Dosimetric characteristics of INTRABEAM® flat and surface applicators

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Purpose: Spherical applicators INTRABEAM® system has been successfully used for post-lumpectomy Intra-Operative Radiation Therapy (IORT). Recently Zeiss Meditec AG obtained USA FDA approval of their Flat and Surface applicators for gastrointestinal and or skin tumors. We investigated the dosimetric characteristics of these applicators and considered their feasible clinical applications.

Investigation design: Investigation was performed using the Gafchromic EBT 2 QD+ (GEBT) film in solid water phantom, ionization chamber and solid state detector in scanning water phantom.

Results: Conventional and unconventional dosimetry findings revealed uniqueness of these applicators. It is found to have good potential for clinical application for skin cancer treatment and intra-abdomen and intra-pelvis IORT.

Conclusions: From the study, it is clear that the two types of applicator may be interchangeable. It is however important to appreciate the different characteristics of the applicators and take advantage of its special features. Generally, the surface applicators have a higher dose rate with less uniform dose at depth. They provide uniform dosimetry at the surface without any hot spots at the perimeter of the field. This feature is good for uniform dose treatment for the first 2-3 millimeters. For treatment with larger field sizes and deeper depth, one needs to allow larger margin for treament volume to compensate for the dose tappering at the edge of the field. The flat applicators has high penetration and uniform dose at depth. They provide uniform dosimetry at 5 millimeter depth. This feature is good for treatments desiring uniform dose across the field at 5 to 8 millimeter depth. For larger field sizes one needs to watch for the a higher dose ring at 2-3 millimeter depth near the perimeter of the field. Extra margin for treatment volume is not as critical, beacuse of the uniform dose at depth.

Keywords: Intraoperative radiotherapy; electronic brachytherapy; INTRABEAM® Radiotherapy System (IRS); superficial radiotherapy

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Introduction

The Zeiss INTRABEAM® Radiotherapy System (IRS) is a 50 kV X-ray unit that is designed for interstitial brachytherapy. This novel technology was originally the Photon Radiosurgery System (PRS) developed by the Photoelectron Corporation in Massachusetts, USA and is now commercially available as the Zeiss IRS.

The devise has been in use for IORT with the spherical applicators. The dosimetric characteristics of the PRS source and those of the spherical applicators have been well studied and reported (1-7). The clinical efficacy and results are released in the TARGIT-A Trials reports (8,9).

With appropriate collimation and differential attenuation, the PRS source has been modified to direct the beam as a forward projection radiation source for skin cancer treatment (10). Further refinement of the applicators by Carl Zeiss Meditec Inc. made available two sets of forward beam projecting applicators: INTRABEAM® Flat applicator (IFA) and the INTRABEAM® Surface aplicator (ISA). The manufacturer submitted the applicators, which are classified as medical device, to the FDA for approval on 3/4/2013 and it was deemed Substantially Equivalent on 6/26/2013.

Materials and methods

Gafchromic EBT 2 QD+ (GEBT) film was used together with the solid water phantom for capturing the integrated exposure from each of the applicators in axial and cross-section of the beam. The GEBT film was selected due to the convenience and the reported relative independence of energy at the 50 kV range (11-14).

In order to eliminate the possible concern of sensitivity to energy changes due to filtration and the dose rate on film sensitivity the Hurter-Drifield sensitometric curve (H-D) was established by direct relationship of ionization chamber measurements using PTW Unidose electrometer and IC ionization chamber type 34013 in the INTRABEAM® water phantom system with the optical densities measured by the Vidar Dosimetry Pro Advantage® film scanner from the GEBT film. The points of measurement were at the exact corresponding positions relative to the surface of the applicators (*Figure 1*, *Figure 1A-C*). A polynomial expression was fitted to the ion chamber measurements and the optical density for each of the applicator sets as an analogy relation (*Figure 1D*, *E*) for 2D dosimetry analysis.

Imaging processing and isodose generation was performed using the Radiological Imaging Technology® software with special attention to the film H-D calibration.

Dosimetric characteristics

Ion chamber and film data were analysed for both conventional characteristics and unique characterisitics of these short source-to-skin distance applicators. Analysis was performed on the conventional dosimetric characteristics included Dose Rate (DR) and Central Axis Percentage Depth Dose (PDD).

On account of the uniqueness of the 50 kV beam energy, together with the short target-to-surface distance (TSD) and the individuallized filtration for the uniform isodose curve at a 5 mm tissue depth for the IFA and uniform isodose curve at the surface for the ISA; analysis was considered for the unconventional dosimetric characteristics. The investigation included Beam Divergence, Beam Hardening effects of off-central-axis Beam Quality expressed in PDD and the Penumbra width of the applicators which are expressed in the full-width-half-maximun index (FWHM) for the measurement for different sizes.

