Queensland University of Technology
Brisbane Australia

This is the author's version of a work that was submitted/accepted for publication in the following source:

Kairn, T., Ibrahim, S., Inness, E., Crowe, S.B., & Trapp, J.V.
(2015)
Suitability of diodes for point dose measurements in IMRT/VMAT beams.
In Jaffray, David (Ed.) *World Congress on Medical Physics and Biomedical Engineering, June 7-12, 2015, Toronto, Canada.*
Springer, pp. 657-660.

This file was downloaded from: https://eprints.qut.edu.au/85983/

© Copyright 2015 Springer

Notice: *Changes introduced as a result of publishing processes such as copy-editing and formatting may not be reflected in this document. For a definitive version of this work, please refer to the published source:*

https://doi.org/10.1007/978-3-319-19387-8_160

Suitability of Diodes for Point Dose Measurements in IMRT/VMAT Beams

T. Kairn[1,2], S. Ibrahim[3], E. Inness[3], S. B. Crowe[2,4] and J. V. Trapp[2]

[1] Genesis CancerCare Queensland, Auchenflower, Australia
[2]Queensland University of Technology, Brisbane, Australia
[3]Princess Alexandra Hospital, Woolloongabba, Australia
[4]Royal Brisbane and Women's Hospital, Herston, Australia

Abstract— **This study investigated a potential source of inaccuracy for diode measurements in modulated beams; the effect of diode housing asymmetry on measurement results. The possible effects of diode housing asymmetry on the measurement of steep dose gradients were evaluated by measuring 5x5 cm^2 beam profiles, with three cylindrical diodes and two commonly used ionization chambers, with each dosimeter positioned in a 3D scanning water tank with its stem perpendicular to the beam axis (horizontal) and parallel to the direction of scanning. The resulting profiles were used to compare the penumbrae measured with the diode stem pointing into (equivalent to a "stem-first" setup) and out of the field (equivalent to a "stem-last" setup) in order to evaluate the effects of dosimeter alignment and thereby identify the effects of dosimeter asymmetry. The stem-first and stem-last orientations resulted in differences of up to 0.2 mm in the measured 20-80% penumbra widths and differences of up to 0.4 mm in the off-axis position of the 90% isodose. These differences, which are smaller than previously reported for older model dosimeters, were apparent in the profile results for both diodes and small-volume ionization chambers. As an extension to this study, the practical use of all five dosimeters was exemplified by measuring point doses in IMRT test beams. These measurements showed good agreement (within 2%) between the diodes and the small volume ionization chamber, with all of these dosimeters being able to identify a region 3% under-dosage which was not identified by a larger volume (6 mm diameter) ionization chamber. The results of this work should help to remove some of the barriers to the use of diodes for modulated radiotherapy dosimetry in the future.**

Keywords— **Radiation therapy, diode dosimetry, relative dosimetry, quality assurance.**

I. Introduction

Recent advances in diode dosimetry analysis techniques [1,2] and the resulting recommendations that diodes can be used to accurately measure relative dose in small radiation fields, provided that suitable corrections are applied to the results [2,3,4], have led to renewed interest in the use of diodes to measure point doses in modulated radiation fields. This study investigates one potential source of inaccuracy for diode measurements in modulated beams; the effect of diode housing asymmetry on measurement results.

Intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) treatments use large numbers of small beam segments to produce dose distributions that are able to closely conform to curved and concave targets [5] while sparing adjacent healthy tissues [6]. Due to the complexity of these modulated beams and the resulting challenges of accurately calculating the treatment dose and precisely reproducing the planned collimation patterns, careful commissioning of the IMRT/VMAT treatment planning and delivery system is required [7], in addition to pre-treatment verification of individual IMRT/VMAT treatment plans [5]. Point dose measurements in modulated beams can be used to augment dose plane measurements, for system commissioning and treatment verification. It is important that these point dose measurements provide an accurate indication of the dose delivered by each modulated beam.

