Radiotherapy and Oncology 132 (2019) 218–222

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Original Article

Community approach for reducing small field measurement errors: Experience over 24 centres

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ARTICLE INFO

Article history:
Received 7 January 2018
Received in revised form 20 August 2018
Accepted 10 October 2018
Available online 29 October 2018

Keywords:
Multicentre evaluation
Crowd knowledge method
Small field output factor
Silicon diode detector

ABSTRACT

Purpose: The complexity of the modern Stereotactic Body Radiation Therapy (SBRT) techniques requires comprehensive quality assurance programs, to ensure the right treatment to the patient. Dosimetry of small radiation fields is a challenge especially for radiotherapy centres starting to work on this issue. The matter to be discussed here concerns the need of detailed measurement procedures and cross checks to be paired to the usual recommendations on detectors and correction factors.

Materials and Methods: The presented work involved 24 Italian radiotherapy centres, with the specific purpose to minimize systematic errors in output factor measurements over different radiotherapy centres. Using the unshielded silicon diode IBA Razor, reference curves for the relative signal ratio (RSR) as a function of beam size were created for each Linac family.

Results: With this study we have demonstrated consistency of small field dosimetry on all the centres involved, moreover all radiotherapy centres using Razor are allowed to compare measurements amongst each other and centres with values deviating more than 5% from the reference curve are advised to repeat their measurements. With this procedure, some critical issues were detected from two centres in RSR measurements, that, if implemented into the own treatment planning system, would induce an unwanted overdosage larger than 5%.

Conclusions: The proposed approach could allow one to envision high-skilled therapy centres providing support to those featuring minor experience and could represent an important strategy for the clinical implementation of emerging technologies at high quality levels. The methodology adopted exploits crowd knowledge methods which could be applied in others areas of radiation dosimetry.

The complexity of the modern Stereotactic Body Radiation Therapy (SBRT) techniques requires comprehensive quality assurance programs, to ensure the right treatment to the patient. Dosimetry of small radiation fields [1] is a challenge especially for radiotherapy centres starting to work on this issue with lack of expertise, since small fields are increasingly being used in SBRT. Dosimetric errors in measuring these non standard fields are potentially high because physics differs from large fields. Loss of lateral electronic equilibrium, possible source occlusion by the collimating devices, and changes in the energy spectrum as a function of field size make challenging measurements in small beams. Moreover, detector properties play a crucial role in the dosimetry accuracy. A number of authors have suggested that unshielded silicon diodes are suitable for small-field dosimetry [2,3]. The matter to be discussed here concerns the need of detailed measurement procedures and cross checks to be paired to the usual recommendations on detectors and correction factors.

In 2012, the Italian Association of Medical Physics (AIFM) instituted a working group dedicated to the SBRT technique aiming to support the standardization of dosimetric and planning aspects and to help medical physicists in reaching high level of confidence in the whole treatment procedure [4–13]. The present study has been conducted in the same context with the specific purpose to minimize systematic errors in output factor measurement over different radiotherapy centres. To this aims a new unshielded silicon diode commercially available, named Razor (IBA) [4,14,15], has been used in each centre following the same measurement procedure. Dataset of measured Razor signal as a function of beam

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https://doi.org/10.1016/j.radonc.2018.10.012

size was used to generate relative signal ratio curves by which the consistency of measurements amongst different centres was checked, adopting a crowd knowledge based community approach [16]. In this approach, no pre-defined hierarchy is defined, as in case of the classical teaching/learning approach in which teacher/student hierarchy is defined a-priori, but hierarchy is dynamically determined by the results. Following this approach, the sharing of small field dosimetric data allowed to improve and harmonize the expertise of different radiotherapy centres. The agreement of the relative signal ratios measured by each centre with the crowd knowledge curve with a fluctuation band of ±5% can be used as a redundant Quality Assurance check. The methodology used to develop the relative signal ratios' curves, exploits knowledge-based methods which could be applied in others areas of radiation dosimetry.

Materials and methods

Linear accelerators

Dosimetric measurements were carried out with 6 MV photon beams generated by four Elekta Agility, two Elekta Synergy (Elekta Crawley, UK), six Elekta Beam Modulator and twelve Varian (Trilogy, Clinac, iX and Unique) linear accelerators located at 24 different institutions. Relative measurements of square small fields with side ranging from 5 to 54 mm were performed. For the Varian and Elekta linacs fixed jaws and MLC followed by jaws were adopted, respectively.