Evaluation of the two sets of applicators, gave us an appreciation on the characteristic differences between the IFA and the ISA. Consultations with physicians gave us some insight on the potential clinical applications for these forward projecting applicators.

Results

Conventional dosimetry characteristics

Figure 1F,G and *Figure 2*, *Figure 2A,B* represent a graphic presentation (not to scale) of two dimensional views of both dose rate and percentage depth dose relationships as a function of applicator type and cone size.

Output-factors

Contrary to conventional wisdom in radiotherapy that larger field sizes have larger dose rate, these applicators have the highest dose rate with the smallest field size applicator (*Figure 2H,I*).

Flat applicators have a lower dose rate compared to those of the Surface applicators of the same size (*Figure 2D*) (note: unit of the table is charge per unit time)

Surface applicators are two to three times higher in dose rate than those of the Flat applicators of a given depth of the same size.

Percentage depth dose

PDD's increases with field size of the same type of applicator; Flat applicators are about 1.5 time higher in PDD value than the Surface applicator of the same size at a given depth, on account more attenuation by the flattening filter (*Figure 2E-G*).

Unconventional dosimetry characteristics

Beam divergence

The virtual-source-to-surface distance of the applicator distance (indicated as Y in *Figure 1G*) (*Figure 2B*), and the divergent angle indicated as angle (Θ) increases as field size increases.

