STEREOTACTIC BEAM CHARACTERIZATION USING THE IBA STEALTH REFERENCE DETECTOR

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I. INTRODUCTION

Linear accelerators used in medicine deliver radiation as a pulsed field, causing a fluctuation in the signal acquired by detectors used to characterize the beam. This fluctuation is mitigated by two methods[1]. The first method is the statistical approach, where several measurements are acquired in order to obtain an average value which suppresses the inherent signal fluctuations. This can be a very accurate method, though it is a very time-consuming technique. The preferred method is the use of a reference detectors placed at a fixed position in-air, inside the radiation field, and placed in the edge of the field so as to minimally perturb the field. Since both the reference detectors and the field detector will be subject to the same fluctuations, the fluctuations can be easily mathematically suppressed, thus giving rise to more stable signal acquisition and more efficient scanning[2]. As fields approach smaller sizes, as is the case for stereotactic fields, the maintenance of the reference detector in the radiation field gives rise to an uneven perturbation of the field (as seen by the field detector). This perturbation becomes especially large with the case of diodes which, though small in size, contain high-Z components which induce a higher magnitude of perturbation of the beam[3]. Additionally, the time saved by using shorter integration times is lost by the requirement that the user continually reenter the vault in between field sizes in order to readjust the reference field so that it remains in the edge of the field.

I.A. Purpose

The technique proposed in this study uses a transmission detector, similar in function to the monitor chambers of a linac, as the scanning reference chamber. Evaluated in this study is the Stealth Detector (IBA Dosimetry), a transmission detector which perturbs the primary beam minimally, evenly, and consistently. The use of this detector would give rise to a time savings associated the user not having to perform a readjustment of the reference detector prior to each field-size change. The purpose of this study is threefold. First, it is important to determining the extent by which the beam is perturbed along the central axis by the inclusion of this transmission detector. Next, is the determination of the effect on the energy spectra of the field by evaluating percent depth dose scans using the transmission detector and comparing those to scans using standard reference detectors. Finally, profile scans using both types of reference detectors are compared.

Fig. 1. The Stealth Detector (IBA Dosimetry) is attached to an interface plate which is securely slid into the interface mount of the Varian TrueBeam (Version 1.6).

II. MATERIALS AND METHODS

The Stealth Detector is a transmission detector with a circular active area with a diameter of 72 mm. The active detecting area is constructed of carbon fiber and has a total attenuation equivalent of less than 0.5mm Al. The detector is attached to a Varian TrueBeam using the interface mount which is 57.4 cm from the source. With the maximum detector width of 70mm at a distance of 1.75 cm (detector thickness) below the interface mount, the largest field measurable with this detector is 8.44 cm x 8.44 cm. The Stealth detector is held at a negative bias voltage of -420 V. Central axis point measurements, percent depth dose, and profile data are acquired using a Blue Phantom 2 scanning system (IBA Dosimetry) with a TN60019 microDiamond detector (PTW-Freiberg)[4,5]. For scans using an in-field reference detector, another TN60019 detector is used. This is waterproof solid-state detector with a 0.004 mm^3 sensitive volume. This detector is irradiation axially with its effective point of measurement being 1 mm from the detector tip. When used as a reference detector, the TN60019 is placed at 15 degrees above the horizontal, exposing the effective point of measurement by allowing the detector to physically protrude into the field. The TN60019 serves well as a reference chamber because of three major design aspects: it is nearly water-equivalent, it has a small collecting volume, and it produces a large signal. All data are acquired using a Varian TrueBeam (Varian Medical Systems, Palo Alto, CA) Version 1.6 using a 6 MV beam. The software used to acquire data is IBA OmniProAccept v7.4.18C, which as an important feature (vital required for the current application) which allows separate bias voltages to be set for different detector channels.

II.A. Central Axis Point Measurements

As the first step of this study, the actual transmission of the 6 MV beam through the Stealth detector is determined for smallest field of studied (0.5 cm x 0.5 cm). Transmission is determined by placing a single detector at 100 cm SSD at a depth of 10 cm in the water phantom, and calculating the ratio of the signal measured with the reference detector in-place to the signal measured without the reference detector in-place. A similar measurement is performed, except that the 60019 reference detector is placed in the edge of the open field with a constant intrusion of approximately 2.0 mm. Though the reference detector is not connected or used for measurements, its inclusion into the primary field for CAX point measurements allows for a quantification of the perturbation association with its use. Similarly, this is performed for a 0.5 cm x 0.5 cm field size, yielding the detector's "effective transmission."