The use of ionization chambers with collecting volumes as small as 6 mm across can result in volume averaging effects that substantially reduce measurement accuracy in high dose gradient regions [8,9,10]. When used in modulated beams, therefore, these chambers are deliberately positioned in dose plateaus – a solution which may take time (finding an appropriate point in the treatment plan), result in unidentified inaccuracy (due to the difficulty of off-axis chamber positioning in a solid phantom) or be unachievable (if the beam fluence is especially modulated, such as in a head and neck treatment). The use of a dosimeter with a small active volume reduces the need to identify and use a dose plateau. For this reason, diodes are an attractive option for the measurement of IMRT/VMAT point doses.

Diodes, however, use a non-water-equivalent (silicon) active volume and are known to over-respond in small radiation fields [1,2,11], while also over-responding to the increased low-energy component of large radiation fields [12,13,14]. Diode dies are often embedded in epoxy resins and surrounded by high-density shielding (even unshielded diodes can contain thin metal filters [15]) and electrical contacts. Cylindrical diodes designed to acquire relative dose measurements while aligned parallel with the radiation beam (usually vertically) in a water tank are designed asymmetrically in the longitudinal direction and may therefore produce inaccurate or unpredictable results when positioned perpendicular to the beam (usually horizontally) in a solid phantom, for IMRT/VMAT point dose measurements.

While methods to correct or avoid diode over-response are currently under investigation [16,17,18], the possible effects of diode housing asymmetry remain a concern [19,20,21]. For example, in 1994 Beddar et al used profile measurements made using Scanditronix photon and electron diodes (IBA Dosimetry GmbH, Schwarzenbruck, Germany) to illustrate the different effects of scanning the diode through the radiation field stem-first and stem-last, and showed that asymmetries in the diodes' construction had substantial effects on the results, potentially altering the position of the 90% isodose by 0.6 mm [19]. While this study has been highly influential, encouraging the vertical (parallel to the beam) positioning of diodes for relative dosimetry [19], no published study has verified the results of this work, for contemporary diode designs.

This study therefore aims to assess the effect of diode housing asymmetry on penumbra measurements, for a set of three contemporary diodes, and to compare these results with measurements made using plastic-walled ionization chambers. Additionally, this study exemplifies the use of both chambers and diodes for measuring at various high and low dose points in a modulated treatment beam.

II. Materials and methods

A. Dosimeter selection and preparation

The dosimeters selected for use in this study were: the IBA (formerly Scanditronix/Wellhofer) CC13 compact ionization chamber (IBA Dosimetry GmbH, Schwarzenbruck, Germany) with 6 mm inner diameter and 0.13 cm^3 collecting volume; the Exradin A16 micro-ionization chamber (Standard Imaging, Middleton, USA) with 2.4 mm inner diameter and 0.007 cm^3 collecting volume; the IBA SFD stereotactic diode with 0.6 mm active area diameter and 0.06 mm active area thickness; the PTW 60016 diode P (PTW, Freiburg, Germany) with 0.03 mm^3 active volume and low-energy shielding; and the PTW 60017 diode E with 0.03 mm^3 and minimal shielding.

Prior to first use, all dosimeters were tested for overall system integrity, post-irradiation signal drift, short-term reproducibility and dose linearity, using procedures recommended for use in the acceptance testing of diodes [12].

B. Beam profiles

This study used an Elekta Infinity linear accelerator with Agility head (Elekta Ltd, Crawley, United Kingdom), operating in 6 MV photon mode, to produce a 5x5 cm^2 field for use in beam penumbra measurements. Beam profiles were measured at the depth of maximum dose (separately identified via depth dose scanning, for each dosimeter), to maximize the effects of dosimeter housing asymmetry and minimize the contributions from electron contamination and phantom scatter. Measurements were made with each dosimeter positioned with the stem horizontal, perpendicular to the beam axis and parallel to the profile scanning direction, in an IBA Dosimetry Blue Phantom 3D scanning water tank. A uniform scanning step size of 0.5 mm was used with a measurement time of 0.3 s.

Profile scans were acquired using Scanditronix Wellhofer (IBA) Omnipro Accept water tank scanning software. Raw scan data was manually centered and normalized to the central axis. Profiles were not smoothed or symmetrized.

