Assessing small-field output factors using a 2D monolithic diode array on a beam-matched Elekta linear accelerator

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Abstract. The goal of this work was to assess small-field output factors (OPF) on a newly commissioned linear accelerator (linac) using a ‘correction-less’ 2D monolithic array of diodes, the Duo, which has a spatial resolution of 0.2 mm. The results would validate a set of OPF extracted from the golden beam data (GBD) used to represent the dosimetric characteristics of that linac, an Elekta Versa HD (Elekta, Crawley), fit with an Agility multileaf collimator (MLC). The Duo acquired relative OPF in real time for square fields of nominal side 1, 2, 3 and 4 cm, for 6 MV with flattening filter (WFF) and 6 MV flattening filter free (FFF) photon energies. Results revealed at most a 1.0% difference in OPF when compared to baseline, and bolstered confidence in the acceptance and commissioning of the linac using local GBD as a baseline match.

1. Introduction
Beam matching of linear accelerators (linacs) is common practice within institutions having more than a single linac. Beam matching involves replicating the dosimetric characteristics of a linac, such that all linacs within a cohort can be described by a single set of golden beam data (GBD), conforming to a single beam model within the treatment planning system (TPS) [1, 2]. The data can be utilized to validate the reproducibility of linacs during acceptance, commissioning, or routine quality assurance (QA), preventing any deviation of dosimetric characteristics from the beam model in the TPS [2-5].

GBD is generated based on an aggregate of scanned and non-scanned beam data [6]. An end user may opt to use vendor provided factory GBD explicitly or a set of local GBD. A local GBD must comply with International Electrotechnical Commission (IEC) standards, and be approved and endorsed by the vendor. At our institution, the beam model for our cohort of Elekta Versa HD (Elekta, Crawley, UK) linacs is based on local GBD.

The accuracy of GBD and, in particular, of small-field GBD is becoming increasingly important with the delivery of complex therapies that use small-beam apertures for treatment [7]. The validation and propagation of correct data is an imperative [8] because any inaccuracy would present as a systematic error within delivery, propagating to poor treatment outcome and potential patient harm [9]. For example, Lechner et al. detailed the impact of inaccuracies of small-field output factor (OPF) to
plan quality for stereotactic treatments [10], likewise Kairn et al. reported errors in excess of 10% for clinical treatments if small field output factors were incorrectly measured [11].

The wider physics community acknowledges the potential for error, with audit groups initiating measurement of small fields across linacs, beam-matched or otherwise [12, 13]. However, small-field measurements require a concerted effort as their acquisition can pose a challenge for physicists [14, 15]. Difficulties associated can be attributed to incorrect choice of detector or positional errors, which can contribute to outlier results when using point-like detectors [16]. Small fields, whether shaped by multileaf collimator (MLC) or cone, produce steep dose gradients, where detectors are essentially measuring penumbra. Detectors, whether passive or active, require sufficient spatial resolution and need to be of appropriate size to overcome volume averaging for the verification of scanned and non-scanned data [17]. Furthermore, the potential incorrect application of correction factors to measured results can also exacerbate the challenge [18].

This work is intended to use an innovative real-time high-resolution monolithic diode array, the Duo, to assess small field OPF from a newly commissioned linac which was matched against local GBD, acquired across a network of Elekta Versa HD linacs.

2. Methods and materials

2.1. Local Golden Beam Data

Prior and independent of the present study, GBD was generated by our institution based on dosimetric data from three linacs. Assessment of scanned data was completed using the OMNIPRO-ACCEPT (IBA Dosimetry, Germany) software, and included percentage depth dose (PDD) and lateral beam profiles for square fields of side 1, 2, 3, 10 and 30 cm at 90 cm source to surface distance (SSD) and depth of 10 cm in water. IBA CC13 ionization chambers (IC) were used to acquire large field data and an IBA CC01 small-volume IC and IBA photon diodes validated with Gafchromic film (Ashland ISP, Wayne, NJ) were employed where higher spatial resolution was required [2]. For non-scanned data, OPF measurements for fields of equal size were completed with a variety of detectors including IBA CC01 and IBA CC04 IC, along with IBA unshielded electron diodes in combination with CC13 using the daisy chain method at a 4 cm square field, for a 10 cm square reference field to achieve corrected small field OPFs [15].