II.B. Evaluation of Field Perturbation

To evaluate the perturbation of the field caused by the inclusion of the reference detectors in the primary field, depth-dose scans are acquired using three different reference detector configurations: using no reference detector, using a Stealth detector as a reference detector, and using a microDiamond detector as a reference detector. This test only evaluates the physical presence of the reference detector, not the actual functionality of the system when utilizing the specific reference detector. In all cases, data are acquired using a "no reference" configuration, where linac output fluctuation is suppressed by acquiring more signal. The analysis of these data provides possible effect the transmission detector has on the energy spectrum of the photons reaching the primary field detector (for the case of the Stealth detector) and the perturbation caused by the presence of the reference detector (for the case of the microDiamond reference chamber). These scans are performed with the tank being set to 100 cm SSD and the beam being collimated to irradiate fields from 0.5 cm x 0.5 cm to 4.0 cm x 4.0 cm. For the current study, scan data are acquired using a step-by-step mode, where each data point is acquired for 5 seconds following a 1-second stabilization period. Positioning speed between subsequent point measurements is 1 cm/s. The step distances are 0.5 cm. Based on these parameters, a set of 5 scans are acquired in serial, and their comparison is made without normalization. Furthermore, in these scans, and all scans presented in the current study, no data manipulation has been performed (through curve fitting for example).

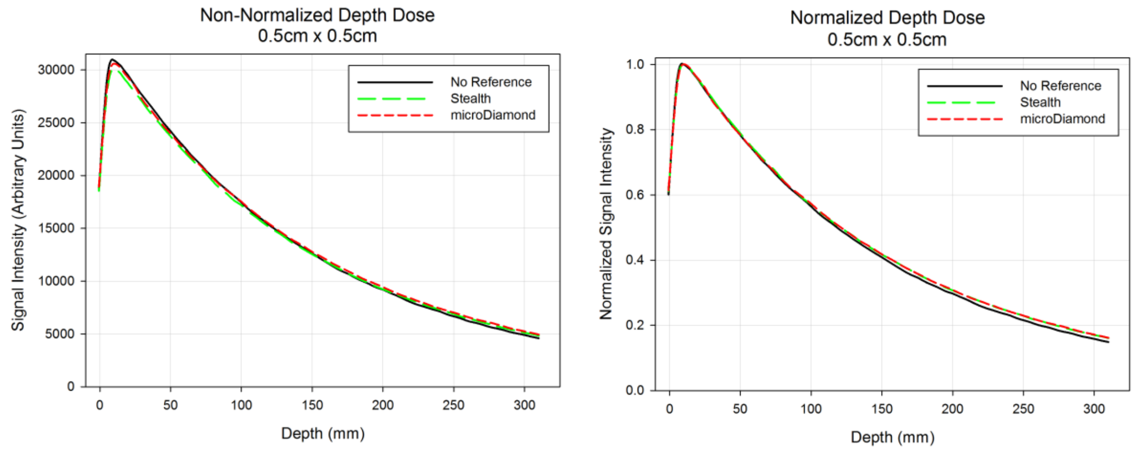

Fig 2. *Left.* For the smallest field sizes studied in this project, raw PDD point measurements are acquired using step-by-step acquisition modes (0.5 cm steps) with all results presented in arbitrary units. No smoothing or normalization is performed. At d_{max}, this plot shows the extent by which the primary beam is attenuated. *Right.* This identical plot with each curve normalized, and again, no smoothing is performed. This set of plots shows that while primary attenuation effects can be reduced using normalization, spectral changes remain at-depth, though only for the smallest field size studied.

II.B.1. PDD Measurements

Percent Depth Dose Measurements are acquired at 100 cm SSD using the three reference conditions described herein: not using any reference detector, using the Stealth detector, and using a microDiamond detector as a reference detector. The scan parameters of no-reference condition are identical to those in the previous section. For PDD measurements using the Stealth detector, the stabilization period is 0.8s while the point acquisition time is 1 second. All other parameters remain consistent, as shown in Table I.

II.B.2. Profile Measurements

Photon profile measurements are acquired at 100 cm SSD at a depth of 10 cm using the microDiamond detector (as the primary detector) using all three reference scenarios; one set without a reference detector, one with the Stealth detector, and one with a similar microDiamond detector. The purpose of these scans is to compare the performance of a scanning system which uses the Stealth detector to the standard scenario, where a similar detector is used in-air at the edge of the field. Scans are performed for field sizes ranging from 0.5 cm x 0.5 cm to 4.0 cm to 4.0 cm and acquired using a scan speed of 0.5 cm/s. For profile measurements using the Stealth detector and the microDiamond detector, the stabilization period is 0.8s while the point acquisition time is 1 second. All other parameters remain consistent, as shown in Table II.

