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Dose Homogeneity in Surface Applicator Overlapping and Non-Overlapping Region Using Homemade Bolus with 3D Printer in INTRABEAM System for Skin Cancer

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Abstract

The Carl Zeiss INTRABEAM system is a mobile compact miniature x-rays device which delivers treatment by various techniques including intraoperative, interstitial, intra-cavity, and surface treatments. The main purpose of the study was to observe dose homogeneity in surface applicator overlapping and non-overlapping region using 3D printed bolus in INTRABEAM System for skin cancer treatment. Dose uniformity plays a crucial role between overlapping and non-overlapping region of applicator during dose delivery in skin cancer. The different thickness, shape (concave, convex) and filament densities of ABS (Acrylonitrile Butadiene Styrene) were made to form main body parts of bolus for surface applicator of diameter 4 cm in Carl Zeiss INTRABEAM system with the help of German RepRap 3D printer. Concave and Convex part refer to the structures similar to the cross section of concave and convex lens respectively. GafChromic eBT films which were irradiated with 50 kV x-ray with surface applicator in presence of bolus. After those films were scanned with an EPSON® Expression 10000 XL/Pro flatbed scanner and dose profile were plotted with ImageJ Software, from which dose homogeneity was determined. The dose profiles were plotted for the different combination (filament density) of concave and convex parts of bolus (printed from 3D printer) with thickness 5 mm, 6 mm, 7 mm, 8 mm, 9 mm and 10 mm. From the plotted profiles, the maximum flat profile was seen in the bolus with thickness 10 mm and combination of concave filament density 45% and convex filament density 100%.The dose homogeneity is better achieved for the INTRABEAM system Surface applicator at overlapping and non-overlapping region by using homemade bolus with appropriate combination (filament density) of concave and convex parts of bolus comparative to the other methods. The aim of the research is to provide a better method for the treatment of the localized skin cancer of the size>4 cm.

Keywords: Bolus; Dose homogeneity; INTRABEAM system (Electronic Brachytherapy); Surface applicator

Introduction

According to World Health Organization (WHO) skin cancer incidence is increasing in past decades and estimates about 2-3 million Non-Melanoma Skin Cancers (NMSC) occur worldwide each year with one in every three cancers diagnosed being a skin cancer. The incidence rates in Europe varied between 40-130/100,000 person years for Basal Cell Carcinoma (BCC) and 8-30/100,000 person years for Squamous Cell Carcinoma (SCC) respectively. It is expected that NMSC may soon start to represent a major public health problem and pose a significant burden to any health care system [1]. Hence skin cancer became ideal topic of choice for many researchers.

Various radiotherapy techniques have been developed to treat skin cancer: Superficial and orthovoltage X-rays, electron and megavoltage photon treatment and brachytherapy (Radionuclide and Electronic). The treatment choice is usually based on institutional resources and specialist experience and should consider local control, cosmesis, toxicity and convenience/expected compliance of the treatment. Electronic Brachytherapy (eBT) is an appropriate and effective treatment option for selected skin cancers, mainly NMSC that are not better served by surgical removal [1].

Electronic Brachytherapy (eBT) is a cancer treatment technique, using ≤ 50 keV X-rays source which are placed in close or contact with the treated tumour [2,3]. The purpose of eBT is to eradicate microscopic tumour foci by maximizing the radiobiological effects of a single dose [4]. A single high dose of radiation delivered directly to the tumor within a few minutes in eBT is safe, effective, cost saving and optimizes the treatment duration compared to Linac and radionuclide BT [5]. Hence eBT offers non-invasive or minimally invasive treatment that particularly appeals to elders and frail population [1]. eBT also eliminates some of the accidents related to radionuclide brachytherapy such as loss of sources, radiation leakage in off state, transportation accidents and radioactive waste [5-7]. It uses a miniaturized x-ray source that can be turned on or off, instead of the traditional radioactive seeds that are always emitting radiation [5]. For local recurrences, irradiation with eBT is the only radio therapeutic option if repeated EBRT is no longer possible [8].

