Measurements of superficial dose distributions in radiation therapy using translucent cryogel dosimeters

M M Eyadeh¹, M Wierzbicki², K R Diamond²
¹Physics Department, Faculty of Science, Yarmouk University, Irbid, 21163 Jordan
²Department of Medical Physics and Applied Radiation Sciences, McMaster University and Juravinski Cancer Centre, 699 Concession St, Hamilton, ON, L8V 5C2, Canada

Email: molhem.e@yu.edu.jo

Abstract. Superficial dose distributions were measured using radiochromic translucent poly(vinyl alcohol) cryogels. The relationship between dose to the skin surface and dose measured with the bolus (cryogel) was established using a series of oblique irradiations. Gafchromic film was placed under the bolus, and the ratio of bolus-film dose was determined for angle ranging from 0° to 90°. The average ratio over 0-67.5 degrees (0.800 ± 0.064) was used as the single correction factor to convert dose in bolus to dose to the skin surface, and applied to bolus measurements of skin dose from head and neck intensity modulated radiation therapy (IMRT) treatments delivered to a RANDO phantom. The resulting dose distributions were compared to film measurements using gamma analysis with a 3%/3mm tolerance and a 10% threshold. The minimum gamma pass rate was 95.2%. This study is the first report on the use of a poly(vinyl alcohol) cryogels based dosimeter to provide an accurate estimation of superficial dose distributions in megavoltage photon beams.

1. Introduction
In radiation therapy, the dose deposited at the skin surface by megavoltage photon beams may be substantially lower than the underline tissue [1]. However, treatment of superficial disease requires that the prescribed dose be delivered up to the skin surface. A layer of bolus may be placed on the skin to increase the dose deposited in the superficial tissues [2, 3]. Accurate knowledge of dose to superficial tissues is important, but this confounded due to the inaccuracy of most treatment planning systems (TPSs) in the buildup region [4]. TPSs are able to calculate skin dose within ± 25% [5-10]. Therefore, in vivo measurements are desirable to verify the skin surface dose.

Dosimetric systems such as thermoluminescent detectors (TLDs) [11] metal-oxide semiconductor field-effect transistors (MOSFETs) [12] and radiochromic film [13] are used during radiotherapy for dose verification purposes [14]. Film is difficult to form to surfaces that contain both convex and concave regions, which complicates dosimetry [15]. Another approach would be to use gel dosimeters [16, 17]. Dosimetric cryogels are flexible materials that conform easily to curved regions of the body. It may provide an accurate estimation of superficial dose distributions [18]. Recently, these cryogels were used to monitor chest wall radiation therapy treatment [19].

The dose estimated using TPS at depths of 0.5 to 1.0 cm lacks the accuracy desired during radiotherapy. For megavoltage photon beams, the dose increases up to 60% within the first 0.5 cm depth, making the measured surface dose sensitive to the buildup thickness [20-22]. Due to the rapid dose build up, the dose will not be uniform throughout the 0.5 cm thick bolus material, and not equal to the actual...
surface dose. It may be possible to derive a correction factor from the dose measured in the gel dosimeter to the surface dose.

The purpose of the presented here work is to evaluate the ability of a translucent poly(vinyl alcohol) cryogel (PVA-C) containing ferrous benzoic xylenol orange (FBX) radiosensitive bolus material [23] to measure skin dose during radiotherapy. The concept is demonstrated using clinical IMRT fields delivered to the head and neck region of a RANDO phantom (Phantom Laboratory, Salem, NY, United States).

2. Materials and Methods

In this study, translucent FBX-PVA-C was used as radiochromic bolus using PVA concentration of 15% by weight. A detailed description of its production was described elsewhere [19, 23]. The hydrogel was decanted into custom plastic moulds with interior dimensions of 15 x 15 cm² and 0.5 cm thickness; the hydrogels were subjected to 3 cycles of 18 hour freezing at -80 °C and 6 hours thawing at room temperature. The cryogel is flexible and can conform to most parts of a patient’s body. The bolus samples were imaged pre- and post-irradiation using 2D camera system using charge coupled device (CCD) camera, a Lumen-Essence BK-600 uniform red light emitting diode (LED) array, and a light tight box. 2D images were collected by the 16-bit CCD and stored as ‘TIFF gray image’ files. 2D Absorption coefficient maps were generated using an in-house MATLAB program.