The profiles were used to compare penumbrae measured with the diode stem pointing into (equivalent to a "stem-first" setup) and out of the field (equivalent to a "stem-last" setup), to evaluate the effects of dosimeter alignment and thus identify the effects of dosimeter asymmetry.

C. IMRT dose measurement

Point doses from modulated beams, in a high dose plateau as well as in small low dose regions, were measured with each dosimeter and compared with the doses predicted by the radiotherapy treatment planning system (RTPS) and measured with film, in order to evaluate measurement accuracy under different conditions.

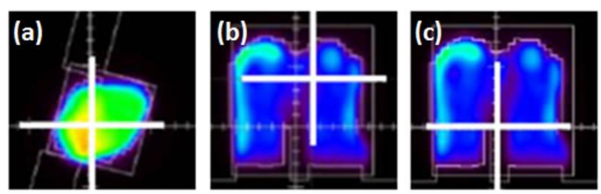

Fig. 1 IMRT beams and measurement points (white crosses) used to exemplify dosimeter response: (a) high-dose plateau, (b) narrow low-dose region, (c) low dose region, blocked by multileaf collimator (MLC).

The two treatment beams and three measurement positions shown in Figure 1 were selected for use in this study. Measurements were made with each dosimeter positioned at the centre of a 20 x 20 x 10 cm^3 block of water-equivalent plastic (Blue Water, Standard Imaging). The block was shifted laterally so that measurements could be made at the points shown in Figure 1 while maintaining full scatter conditions at the centre of the block. The dosimeters were also irradiated using a square reference field, so that their readings could be converted to dose in Gy and compared with the treatment plan.

Both IMRT treatment beams were planned and calculated using the Varian Eclipse RTPS and delivered using a

Varian iX linear accelerator (Varian Medical Systems, Palo Alto, USA) operating in 6 MV photon mode.

III. Results and discussion

A. Penumbra measurements

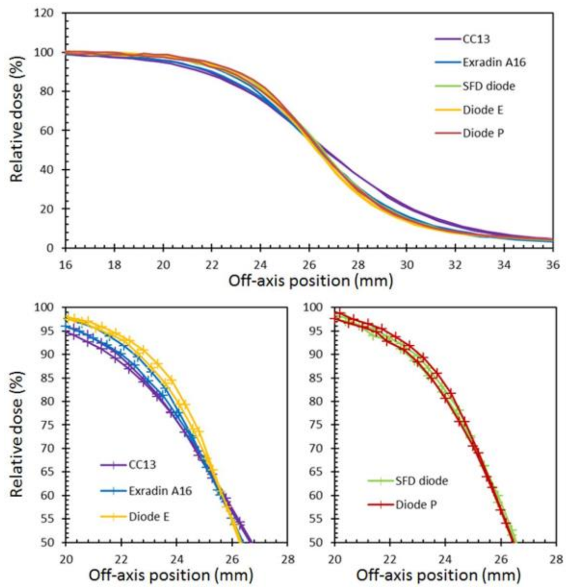

Fig. 2 Beam penumbrae measurement results: (a) results for all dosimeters on 0-100% dose scale, (b) and (c) results on a 50-100% dose scale, separated for clarity. Stem-first and stem-last results are shown overlying each other, producing one pair of lines for each dosimeter.

Figure 2 shows that there are noticeable differences between the penumbrae measured in the stem-first and stem-last directions, for all five different dosimeters used in this study. While differences are very slight (barely distinguishable above the 0.1 mm certified accuracy of the IBA Blue Water scanning system) for the IBA CC13 chamber, all pairs of lines representing the stem-first and stem-last measurements diverge at the 80-90% isodose level.

The off-axis positions of the 90% dose points measured in the two directions differ by 0.2 mm for the IBA CC13 chamber, 0.3 mm for the IBA SFD diode and the PTW diode E, and 0.4 mm for the Exradin A16 chamber and the PTW diode P. All of these differences are smaller than the 0.6 mm difference measured by Beddar et al using an older photon diode [19].