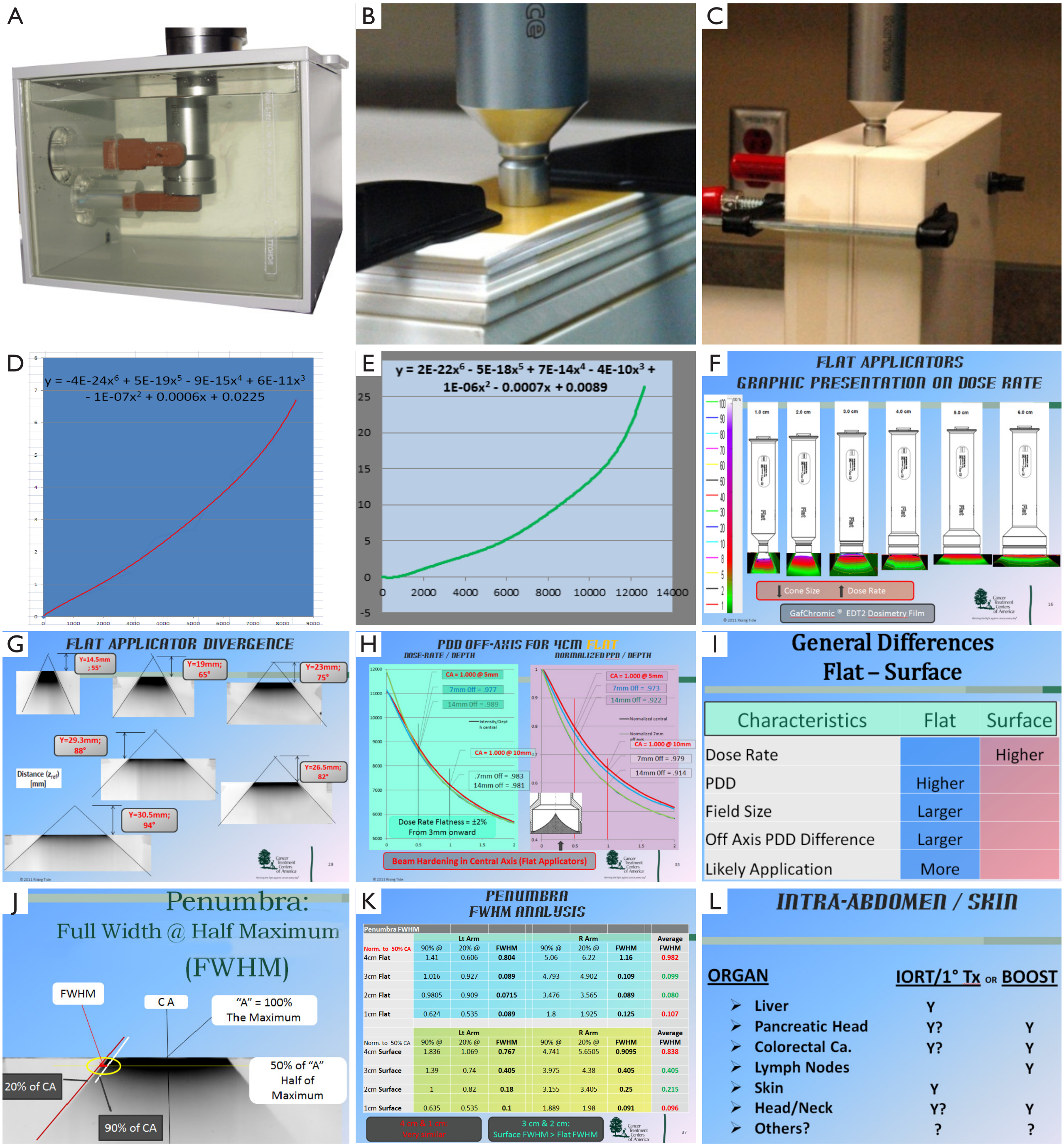

Figure 1 (A-C) Ion chmaber measurement, and film dosimetry setup; (D,E) Polynomial expression between ion-chamber readings and film density; (F,G) 2D Graphic view of flat applicators dose rate and percentage depth dose; (G) Flat applicators beam divergence and virtual-source-to-surface distance; (H,I) Output factors is highest with smallest field and the general difference betweew flat and surface applicators; (J,K) Penumbra studies and comparison of results between flat and surfact applicators; (L) Feasible clinical applications.