The relationship between bolus absorption coefficient and delivered dose was established using a Varian iX linear accelerator (Varian Inc., Palo Alto, United States) under full scatter condition. The expected doses in cGy were computed using the Pinnacle v9.2 TPS (Philips, Amsterdam, Netherlands). The same procedure was employed to relate optical density and dose in pieces of EBT-2 Gafchromic film (lot #A052810-01) [International Specialty Products, Wayne, New Jersey, United States]. The EBT-2 film was scanned using an Epson 11000XL Scanner (Proscan, Avision, Australia) and analyzed using Film QA™ Pro (Ashland, Wayne, New Jersey, United States).

Open field irradiations were used to examine the relationship between the dose distribution recorded by the radiochromic bolus and the true surface dose, which was estimated using EBT-2 film by using a stack of radiochromic bolus and film on the surface of a polystyrene phantom. The configuration of these measurements is shown in figure 1.

**Figure 1.** Schematic of the radiochromic bolus and EBT-2 film irradiation. The irradiation was repeated with gantry angles of 0°, 22.5°, 45°, 67.5°, and 90°. At each angle, a 3 x 3 cm² field was formed using the jaw collimator and 1000 MU were delivered with a rate of 600 MU/min.

Proof-of-principle *in vivo* dosimetry measurements were performed on clinical head and neck IMRT treatment plans that were delivered to a RANDO phantom. A Philips Brilliance Big Bore scanner was used to acquire 1 mm thick CT slices of the head and neck portion of a RANDO phantom. Two
Simple static parallel-opposed-pair (POP) beam arrangements were planned for the neck region; two previously treated clinical cases with bolus including a 3-field larynx and a 9-field head and neck IMRT were selected and positioned on the RANDO data to approximate the arrangement on the patient. The bolus was manually cut to size on the phantom surface using orthogonal light field projections as a guide. These plans were then delivered to the phantom with EBT-2 film placed on the phantom surface below a layer of 0.5 cm radiochromic bolus to evaluate the skin surface dose directly.

3. Results and Discussion

The dose measured in the radiochromic bolus and the dose at the underlying surface both increased with increasing gantry angle. This is consistent with previous studies that reported increasing surface doses with incident beam angles [11, 24, 25].

Film QA Pro software was used to visually align dose maps. The point-by-point ratio was computed. The mean ratios for the irradiated areas are summarized in Table 1. If we restrict ourselves to a range of angles, 0° to 67.5° for example, we find that the average ratio between radiochromic bolus and film is 0.800 ± 0.064. Using this correction factor, the agreement between the film and the corrected bolus was improved at all gantry angles with average differences ranging from 1.4 to 1.9%. This suggests that a 0.5 cm radiochromic cryogel should be able to predict dose deposited at the bolus-skin interface. This factor was used to correct all subsequent bolus images.

Table 1. The mean ratio between surface dose and the dose measured in the radiochromic bolus at different gantry angles ranging from 0° to 90°.

| Gantry angle | Mean ratio ± Standard deviation |
|--------------|--------------------------------|
| 0°           | 0.749 ± 0.005                  |
| 22.5°        | 0.760 ± 0.005                  |
| 45°          | 0.802 ± 0.009                  |
| 67.5°        | 0.890 ± 0.016                  |
| 90°          | 0.930 ± 0.002                  |

For all gantry angles, the TPS overestimated the surface dose measured with film by 14.3 to 25.6%. This is consistent with related studies. Previously, it was reported that two TPSs overestimated surface dose by up to 18.5% when compared to Gafchromic film measurements [7].