Measurements equipments

Measurements were performed using the beam scanning water tank and the electrometer available in each centre. Small beams were scanned using the new generation IBA unshielded silicon diode Razor. It has an active volume 0.6 mm in diameter and 20 μm in height. It is made with an n-type implant in p-type silicon and operates in photovoltaic mode, without any bias voltage. The long axis of the diode detector was placed parallel to the beam axis and the active volume was positioned at the isocentre. The active volume is located at a water equivalent depth of 0.4 mm below the detector surface. For the technical characteristics we refer to several recent publication [4,14,15].

Two Razors have been used to speed up the acquisition procedures. Even if the equivalence of different Razor detectors has been previously assessed by [14], the two detectors used have been characterized using a Co-60 unit at ENEA laboratories, in order to definitively exclude possible differences in Razor manufacturing. The detectors were characterized in terms of signal stability and reproducibility, dose linearity, angular dependence and sensitivity. Furthermore, in a previous study same tests were performed with a TrueBeam (Varian Medical System, Palo Alto (CA)) photon beam resulting in a maximum difference of 0.5% for 5×5 mm^2 field size and mean difference over all fields of 0.2% ± 0.3% [4].

The Stealth Detector (IBA Dosimetry, Schwarzenbruck, Germany) was used as external accelerator monitor to take into account output fluctuations during beam profile acquisition. It is a transmission detector made of carbon fibre and has a total attenuation equivalent thickness of less than 0.5 mm Al. The active area is disc shaped with a diameter of 72 mm and a thickness of 17.5 mm. The detector is attached to the linac using the interface mount, which is placed 57.4 cm from the source. A negative bias voltage of −420 V must be applied.

Experimental set up

Each institute was required to measure profiles and central axis point measurements for square field size ranging 5–54 mm. For each field dimension, the detector was centred (accuracy <0.1 mm) performing in-line and cross-line profiles in continuous mode at two different depths (10 cm and 20 cm) in order to correct for the inclination of the beam with respect to the water surface. This guaranteed that the detector was on the beam axis in all depths. Then, in-line and cross-line profiles were acquired at 10 cm depth using step-by-step acquisition mode (parameters: distance between points: 0.2 mm; acquisition time: 0.5 s; stabilization time: 0.08 s; speed between subsequent point measurements: 3 mm/s). Finally, central point measurements were acquired using 200 monitor units (MU) exposures. Measurements were averaged over 3 acquisitions. Measurement uncertainties were estimated propagating the uncertainty due to the detector positioning, the uncertainty related to the electrometer, and the statistical dispersion of the repeated measurements.

According to the Cranmer–Sargison approach [18], the effective field size (FS) was determined as $FS = \sqrt{A \cdot B}$where A and B correspond to the full width of half maximum (FWHM) of in-plane and cross-plane profiles.

Relative signal ratio definition

In this work the Relative Signal Ratio (RSR) is defined as the ratio of central axis Razor readings for the actual field size and for the reference square field of side 30 mm. This reference field was chosen because it is the smallest field that ensures the lateral charged particle equilibrium on the beam axis. Alfonso [17] has introduced the field factor, to report corrected output factors for small and non standard fields, which is defined as the ratio of the experimental measurements (relative detector signal ratios) multiplied by a detector specific correction factor. The Alfonso's formalism has been adopted in the IAEA TRS 483 protocol [19] that provides values of correction factors for many detectors on the basis of the available literature. Due to the novelty of the Razor, values of small field correction factors are still not available for this detector except for the data from Liu et al. [14] showing, for Varian Linacs, an over-response of the Razor in field sizes below 1 cm. Therefore this study has been made in terms of ratios of detector signals, but for the Varian linacs the corrected RSR values have been presented too.

Crowd-knowledge based approach

The RSR data obtained for field sizes from 5 to 54 mm were fitted using Eq. (1), which is based on the one reported by Sauer et al. [20], and adopted by Cagni et al. [4]:

$$RSR(FS) = P_\infty * \frac{FS^n}{l^n + FS^n} + S_\infty * [1 - \exp(-b * FS)] \quad (1)$$

where, RSR is the detector signal ratio, FS is the measured effective field size, P_∞, S_∞ l and n, are fitting parameters, whilst b has a fixed value (0.001). P_∞ represents the maximum primary dose component and S_∞ the maximum scatter component. The function was forced to be equal to one at the reference field FS_{Ref} (i.e. 30 mm). No other pre-defined values were imposed as contour conditions.