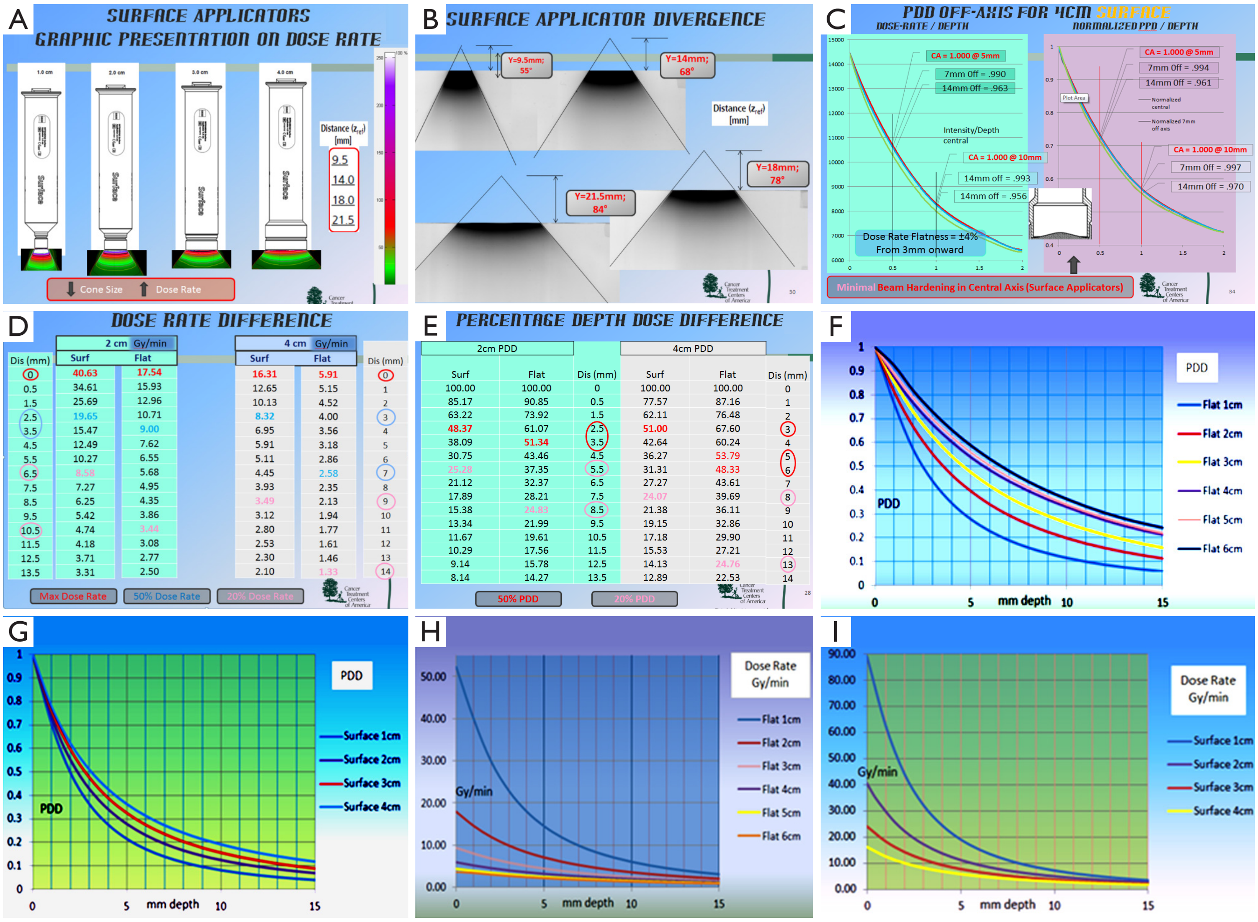

Figure 2 (A,B) 2D Graphic view of surface applicators dose rate and percentage depth dose; (B) Surface applicators beam divergence and virtual-source-to-surface; (C) Off-central-axis beam quality comparisons from central axis to 7 mm and 14 mm off-axis for a 4 cm diameter flat and surface applicators; (D) Output factor comparison between flat and surface applicators, (note: unit of the table is Gray/minute); (E-G) Percentage depth dose comparison between flat and surface applicators; (H,I) Dose rate plots as a function of depth in water in Gray/minute for flat and surface applicators.

Flat applicators (*Figure 1G*)

The (Y mm, ϴ°) values of 1, 2, 3, 4, 5, 6 cm diameter cones are determined graphically. The values are (14.5, 55°), (19.0, 65°), (23.0, 75°), (26.5,82°), (29.3, 88°) and (30.5, 94°) respectively.

Surface applicators (*Figure 2B*)

The (Y mm, ϴ°) values of 1, 2, 3, 4, cm diameter cones are (9.5, 55°), (14.0, 68°), (18.0, 78°), (21.5, 84°) respectively.

Between the the Flat and Surface applicator sets of the same size, the divergent angles are very similar; whereas the ISA have an approximately 5.0 mm shorter virtual-source-to-surface. Together with less attenuation for the ISA as compared to the IFA, it explains its higher dose rate as compared to the ISA with identical kV and mA, as compared to those of the IFA of the same size.

Off-central-axis beam quality

The largest ISA is a 4.0 cm diameter (*Figure 2C*), for comparison same size IFA were studied (*Figure 1H*, *Figure 2C*). There is more attenuation for the IFA. The Dose rate at depth was measured at the central axis, as well at 7.0 mm and at 14.0 mm off central axis. PDD was determined by normalizing each set of data to the maximum dose rate for each off-axis distance.

Flat applicators

Figure 1H demonstrated that the dose rate of the three axes are within ±2% through out different depths. The PDD of the central axis shows a higher PDD at any given depth. At 5 mm depth, the ratio of PDD of central, 7, 14 mm are 1.0, 0.973 and 0.922. The farther off axis beams are of softer X-rays.

Surface applicators

Figure 2C demonstrated that the dose rate of three axes are within ±4% through out different depths. The PDD of the central axis shows less differences in PDD at any given depth. At 5 mm depth, the ratio of PDD of central, 7, 14 mm are 1.0, 0.997 and 0.970. The off axis beams are of rather similar X-rays quality for the ISA.

Penumbra (FWHM)

Figure 1J,K illustrates the FWHM index and the values measured for both IFA and ISA. For comparison purposes, only cone sizes of 1, 2, 3 and 4 cm were measured. In general the penumbra size was expressed as distance between the 90% and the 20% divergent lines of central axis maximum value. The result is around 1% of the field width. There is not much of difference between the two types of applicators.

Conclusions and discussion

This study using an ionization chamber for calibrated dose rate measurements and GEBT film for 2D analysis, gave a general understanding of the basic characteristics of the two sets of forward beam applicators. *Figure 1I* listed the general differences between the applicators sets.

On the whole the IFA set provided a larger field size, and higher PDD and it may indicate a wider clinical application eventually. Whereas at the lower dose rate, it was two to three times lower as compared to the ISA. The different quality of radiation across the larger field sizes may raise possible concern for relative biological effectiveness (RBE) differences within a treatment field. These factors may shift favor to the Surface applicators.

General awareness on the differences between the two sets of applicators should be considered in evaluating clinical application and analyzing the clinical results.

In consultation with clinical colleagues, *Figure 1L* summarizes our consideration in using the applicators for intra-pelvic, intra-abdominal and skin applications.

Reviewing the recent publication by Schneider F *et al.* (15) in January 2014 on their investigation of the flat and surface applicators and a case report of using a Flat applicator, we concur with their findings that the flat applicators have better dose homogeneity across beam profile, and surface applicators show a steeper depth dose gradient and higher dose rate.

In the USA, clinical approval for patient treatment with the flat applicators only happened in the beginning of Feb. 2014. We did however treat one patient with a 3.5 cm spherical applicator for gastrointestinal recurrent cancer by individualized shielding recently.

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Footnote

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