Table I. Perecent Depth Dose Measurment Parameters

	Reference Detector		
Scan Parameter	No Reference	Stealth	microDiamond
Scan Distance (cm)		30.5	
Step width (cm)		0.5	
Stabilization Period (s)	1	0.08	0.08
Point Acquisition Time (s)	5	1	1
Intra-Scan speed (cm/s)[a]		0.5	
Inter-Scan speed (cm/s)[b]		0.5	
Inter-Scan Setup (s)[c]	0	0	180
Number of Points		61	
Total Acquisition Time(s)	366	66	66
Total Intra-Scan Motion(s)	183	61	61
Total Inter-Scan Motion(s)	92	31	211
Total PDD Scan Time(s/scan)	641	157	337

[a] Speed of detector travel while not acquiring data (between measurment points)

[b] Speed of detector travel when not acquiring data.

[c] Time required to manually prepare for next scan. In this case, the time required to move the reference chamber into place.)

III. RESULTS AND DISCUSSION

III.A. Central Axis Point Measurements

The transmission measured through the Stealth detector for the 0.5 cm x 0.5 cm is 0.980. The mean effective transmission measured through the water-equivalent 60019 microDiamond detector is 1.007. This perturbation is caused by the additional scatter induced by the inclusion of the detector.

III.B. Beam Perturbation Evaluation

In Figure 2, two effects are seen. As shown in the left pane, (the non-normalized of the two plots), the raw signal intensity of the PDD curve is lower for the stealth detector than the open beam as an affect of primary beam attenuation. As shown in the right pane of Figure 2, when these curves are normalized, the attenuation effect is reduced. The remaining effect is the spectral difference between the open beam and the beam which traverses a reference chamber prior to irradiation a field detector. This occurs with equal magnitude with both reference detectors used in the study, and both only present a deviation of a field size of 0.5 cm x 0.5 cm. This deviation likely has more to do with characteristic small-field detector performance than its performance as a reference detector.

III.C. Depth Dose and Profile Measurements

In the left column of Figure 3, PDD curves are compared for all field sizes and for each reference detector configuration (including no reference detector). With the exception of the PDD curves for the 0.5 cm x 0.5 cm field, there is close agreement between the performances of both reference detector configurations (as compared with the gold standard). In the right column of Figure 3, profiled curves at 10 cm in-water depth are compared for all field sizes and for each reference detector configuration (including no reference detector). As is the case of the PDD curves, there is a close agreement between the profiles measured with both reference detectors and those measured without a reference detector.

III.C.1. Efficiency

Inarguably, the most accurate method in which to acquire scan data would be a utilizing a slow point-by-point acquisition with data being inherently statistically smoothed by performing long point measurements. In the current study, the gold standards for comparative analysis are data acquired using this technique. The scan parameters for these accurate scans are summarized in Tables I and II. While providing good data, this technique lacks the realistic efficiency to make it clinically implementable. Therefore, a balance between accuracy and data acquisition efficiency is continually being sought. Tables I and II also show the approximate time required to perform the specific scan using the specific technique and subsequent reference detector configuration. A substantial time savings is associated with the use of reference detectors instead of single-detector methods. For the PDD scans acquired during this study, dhe use of the Stealth detector reduced the PDD scan time by approximately 75% per scan while the use of the microDiamond detector reduced scan time by almost 50%. The amount of time savings depends on the number of points acquired all reference detector configurations. For the case of the microDiamond detector (and in the case of all comparable non-transmission reference detectors), additional scan time is associated with the manual placement of the detector in the beam edge. This will add several minutes to every change in collimator size. While these time differences appear small when presented as a "per-scan" value, they combine to cause a large time decrease in scan efficiency. As shown in Table II, similar differences in scan time are apparent.

Table II. Profile Measurment Parameters

	Reference Detector		
Scan Parameter	No Reference	Stealth	microDiamond
Scan Distance (cm)[a]		22.2	
Step width (cm)		0.1	
Stabilization Period (s)	1	0.08	0.08
Point Acquisition Time (s)	5	1	1
Intra-Scan speed (cm/s)[b]		0.5	
Inter-Scan speed (cm/s)[c]		0.5	
Inter-Scan Setup (s)[d]	0	0	180
Number of Points		222	
Total Acquisition Time(s)	1332	240	240
Total Intra-Scan Motion(s)	666	44	44
Total Inter-Scan Motion(s)	333	22	202
Total PDD Scan Time(s/scan)	2331	306	486

[a] Scan distance based on a width of 22.2 cm, which is a calculated distance for a 2cm-wide field to provide accurate coverage at the depth and SSD of measurment.

[b] Speed of detector travel while not acquiring data (between measurment points)

[c] Speed of detector travel when not acquiring data.

[d] Time required to manually prepare for next scan. In this case, the time required to move the reference chamber into place.)