The fit was used to evaluate the consistency of each single RSR value. Centres with values far away from the fitting curve were requested to check their data and to repeat the measurements.

In particular, two series of fits were generated, considering: (i) all centres together, (ii) centres with the same Linac model.

Results

In this study measurement uncertainty was estimated to be 0.9% (1SD) for all field sizes except for the 6–10 mm fields where the uncertainty was 1.5% (1SD).

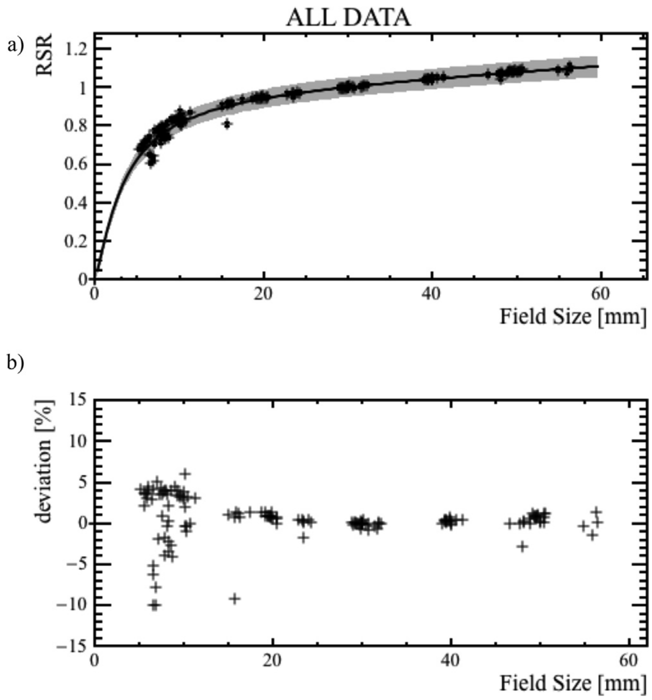

Fig. 1. RSR of all linac model data with the fitted function (a), and deviation of RSR from the fitted curve.

The Relative Signal Ratios data used to determine the fit parameters of Eq. (1) are presented together with the fitted function for all linac models in Fig. 1a. In the Supplementary material (Tab1.sup), the values of the fit parameters are summarized. In Fig. 1b the deviation of the measured RSR values from the fitted curve are shown. Deviations for FS greater than 20 mm are of the order of 0.5%. For field sizes smaller than 20 mm the deviation values rise to more than 10%, showing that a single curve cannot provide a good fit of all data. Instead, in this FS range, different fitting functions can be used consistently to fit RSR data from different linac models, see Fig. 2. In the Supplementary material in Fig. 3, corrected Varian RSR values according to [14] are shown together with the fitted function.

Two centres, using Elekta Beam Modulator and Varian linac, showed data points with deviations greater than 5%. They have been crosschecked and the measurements have been redone resulting in a narrower deviation distribution.

Discussion

This multicentre analysis is part of a wider context study dedicated to stereotactic body radiotherapy dosimetry whose main objectives are manifold but sharing the knowledge between different clinics being one of the most important. The measurements reported on this paper were performed using the Razor device, a new IBA unshielded silicon detector for small field measurements. The Razor diode has the same spatial resolution and performance reliability as its predecessor (SFD), but exhibits the additional advantage of improved response stability, in terms of measured dose, dose rate, dose per pulse, and dark current [15] so it is a good candidate for small beam dosimetry.

RSR as function of the effective field size shows that all the linac from 20 mm × 20 mm to 54 mm × 54 mm field size are in good agreement, deviations from the fit being below 1%. In the smallest field size region a different behaviour is observed for different linac's manufacturers and models and different fit functions are required. This is due to the different collimation system mounted by the linacs and the different electron focalization system. It can reasonably be excluded that the differences in results between the accelerators are due to the detector response. In fact, the dimensions of the detector are such that the volume effect is negligible, therefore the only effect on the response is due to the no-water equivalence of the detector materials and this effect depends weakly on the characteristics of the radiation beam excluding the field size.

