Small fields profiles correction through detectors spatial response functions and size dependence analysis

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Introduction

The use of small fields, such as those reached in SRS and sophisticated techniques require high resolution measurements in the penumbra region of the radiation field. The determination of beam profile is greatly influenced by the detector used. It is important to properly measure the dose in penumbra region, thus allowing an accurate treatment planning. However, due to the lack of lateral electron equilibrium and steep dose gradients, it is challenging to accurately measure the dosimetric parameters required for the commissioning of stereotactic radiosurgery and radiotherapy systems. Therefore, the exact measurement of radiation fields in high-gradient regions would theoretically require a system with perfect spatial resolution, which involves an infinitely small detector without perturbation. The practical impossibility of having such a device implies that we have to model mathematically the perturbation introduced, which is represented by the spatial response function of the used detector.

The purpose of this work was to calculate the spatial response function of various radiation detectors, evaluate its dependence on the field size and analyze a beam profile correction method using deconvolution technique for small field dosimetry.

Method and Materials

A 6MV photon beam produced by a Novalis TX linear accelerator (Varian-BrainLAB) equipped with a HDMLC (2.5mm central leaf width) was used. Crossline profiles were measured at a SSD=100cm and d=5cm, using two passive detectors (EBT3 Gafchromic film and linear array of TLD700 micro chips), four ionization chambers (PTW 30013, PTW 31003, IBA CC04 and PTW PinPoint 31016) and two diodes (PTW 60012 and IBA SFD), Table 1 and Figure 1. Passive detectors measurements were done in solid water and its results were adopted as the actual beam profile. Active detector measurements were done in water using a Blue Phantom 2 (IBA) with step-by-step acquisition mode, step size of 0.3mm, acquisition time of 2 second and noise post processing filters without affecting gradient of penumbra region. Penumbra was determined by the distance between the 20% to 80% of the corresponding profile. Detector’s field size response dependence was analyzed measuring profiles for 5 field sizes of 200x200mm², 100x100mm², 20x20mm², 10x10mm² and 5x5mm². It was assumed that measured profile could be obtained as the convolution of the actual profile with the detector spatial response function. Detector’s kernels, modeled by Gaussian functions, were calculated by an iterative process based on a least squares criterion. The deconvolution of measured profile was calculated with the Richardson-Lucy method, deduced from Bayes’s theorem. Because it is based on conditional probabilities, the algorithm takes into account statistical fluctuations in the signal and therefore has the ability to reconstruct noise signals. It has been confirmed that this method can obtain accurate deconvolution resolutions.

Results

Once all the profiles were measured, mathematical adjustment was performed only to reduce the noise in the signal, without affecting the gradient or penumbra region. Significant differences among the results obtained by the different detectors were observed, particularly for the smallest field size (Figure 1).

Both diodes responded correctly, with a penumbra error less than 0.16mm (in regard to the EBT3 results). The agreement among the profiles measured with passive dosimeters (TLD and EBT3) is better than 0.1mm. On the other hand, the other detectors overestimated the penumbra significantly. Furthermore, the inaccuracy increased in the smaller fields (see Table 2) and for this reason the profiles of the ionization chambers were considered for correction. The FWHM of the resulting kernels are shown in Figure 2, for the IBA CC04, PTW31016, PTW31003 and PTW30013 ionization chambers. The media value is slightly bigger than the diameter of the detectors and the standard deviation is similar to the detector’s radio and constant for all fields analyzed. The variation of the standard deviation for the smaller and bigger fields is less than 1% (0.04mm) and the use of a single spatial response function with a standard deviation equal to the sensile volume radio achieves an approximation to the real penumbra with an error less than 0.1mm, for all the field sizes (Figures 3-5 and Table 3).

To analyze the use of a single spatial response function with a standard deviation equal to the detector radius, the convolution of the real profile with the response function was compared with the measured profile, for a given detector. Figure 6 shows that the penumbra region is well estimated, with a difference of 0.01mm (3.19mm for the measured profile and 3.18 for the convolution profile) for the detector IBA CC04 and the smaller field.

Conclusions

This work concludes that the response function of a radiation detector is independent on the field size, even for small radiation beams. The profile’s correction, using deconvolution techniques and response functions of standard deviation equal to the radius of the detector, gives penumbra values with less than 0.05mm difference to the real profile. The implementation of this technique allows estimating the real profile, freeing from the effects of the detector used for the acquisition.