depth of 20 cm and 10 cm in RW3 slab phantom and then establishing the ratio of charge accumulated for 100MU at these two depths. Active volume of CC13 is 0.13 cm^3. Measurements were carried out for all open fields and attenuated fields for different compensator thicknesses and different field sizes.

2.2.4. Surface dose (D_s)

Surface dose was measured with PPC05 parallel plate ionization chamber (IBA Dosimetry, Germany) at surface in water phantom. Charge collected for 100 monitor units (MU) has been reported for surface dose analysis.

2.2.5. Percentage depth doses (PDDs)

PDDs studies were carried out with radiation field analyzer, RFA300 (IBA Dosimetry, Germany) with Omnipro Accept® v7.0 software (IBA Dosimetry, Germany). Depth dose profiles were measured by 0.13 cm^3 CC13S ion chamber (IBA Dosimetry, Germany) up to 28 cm depth in water. PDDs were measured for different field sizes and for different thickness of compensator.

3. Results and discussion

3.1. Density

Calculated density of sample using percentage by weight and density of individual constituents was 9.802 g/cm^3. Density of sample measured in laboratory was found 9.5456 g/cm^3. The sample was melted three times and density variation was found negligible. This shows the reusability of the alloy clinically as a compensator. This density of compensator is good enough to produce high degree of dose modulation which is essential in cIMRT. Perusal of data presented in Fig. 2 reveals the absence of any air bubble in the prepared slabs, as the flatness and symmetry of the profiles appear continuous.