The vetted consensus beam data was submitted to the vendor for the creation of a virtual source model (VSM) within Monaco 5.11 (Elekta, Crawley), with photon beam data requirements stipulated in the Elekta technical document (LSSMON001). Once a VSM was received from the vendor, tests detailed within the International Atomic Energy Agency (IAEA) Technical Document (TD) 1540 [19] and TD 1583 [20] were completed along with the vendor recommended quickbeam tests for characterization and optimization of MLC characteristics [21]. External audit of this beam model was completed by the Australian Clinical Dosimetry Service (ACDS).

2.2. The newly commissioned matched linac

The aforementioned GBD was recently used as a baseline to match the dosimetric characteristics of a newly commissioned linac. To ensure a consistent match during customer acceptance testing, scanned and non-scanned data was acquired using detectors consistent with what was used for the acquisition of GBD. This would ensure that profile matching within the buildup region for PDD and penumbral regions in profile scans would be similar and therefore highlight any irregularities with chamber offsets for measurement at the effective point of measurement. The photon energies to be audited were 6 MV with flattening filter (WFF) and 6 MV flattening filter free (FFF), with nominal dose rates of 600 MU/min and 1500 MU/min respectively. At the time of this study a 10 MV beam model had not yet been established.

As a result of the matching, both energies to be audited were within ≤ 0.5% of the nominal beam quality value for tissue phantom ratio in water at depths of 20 cm and 10 cm (TPR_{20,10}), and for PDD scans a difference of ≤ 1% was evidenced and ≤ 0.5% for profiles across the central 80% of open square
fields of side 10 and 30 cm at 10 cm depth in water tank. The linac was calibrated to 1.00 cGy/MU using the IAEA TRS 398 code of practice [22].

2.3. The measurement system
The Duo (Figure 1) is a monolithic array of diodes fashioned as a QA tool that provides high spatial resolution with minimal beam perturbation and real time readout [23]. The detector is composed of two orthogonal 1D arrays with a pitch of 0.2 mm, providing an active area of 52 x 52 mm². This detector system offers a direct and real-time measurement of the fields, with no need to use the intermediate field method as described in the IAEA TRS 483 code of practice which aims to minimize the energy dependence of small field detectors [15]. The Duo was previously validated by Al Shukaili et al against EBT3 Gafchromic film (Ashland, KY), and an IBA stereotactic diode (IBA dosimetry, Nuremberg, Germany) for OPF within cone collimated fields [24].

In this work, the Duo was used to assess a set of square fields of side 1, 2, 3 and 4 cm. Data acquisition was performed using the USA procedure presented within the Elekta customer acceptance tests (Document ID: 1503568 05), using an SSD of 90 cm on the central axis (CAX) and a depth of 10 cm. The detector was centred on CAX using a square field of 0.5 cm under gantry and collimator zero. Measurements were completed within Gammex Solid Water® (Gammex Inc., WI, USA), a 5 cm thick slab for backscatter was placed beneath the Duo detector system to ensure correct scattering conditions. Once positioned correctly, a 20 x 20 cm² open flood field was acquired to equalize the response of the detector system, correcting for slight differences in diode response [25, 26], along with a 10 x 10 cm² field to which all OPF measurements were referenced. No additional corrections were applied to results. The mean of three measurements was calculated for each field, where the response of the central diode would be used to determine the OPF against the reference field. Calculated OPF were reported at a confidence level of 95% using the standard deviation of the mean. Acquired profiles were processed within MATLAB (Math Works, Inc., Natick, Massachusetts, USA) to calculate the full width half maximum (FWHM). Effective field size (EFS) was calculated using the cross line (A) and inline (B) profiles as $EFS = \sqrt{A \times B}$ [27].