Now a day's in some radiotherapy centers skin cancer and superficial tumours are being treated with eBT technique. Some studies have demonstrated that these systems result in lower toxicity and provide excellent cosmesis. But it has some limitation to small skin cancers due to their specific design of applicators. Most of these systems use a surface applicator ranging from 0.5 cm to 4 cm [9,10]. Hence, the treatment of skin cancer of greater size is challenging. So to account this problem, the surface applicator is placed in overlapping position. But while keeping applicator with overlapping position, dose distribution won't be homogeneous. To overcome this problem, in this study homemade bolus (tissue equivalent) of appropriate filament density, shape and thickness has been developed and used in surface applicator (designed with AutoCAD Software and printed in 3D printer) in the INTRABEAM System.

Materials and Methods

Materials

The INTRABEAM system (Carl Zeiss Meditec AG, Oberkochen, Germany) **(Figure 1)** consists of the user terminal (the graphic interface between user and control console), the control console, which controls the X-ray source (XRS 4), quality assurance (QA) equipment, and the XRS 4. Additionally, a support stand and different applicators are also included [11-13]. The XRS 4 itself consists of an electron gun, which emits electrons, the accelerating unit, which accelerates the electrons to a maximum of 50 kV and two pairs of bending coils, which guide the electron beam through a 10 cm long field-free drift tube (probe) to the gold target, where Bremsstrahlung is generated. This results in a spherical dose distribution [12].

Figure 1: The Carl Zeiss INTRABEAM®-system a mobile intraoperative x-ray device during measurement.

The 3D printer used in this research was German RepRap X-350 printer **(Figure 2)**. The X350 is reliable, user-friendly, and can print continuously for one or several hours (Guide, 2016). The printing material used in this research to print bolus was ABS (Acrylonitrile butadiene styrene- copolymer).

Figure 2: The German RepRap X350 3D printer.

Methods

A rectangular block of length 7 cm, width 6 cm and height 2 cm was designed in AutoCAD and two circles of each diameter 4.2 cm were drawn overlapping each other (here 4.2 cm was taken as diameter although size of surface applicator was of 4 cm considering an edge of 0.1 cm enclosed it). The length of overlapping region along diameter was about 3.27 cm and the length of each non-overlapping region along diameter is 1.2 cm as shown in **Figure 3a**. After that a uniform pit of depth 1.7 cm was created along the overlapping and non-overlapping region of two circles, which was required for design of main body of bolus and is shown in **Figure 3b**. Also, convex parts of bolus with length 3.27 cm along the overlapping direction were designed with thickness 5 mm, 6 mm, 7 mm, 8 mm, 9 mm and 10 mm as shown in **Figure 3c** and a pair of concave parts of bolus of size 1.2 cm along the overlapping direction were designed each with thickness 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, and 10 mm as shown in **Figure 3d**.

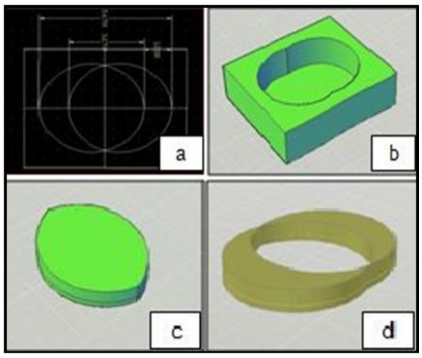

Figure 3: a) A cross sectional view of bolus design b) Design of body c) Design of convex part d) Design of concave parts.

The 3D bolus designed in the AutoCAD Software was first transferred to Repetire Software, where dimension of objects were adjusted to real size by calibration of virtual base. Then the given files were converted to g-code adjusting the bed temperature and extruder temperature to 110°C and 230°C respectively and were fed to printer through SD card. For the printing of main body part or frame, the filament ink fill density was adjusted to the 20% whereas the concave and convex parts of bolus were printed separately with variety of filament ink fill density and are shown in **Table 1**.