20-80% penumbra widths are similarly affected (see Table 1); there are differences of up to 0.2 mm in the penumbra widths measured using the stem-first and stem-last orientations, with the result for the Exradin A16 chamber being similar to the results for the three diodes.

Table 1 Beam geometry measurements (mm) derived from profiles.

Item	CC13	A16	SFD	Diode P	Diode E
Beam width (50-50%)	51.26	51.20	51.17	51.16	51.19
Penumbra width (20-80%), stem first	6.76	5.53	4.93	4.90	4.65
Penumbra width (20-80%), stem last	6.70	5.61	5.07	4.99	4.83

B. IMRT dose

Routine quality assurance testing (film dosimetry) showed good agreement with the RTPS calculated dose plane for the IMRT beam shown in Figures 2(a) and throughout most of the beam shown in Figures 2(b) and (c). However, the RTPS was unable to accurately predict the extent of the dose falloff in the narrow low-dose region indicated in Figure 1(b) and a local under-dose of approximately 3% was detected. The chambers and diodes examined in this study reproduced these results with varying degrees of success.

Results shown in Figure 3 indicate that all five dosimeters measured the same dose, within 2%, for the high-dose plateau point (Figure 1(a)) and the four small-volume dosimeters (the Exradin A16 and the three diodes) all identified the under-dosage at the point in the narrow-low dose region (Figure 1(b)). The four small-volume dosimeter measurements in the narrow low-dose region differed by 7%, which is 1% of the maximum dose in the field (see Figure 3(b)). This under-dosage was not identified by the CC13 measurements, probably due to volume averaging (the low dose region is surrounded on all sides by higher doses).

Figure 3(b) shows that the SFD diode measured a higher-than-planned dose when the beam is blocked by MLC leaves, while all other dosimeters measured a lower-than-planned dose in this region (Figure 1(c)). Further investigation is warranted, to identify whether this difference arises from a genuine over-response from the SFD or whether the small active volume of this dosimeter allowed it to detect a local dose increase due to MLC interleaf-leakage.

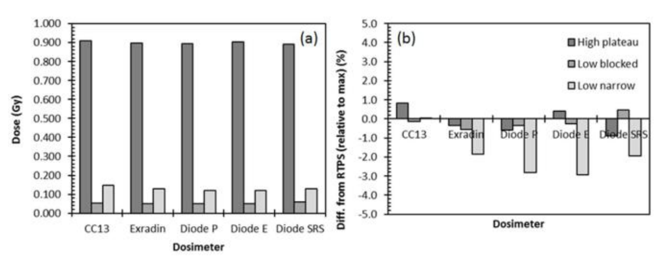

Fig. 3 Comparison of IMRT point dose measurement results for different dosimeters in terms of (a) measured dose (Gy) and (b) difference between measured and planned dose (% of maximum).

IV. Conclusions

While the longitudinally asymmetric housing of contemporary diodes can affect measurement results, in particular the shape of the dose falloff into a high-gradient region, these effects were observed to be similar to the orientation effects identified in small-volume ionization chamber profiles and smaller than the orientation effects identified for older diode models in the existing literature.

When used to measure point doses in IMRT test fields, the diodes used in this study did not over-respond relative to the ionization chambers. Rather, they were able to accurately identify the presence of a small region of under-dosage, which was identified by only the smaller of the two ionization chambers used in the study.

This study does not attempt to resolve the issue of diode over-response in the small beam segments (one of the diodes may have over-responded to the MLC-blocked beam), however the results of this work should help to remove some of the barriers to the use of diodes for modulated radiotherapy dosimetry in the future.