In this study, gamma analysis was used to evaluate the agreement between the corrected radiochromic bolus and EBT-2 film measurements. A 2D gamma analysis was performed using the Film QA Pro software using 3%/3mm criteria and a 10% dose threshold. The percentage of pixels passing the gamma evaluation ranged from 95.2% to 96.4% as shown in Table 2.

Table 2. Gamma pass rates for comparisons of corrected radiochromic bolus and Gafchromic film measurements (3%/3mm, 10% threshold) for different field arrangements.

| Irradiation Geometry          | Gamma passing rate (%) |
|-------------------------------|------------------------|
| 0° / 180° POP, static beams   | 96.1                   |
| 90° / 270° POP, static beams  | 96.4                   |
| 3-field beams larynx, IMRT    | 95.2                   |
| 9-field beams neck, IMRT      | 95.5                   |

The results suggest that the radiochromic bolus measures skin dose with sufficient accuracy for clinical use. Furthermore, the cryogel material is more flexible than film, providing improved skin contact. It can be wrapped easily around curved surfaces and provide in vivo dosimetry in areas where
skin dose verification is desired. Different types of treatments with different cryogel thicknesses may yield different results and would have to be tested. However, for head and neck treatments with a typical bolus thickness the results of this paper should be valid.

4. Conclusion
A comparison of EBT-2 Gafchromic film and FBX-PVA-C radiochromic bolus suggests that the cryogel may provide an accurate estimation of skin surface dose distribution using a simple correction factor. Radiochromic bolus may then be used in place of more traditional forms of bolus to perform in vivo dosimetry in regions where the skin dose is important. The main advantage of this system over film is that it is more flexible, allowing it to be wrapped around complex curved surfaces.

5. Acknowledgement
This work has been supported by the NSERC Discovery Grant program and the Yarmouk University Physics Department.

6. References
[1] Hill R et al 2014 Phys. Med. Biol. 59 R183-231
[2] Khan F M 2010 The Physics of Radiation Therapy: 4th ed, Lippincott Williams & Wilkins, Baltimore, MD, USA.
[3] Vyas V et al 2013 Med. Dosim. 38 268-73
[4] Fraass B et al 1998 Med. Phys. 25 1173-822
[5] Mutic S and Low D A 2000 Med. Phys. 27 163-5
[6] Dogan N and Glasgow G P 2003 Med. Phys. 30 3091-6
[7] Chung H et al 2005 Med. Phys. 32 2682-9
[8] Court L E et al 2008 J. Appl. Clin. Med. Phys. 9 29-35
[9] Penettierei V et al 2009 Radiother. Oncol. 93 94-101
[10] Kry S F et al 2011 J. Appl. Clin. Med. Phys. 13 20-34
[11] Hsu S H et al Phys. Med. Biol. 53 2593-606
[12] Falco M D et al 2015 J. Appl. Clin. Med. Phys. 16 298-10
[13] Morales J E et al 2014 Austral. Phys. Eng. Sci. Med. 37 303-9
[14] Hill R et al 2009 Med. Phys. 36 3971-81
[15] Nakano M et al J. Appl. Clin. Med. Phys. 13 83-97
[16] Johansson S A et al 1997 Acta. Oncol. 36 283-90
[17] Baldock C et al 2010 Phys. Med. Biol. 55 R1-63
[18] Chu K C et al 2000 Phys. Med. Biol. 45 955-69
[19] Eyadeh M M et al 2016 J. Appl. Clinic. Med. Phys. 17 308-19
[20] Devic S et al 2006 Med. Phys. 33 1116-24
[21] Xiang H F et al 2007 Med. Phys. 34 1266-73
[22] Qi Z Y et al 2009 Med. Phys. 36 59-70
[23] Eyadeh M M et al 2014 Phys. Med. Biol. 59 1773-87
[24] Lin J P et al 2001 Appl. Radiat. Isot. 55 383-91
[25] Rinker G and Grussel E 1987 Med. Phys. 14 870-73