Table 1: Concave and Convex parts of a bolus with different filament fill densities and thickness.

Combination	Concave part of a bolus filament density (%)	Convex part of a bolus filament density (%)	Thickness (mm) of parts
1	39	100	5
2	35	90	6
3	35	100	6
4	25	85	7
5	35	85	7
6	50	100	8
7	50	100	9
8	45	100	10
9	50	100	10
10	55	100	10
11	60	100	10

The image of printed body or frame, convex and concave parts of a bolus are shown in **Figure 4.**

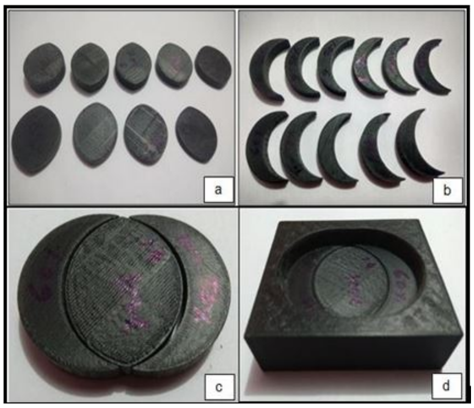

Figure 4: a) Convex parts of bolus b) Concave parts of bolus c) A proper arrangement of concave and convex parts of a bolus d) A bolus.

The INTRABEAM® XRS-4 was adjusted in INTRABEAM® stand after quality assurance check. GafChromic film was placed in appropriate position above the pieces of ceramics tiles, and then printed bolus was placed in their specified position on GafChromic film with marking. After that, XRS probe with surface applicator of diameter 4 cm was place on bolus at designated position. The parameters within the INTRABEAM®-system Software such as the prescription-depth Zpresc, the prescription-dose Dpresc and the prescription-time tpresc were taken as following:

Zpresc=15 mm,

Dpresc=2 Gy,

tpresc=2 mins

Then radiation was exposed to the GafChromic film. The process was repeated for different densities combination of concave and convex parts of bolus. Then the irradiated films were scanned with an EPSON® Expression 10000 XL/Pro flatbed scanner (US Epson®, Long Beach, CA). To ensure that the films are positioned at the middle of the scanner, a specially designed plastic frame EASEL® (ISP, NY) was used. The obtained scan copies were processed using ImageJ® Software.

Results

The radiation exposed films and corresponding dose profiles for the all combinations of concave and convex parts of bolus were listed below side by side from **Figures 5-15.**

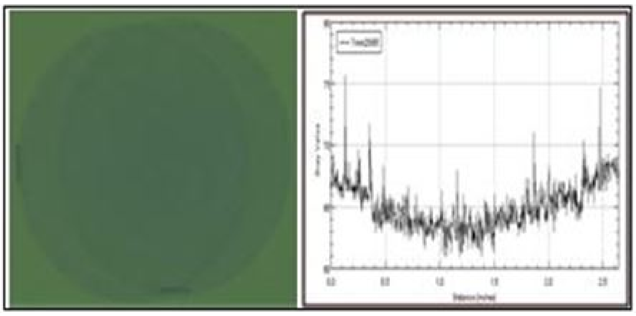

Figure 5: Combination 1 (100% convex part filament density and 39% concave part filament density, 5 mm thickness).

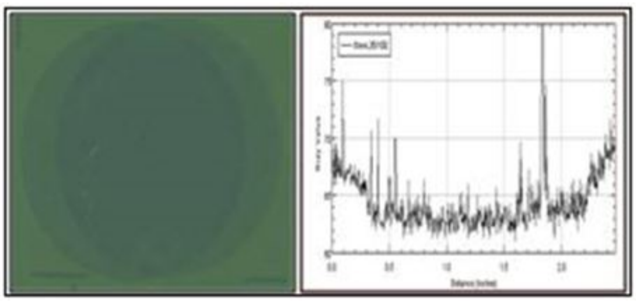

Figure 6: Combination 2 (90% convex part filament density and 35% concave part filament density, 6 mm thickness).