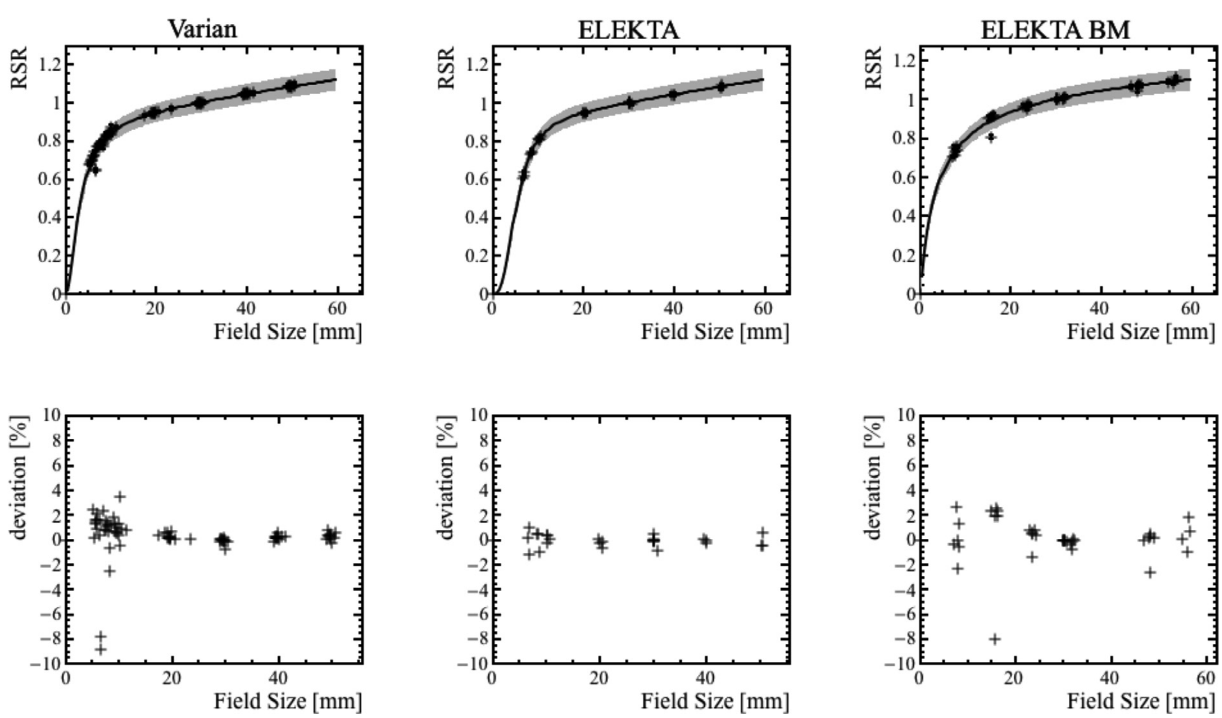

Fig. 2. RSR of each linac model data with the corresponding fitted functions and the RSR deviation from the fitted values.

It is possible from the presented data to predict RSR values for a Razor detector at different field sizes. Even if the Sauer's function was originally proposed for a selected accelerator model and to fit corrected RSR values, modifying the function parameters it appears to fit well both Varian and Elekta RSR values.

Implementing the modified Sauer's function avoids biasing the output data by assuming that the measured value for the reference field is exact. In this way the influence of measurement uncertainties is minimized and it allows accurate determination of values for non-measured field sizes.

Few multicentric measurement campaigns from groups other than the Italian ones are available in literature. A Danish [21] paper presents a study over six centres which assesses the reference dosimetry and small field dosimetry in clinical Danish practice, but it is a comparison work which involved few centres and studied fields down to 10 mm × 10 mm field size.

Followill et al. [22,23] provide a dataset for small field output factors down to 20 mm × 20 mm field size that can be used as QA check of a treatment planning system dosimetry data and against which the institution can compare its measured or calculated values by identifying discrepancies prior to any patients being treated. The uncertainties for 20 mm × 20 mm field size were about 2% for Varian Linac and around 1% for the Elekta accelerator. In the present work the uncertainty was within 1 % for the same field size. Such small uncertainty associated to the RSR determinations is due to the fact that a single measurement setup, operated by the same technician, was brought to and used at the various centres. This ensured that a uniform protocol was used for all the measurements in all the centres, thus reducing additional systematic errors due to different instrumentation or different measurement procedures.