3. Results
Table 1 compares the uncorrected OPF using the Duo against local GBD small field OPF. The results from the Duo evidence a good agreement against the GBD for all field sizes, yielding a maximum difference of -1.0%. Small field sizes were within 0.3 mm of the stated nominal field size for FWHM.
Table 1. Output factor (OPF) for 6MV, with flattening filter (WFF) and flattening filter free (FFF): measurements with the Duo vs local golden beam data (GBD). Nominal and measured field sizes are also shown, in terms of full width half maximum (FWHM) and then effective field size (EFS).

| Nominal field size (mm) | 6MV WFF OPF | 95% Confidence Interval | FWHM Crossline (mm) | FWHM Inline (mm) | EFS (mm) | 6MV WFF GBD OPF | Duo vs. local GBD |
|------------------------|-------------|-------------------------|---------------------|------------------|---------|-----------------|-----------------|
| 10                     | 0.670       | 0.002                   | 10.2                | 9.8              | 10.0    | 0.672           | -0.3%           |
| 20                     | 0.789       | 0.001                   | 20.0                | 20.0             | 20.0    | 0.797           | -1.0%           |
| 30                     | 0.850       | 0.001                   | 29.8                | 29.8             | 29.8    | 0.846           | 0.5%            |
| 40                     | 0.879       | 0.003                   | 39.5                | 39.8             | 39.7    | 0.877           | 0.2%            |

| Nominal field size (mm) | 6MV FFF OPF | 95% Confidence Interval | FWHM Crossline (mm) | FWHM Inline (mm) | EFS (mm) | 6MV FFF GBD OPF | Duo vs. local GBD |
|------------------------|-------------|-------------------------|---------------------|------------------|---------|-----------------|-----------------|
| 10                     | 0.696       | 0.001                   | 10.3                | 10.2             | 10.2    | 0.692           | -0.6%           |
| 20                     | 0.819       | 0.006                   | 19.9                | 20.1             | 20.0    | 0.825           | -0.7%           |
| 30                     | 0.878       | 0.001                   | 29.7                | 29.8             | 29.8    | 0.875           | 0.4%            |
| 40                     | 0.904       | 0.007                   | 39.7                | 39.8             | 39.8    | 0.904           | 0.0%            |

4. Discussion

In this study, an assessment of small field OPF for a newly commissioned linac was conducted using an innovative real-time high-resolution monolithic diode array, the Duo. The linac had been previously matched against local GBD, acquired across a network of beam-matched Elekta Versa HD linacs. Results showed that OPF measured with the Duo were well within a local acceptance window of 2% for small fields < 3 x 3 cm$^2$ when compared to GBD. The maximum difference was of -1%. With the Duo it was possible to overcome the considerable difficulty presented in positioning point-like detectors, resolving an onerous task for small field measurements. The difference in nominal and effective field size was such that limited inference could be made as to whether this contributed to deviations of measured OPF from GBD.

Due to the spectral changes experienced between the reference field size of 10 x 10 cm$^2$ and small fields, the use of the IAEA TRS 483 code of practice establishes a robust approach for acquiring small OPF for a variety of suitable detectors [15]. One of the main successes of the Duo was that it could be used to complete measurements within a reference field of 10 x 10 cm$^2$ followed by the small field, not requiring an intermediate small field or application of a correction factor, as the introduced air gap minimizes the size of correction required to relate readings to dose [28].

5. Conclusion

Within this study, we evidenced the use of a single detector system, the Duo, to assess a newly commissioned linac in a timely manner. Assessment results validated small field OPF values and bolstered acceptance practices. The newly commissioned linac can be considered matched to local GBD, providing confidence that treatments planned within the TPS will deliver optimally.
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7. References
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