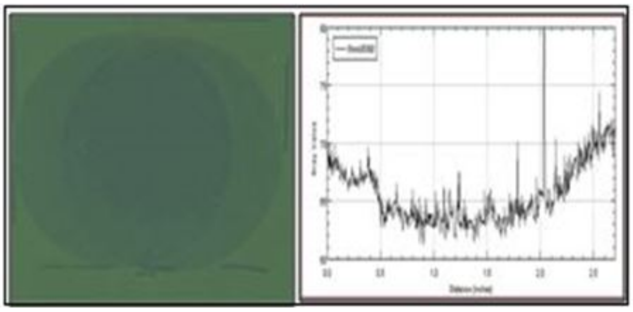

Figure 7: Combination 3 (100% convex part filament density and 35% concave part filament density, 6 mm thickness).

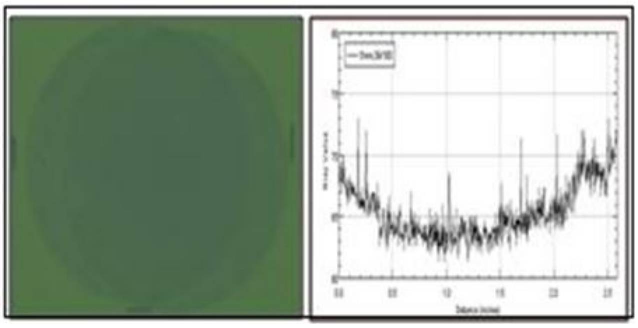

Figure 8: Combination 4 (85% convex part filament density and 25% concave part filament density, 7 mm thickness).

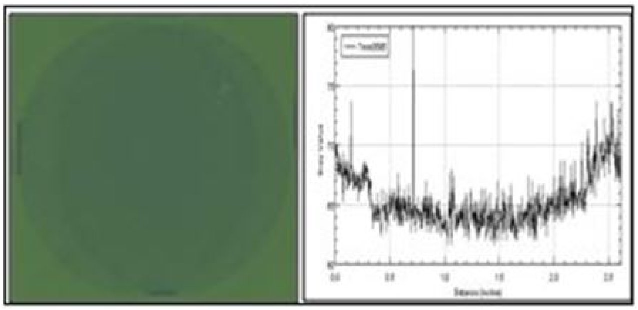

Figure 9: Combination 5 (85% convex part filament density and 35% concave part filament density, 7 mm thickness).

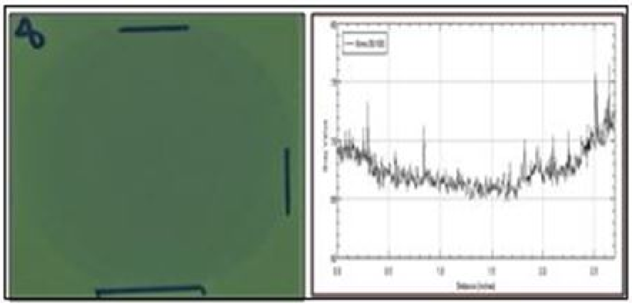

Figure 10: Combination 6 (100% convex part filament density and 50% concave part filament density, 8 mm thickness).