Acknowledgment

S. B. Crowe's contribution to this work was supported by the Australian Research Council, the Wesley Research Institute, Premion and the Queensland University of Technology, through linkage grant number LP110100401.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

1. Francescon P, Cora S, Satariano N (2011) Calculation of kQclin, Qmsrfclin, fmsr for several small detectors and for two linear accelerators using Monte Carlo simulations. Med Phys 38(12):6513-6527
2. Cranmer-Sargison G, Weston S, Evans J A, et al. (2011) Implementing a newly proposed Monte Carlo based small field dosimetry formalism for a comprehensive set of diode detectors. Med Phys 38(12):6592-6602
3. Cranmer-Sargison G, Charles P H, Trapp J V, Thwaites D I (2013). A methodological approach to reporting corrected small field relative outputs. Radiother Oncol 109(3):350-355
4. Kairn T, Charles P H, Cranmer-Sargison G, et al. (2015) Clinical use of diodes and micro-chambers to obtain accurate small field output factor measurements. Australas Phys Eng Sci Med. In press
5. Boyer A L, Butler E B, DiPetrillo T A, et al. (2001) Intensity-modulated radiotherapy: current status and issues of interest. Int J Radiat Oncol Biol Phys 51(4):880-914
6. Crowe S B, Kairn T, Middlebrook N, et al. Retrospective evaluation of dosimetric quality for prostate carcinomas treated with 3D conformal, intensity-modulated and volumetric-modulated arc radiotherapy. J Med Rad Sci 60(4):131-138
7. Ezzell G A, Burmeister J W, Dogan N, et al. (2009). IMRT commissioning: multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119. Medi Phys 36(11):5359-5373
8. Low D A, Parikh P, Dempsey J F, et al. (2003) Ionization chamber volume averaging effects in dynamic intensity modulated radiation therapy beams. Med Phys 30(7):1706-1711
9. Arnfield M R, Otto K, Aroumougame V R, Alkins R D (2005) The use of film dosimetry of the penumbra region to improve the accuracy of intensity modulated radiotherapy. Med Phys 32(1):12-18
10. Yan G, Fox C, Liu C, Li J G (2008) The extraction of true profiles for TPS commissioning and its impact on IMRT patient-specific QA. Med Phys 35(8):3661-3670
11. Scott A J, Kumar S, Nahum A E, Fenwick J D (2012) Characterizing the influence of detector density on dosimeter response in non-equilibrium small photon fields. Phys Med Biol 57(14):4461-4476
12. Yorke E, Alecu R, Ding L, et al. (2005) Diode in vivo dosimetry for patients receiving external beam radiation therapy. Report of Task Group, 62. American Association of Physicists in Medicine. Medical Physics Publishing, Madison
13. Griessbach I, Lapp M, Bohsung J, et al. (2005) Dosimetric characteristics of a new unshielded silicon diode and its application in clinical photon and electron beams. Med Phys 32(12):3750-3754
14. Dieterich S, Sherouse G W (2011) Experimental comparison of seven commercial dosimetry diodes for measurement of stereotactic radiosurgery cone factors. Med Phys 38(7):4166-4173
15. Cranmer-Sargison G, Weston S, Evans J A, et al. (2012) Monte Carlo modelling of diode detectors for small field MV photon dosimetry: detector model simplification and the sensitivity of correction factors to source parameterization. Phys Med Biol 57(16):5141-5153
16. Liu P Z, Suchowerska N, McKenzie D R (2014) Can small field diode correction factors be applied universally? Radiother Oncol 112(3):442-446
17. Charles P H, Crowe S B, Kairn T, et al. (2013). Monte Carlo-based diode design for correction-less small field dosimetry. Phys Med Biol 58(13):4501-4512
18. Charles P H, Cranmer-Sargison G, Crowe S B, et al. (2014) A diode for correction-less small field output factor measurements. Australas Phys Eng Sci Med. 37(1):200-201
19. Beddar A S, Mason D J, O'Brien P F (1994) Absorbed dose perturbation caused by diodes for small field photon dosimetry. Med Phys 21(7):1075-1079
20. Westermark M, Arndt J, Nilsson B, Brahme A (2000) Comparative dosimetry in narrow high-energy photon beams. Phys Med Biol 45(3):685–702
21. McKerracher C, Thwaites D I (1999) Assessment of new small-field detectors against standard-field detectors for practical stereotactic beam data acquisition. Phys Med Biol 44(9):2143–2160

Author:	T. Kairn
Institute:	Genesis CancerCare Queensland
Street:	Suite 1, 40 Chasely St
City:	Auchenflower 4066
Country:	Australia
Email:	t.kairn@gmail.com