The Italian AIFM group has already published multicentric studies using the microdiamond and the plastic scintillators Exradin W1 [24] measuring RSR down to 5 mm × 5 mm field size, but the methodology used in those studies did not include the field size measurements; whilst the one using the stereotactic diode Razor analysed just one single linac model. So at present, this is the first multicentric study which analyzes relative signal ratios of small field sizes down to 5 mm × 5 mm from different linac models using the measured field size and proposes a typical curve in order to extrapole the RSR for an arbitrary field size. It should be mentioned that silicon diodes may require correction factors of a few percent for dose measurement in field sizes smaller than 10 mm. Nevertheless, in this work we don't apply any correction factor to the measured RSR values because at present for the Razor detector there are very few data available in literature and they are valid for a limited number of experimental conditions [14]. Moreover, no correction factors are reported in the IAEA/AAPM protocol [19] for this detector. Therefore, we believe that it is more useful to provide the community with RSR curves that can be easily transformed into OF curves when sets of Razor correction factors are available for different experimental conditions. We could assume that the Razor correction factors are very close to those of the IBA SFD diode but, OF values obtained using generic silicon diode correction factors would represent a lower level reference than RSR values.

Besides the fact to have demonstrated consistency of small field dosimetry on all the centre involved, this study allows radiotherapic centre using Razor, to compare measurements amongst each other and centres with values deviating from the reference curve are advised to repeat their measurements. Even if the reference curve is given in terms of uncorrected RSR values, our approach allows to have a feedback on the quality of the acquired data. Following this approach, in our study we detected two critical issues from a single centre in RSR measurements, that, if implemented into the own treatment planning system, would introduce an unwanted overdosage of >5%.

In this context, we strongly believe that higher standards in small field dosimetry amongst different centres, using different technologies for treatment planning, dosimetry and delivery, can be obtained if a consistent high-level data sharing capability is granted by national and international associations. This manuscript can provide a common database of dosimetry data for radiotherapy departments, so that centers with less experience can cross-check their measured data. Complex modern irradiation techniques are often challenging for dosimetry, and the sharing of knowledge and reference data can avoid dosimetric errors.

Conclusion

The presented work is a dosimetric study involving 24 Italian radiotherapy centers, aimed at improving the overall accuracy in radiotherapy by ensuring high quality of dosimetry. The study aims to minimize systematic errors in output factor measurement over different radiotherapy centres. To this purpose adopting a crowd knowledge based community approach a new unshielded silicon diode (IBA-Razor) was used to measure relative signal ratios in each centre using the same procedure. In particular, various series of curves were generated, one considering all centres together and three selecting centres with the same Linac model. The curves presented in this study can be used as reference values to match with when a radiotherapic center intend to implement new treatment techniques using the unshielded silicon diode Razor. The agreement of the relative signal ratios of the centre with the crowd knowledge curves with a fluctuation band of ±5% can be used as proof of a good measurement practice. Finally it is easy to move from relative signal ratio to Output Factor applying a field size dependent correction factor, when available.

Conflict of interest statement

All authors disclose any financial and personal relationships with other people and organizations that could inappropriately bias the presented work.

Acknowledgements

The authors would like to thank the Italian centers enrolled in the project: AO San Filippo Neri Roma,AO Parma, O.G.P. S.Camillo de Lellis Rieti, A.O. Ospedale Niguarda Milano, Ospedale San Pietro FBF Roma,UPMC San Pietro Roma, IRCCS CROB Potenza, AOU TorVergata Roma, USL 3 Pistoia, USL 2 Lucca, AUSL Pescara, Policlinico Umberto I Roma, AOU Maggiore delle Carità Novara, Asl 1 Carrara, Ecomedica Empoli, Policlinico San Donato Milano, Casa di Cura S.Rossore Pisa , AOU Santa Maria della Misericordia Udine, Usl8 Arezzo, Università Campus Bio-Medico Roma, AO Santa Maria Terni,Centro REM Radioterapia Catania, Spedali Civili Brescia, AO San Gerardo Monza.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.radonc.2018.10.012.

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