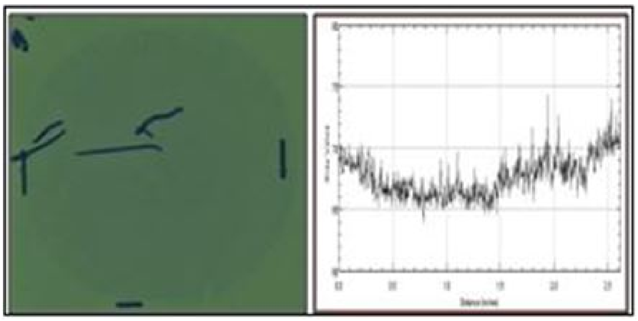

Figure 11: Combination 7 (100% convex part filament density and 50% concave part filament density, 9 mm thickness).

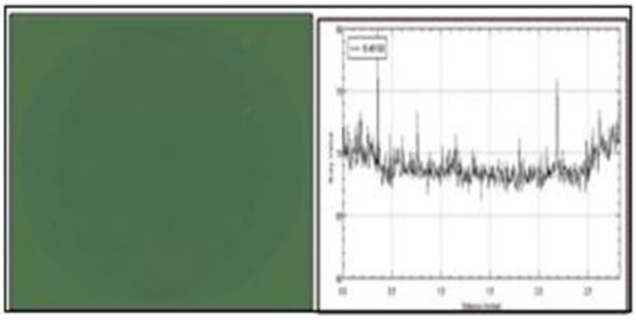

Figure 12: Combination 8 (100% convex part filament density and 45% concave part filament density, 10 mm thickness).

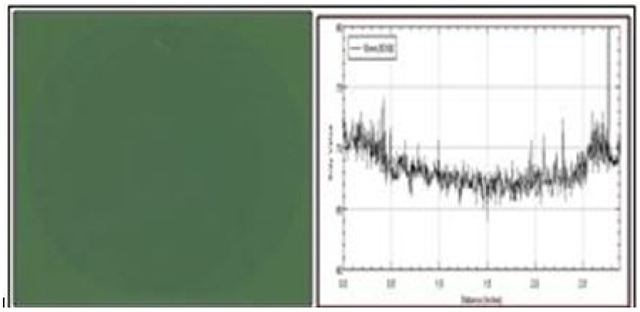

Figure 13: Combination 9 (100% convex part filament density and 50% concave part filament density, 10 mm thickness).

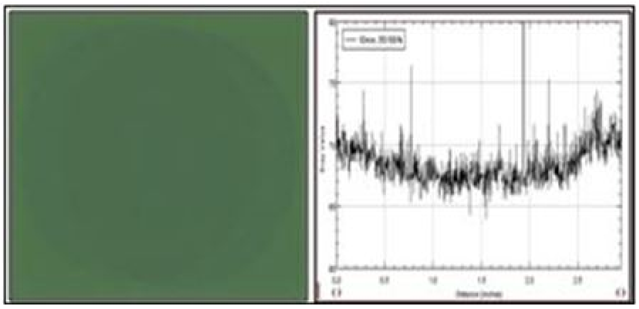

Figure 14: Combination 10 (100% convex part filament density and 55% concave part filament density, 10 mm thickness).

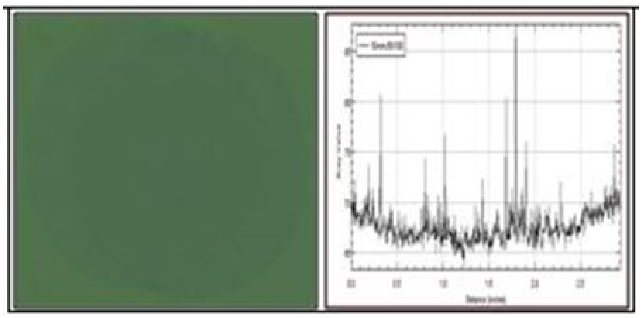

Figure 15: Combination 11 (100% convex part filament density and 60% concave part filament density, 10 mm thickness).

Comparing the profiles generated using ImageJ Software above; we can conclude that the combination-8 (100% convex and 45% concave, 10 mm thickness) had the most homogeous dose distribution.