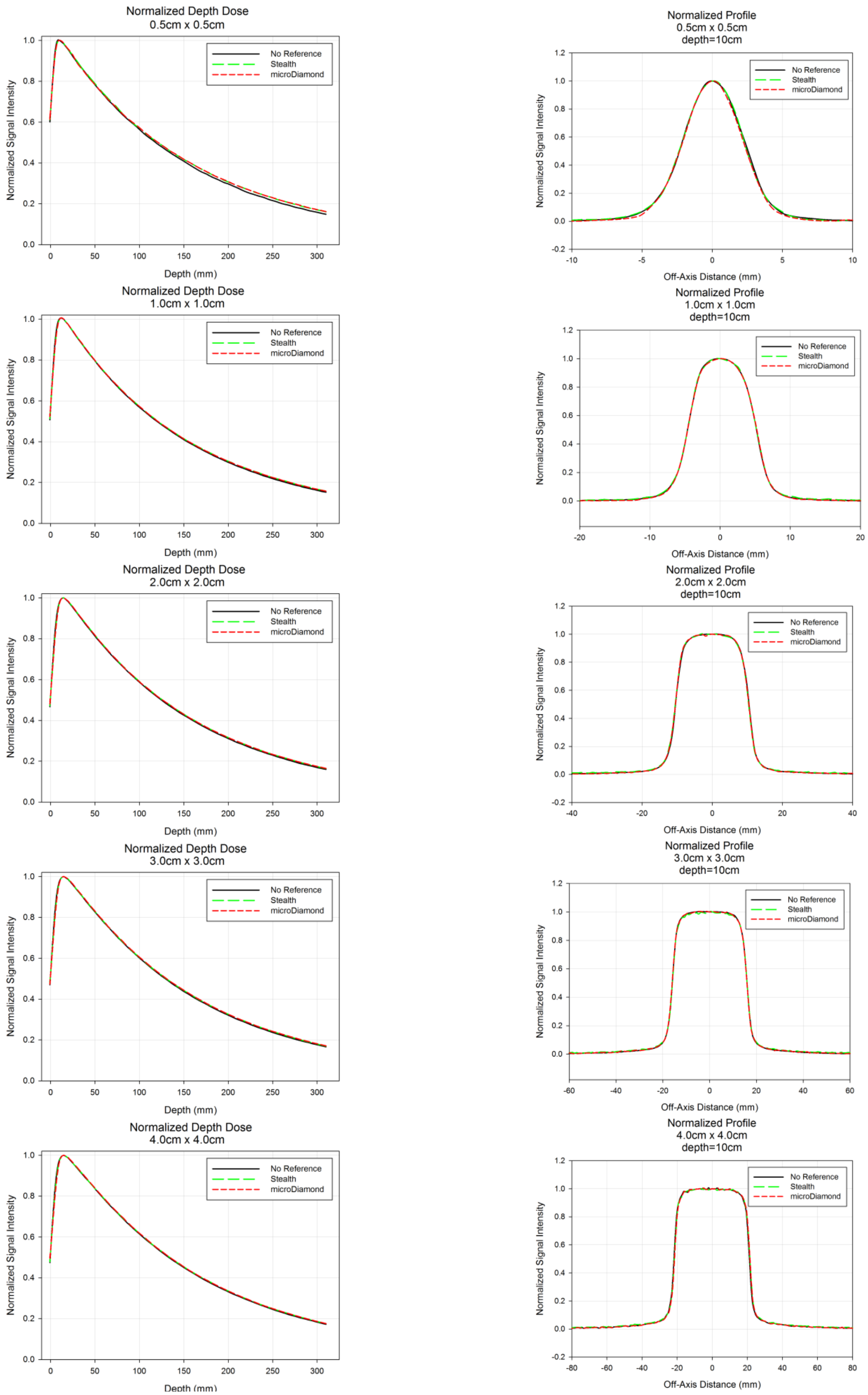

Fig 3. Normalized PDD curves (left column) and 10 cm-deep profile curves (right column) are shown for all five field sizes evaluated in the current study.

IV. CONCLUSIONS

This study compares the use of the Stealth reference detector to the two common reference scenarios in scanning: not using a reference detector and using a detector that is similar to the field detector as a reference chamber. Currently, the use of no reference detector is the most accurate method of beam scanning, but is the most time consuming. In order to suppress the effects of variable dose rates of a pulsed medical linear accelerator, measurements must be made using long integration times. The other method includes the use of a similar detector (though its similarity is not a requirement) placed in the edge of the field. This suppresses any dose rate variations that may occur, providing a substantial increase in scan speed. The increase in scan speed is subsequently reduced by the necessity for the user to manually readjust the reference chamber so that is minimally perturbs the primary beam. The method presented herein maintains the accuracy of a “no-reference detector” system while providing the speed of a reference detector system, while providing the user with two additional advancements. First, since the reference detector is a transmission detector, there is no need for the user to continually readjust the location of the reference detector; reducing scan time. Second, since the Stealth detector is a transmission detector with a reproducible setup, and reproducible results, the user’s experience should mimic the data presented herein, which show a close comparison with data considered as the gold standard.

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