Discussion

The aim of this study was to develop a method for dose homogeneity of overlapping and non-overlapping regions of the surface applicator in INTRABEAM system for skin cancer. So to develop dose homogeneity, a typical homemade bolus was designed and printed with 3D printer. The bolus consists of three parts, body or frame, concave and convex parts. A total of eleven different combinations of these three parts were used, which consists of same thickness but concave and convex parts were used with different filament filling densities. Each combination of bolus was exposed separately by radiation of total dose 2 Gy for two minutes placing a GafChromic film.

Dose profiles are shown above from **Figures 5 to 15**. It is seen that the most flat profile was seen in the 10 mm thickness bolus combination in comparison to other thickness bolus. And among all 10 mm thickness, combination 8 (100% convex and 45% concave, 10 mm thickness) showed maximum flat profile as compared to other, so it showed the most homogeneous dose distribution. The middle convex parts (bolus) of any combinations were designed to account for the double exposures. The convex part had been able to attenuate the radiation on the doubly exposed parts, whereas the concave parts on each side were exposed only once.

Mathematically, Combination 9 (100% convex and 50% concave, 10 mm thickness) could have given the best dose distribution in terms of homogeniety, however that failed, which means the dose addition is not purely arithmetic. This is because the concave parts of bolus lie on periphery of convex part of bolus. The dose distribution is most flat for combination 8 (100% convex and 45% concave, 10 mm thickness) at below 70 Gray-value which is supposed to be equal to 2 Gy in this case. Which means the central part is attenuating more than double and its filament density is also more than double as compared to peripheral density but not proportionally.

Besides all above, the major advantage of this research is, it helps to deliver radiation uniformly for the superficial tumour size>4 cm, reduce overall treatment time reducing risk of tumour cell repopulation, require less effort and time for the positioning of applicator (source), increased tumour control while sparing the surrounding tissue in comparison with radioactive brachytherapy and the external beam radiotherapy.

In the article, Frank Schneider et al. [14] valuate that a new applicators (spherical, flat and surface) with a miniature X-ray source (INTRABEAM system) can be used for the treatment of superficial tumour intraoperatively. They evaluated the homogeneity of dose distribution and depth-dose measurements using film dosimetry in a solid water phantom and a soft X-ray ionization chamber in a water tank. They treated first patient with 5 Gy at depth 1 mm using surface applicator, show a uniformity ratio of 1.15-1.28. The results of their investigation demonstrated that the surface applicators have unique dosimetric characteristics and is possible to perform a superficial localized IORT which provides new application possibilities for use of the INTRABEAM system. From all above points it is clear that Frank Schneider et al. research was related to validation of surface applicator for dose homogeneity. This research was also related to the development of dose homogeneity for the surface applicator, but 3D printed bolus was used to developed dose homogeneity in the IORT beam overlapping and non-overlapping region [9].

According to Guinot et al. surface moulds as applicator usually custom made and designed can provide a more constant and reproducible frame for radioactive source positioning. For the surface treatment dose is prescribe 3-5 mm under the skin surface and a distance from the source to the skin must kept 5 mm to obtain dose homogeneity on the surface of the skin. But in this research homemade bolus with surface applicator was kept in contact to the target region to produce homogeneous dose [1].

Conclusion

The results of the research revealed that dose distribution can be made homogeneous in the single overlapping and non-overlapping regions of the INTRABEAM System surface applicator by using homemade bolus of appropriate shape, density and thickness. The major advantages to patient dose delivery are localized dose to the target, uniform dose distribution, and simplicity of procedure. The aim of the research is to provide a better method for the treatment of the localized skin cancer of the size>4 cm. Thus, the study concludes that the INTRABEAM system can be an appropriate and effective treatment option for selected skin cancers with the use of bolus to improve dose homogeneity in single as well as multiple overlapping and non-overlapping regions of surface applicator, if it is practically exploited in the Hospitals.

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