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Review

Dosimetry quality control based on percent depth dose rate variation for checking beam quality in radiotherapy

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ABSTRACT

Recently, the quality management inside a radiotherapy department has been crucial to treat cancer efficiently. Thus, many international bodies recommend multiple methods to check in periodically the dosimetry quality beyond the depth of 10 cm as the beam quality index. However, they evade checking out the beam dosimetry quality on both the build-up dose and the electronic equilibrium regions. The objective of this study is to cover the overall variation of the percent depth dose (PDD) by including all sub-regions in the procedure evaluation of the beam quality.

In this work, we have studied and examined the dosimetry quality by considering the whole PDD variation. The PDD rate is therefore introduced to determine accurately the quality as an overall notion in external beam radiotherapy according to the field size and photon beam energy. We have presented the reasons and methods to introduce particles contamination, such as electrons and low photon energy in this new approach. The latter enables us to figure the dosimetry quality by extending the International Atomic Energy Agency (IAEA) procedure at any field size less than $25 \times 25\,cm^2$ under the current conditions without being limited to $10 \times 10\,cm^2$ on the exponential decay region.

1. Introduction

The quality control (QC) procedure is a regulatory process in which the real quality performance is reviewed by introducing the basic method in specific conditions used as standards. It is a part of the quality system management recommended by the International Atomic Energy Agency (IAEA) inside any radiotherapy department.[1] The use of an appropriate QC method for an output quality should maximize the detection of both 'normal' and unexpected changes in delivered dose levels at any photon beam energy. The dosimetry quality examinations are programmed periodically by measuring the delivered dose under the reference conditions fixed priory at the Linac commissioning.

Many work groups have studied the beam dosimetry quality by introducing different methods at many photon beam energies.[1] These methods concern operational techniques and activities used to check out whether the beam quality requirements are met or not for a high radiotherapy treatment quality and to correct the changes in the dosimetry monitoring when the Linac is calibrated.[2,3] In our previous works, we studied the flattening filter in geometry and in materials to find an optimal design.[4–7] Therefore, this study aims to increase the radiotherapy efficiency by reinforcing the beam quality management inside the radiotherapy department.[8]

The IAEA TRS 398 protocol recommends evaluating the photon beam quality index based on Tissue Phantom Ratio (TPR) parameter that can be calculated based on PDD.[1] In the Task Group 51 (TG51) of the American Association of Physicists in Medicine (AAPM), the beam quality is determined as the PDD at a depth of 10 cm on the central beam axis for a $10 \times 10\,cm^2$ field size. The previous protocol recommends using a lead (Pb) slab to remove electron contamination of a photon beam.[9] The above mentioned protocols adapt to some specific reference conditions; but do not include electron contamination in any procedure of the beam quality control!

Otto et al. have tried to extend the procedure assessment of the beam quality by working on its determination for photon beams in arbitrary field sizes.[10] Another group from the AAPM has worked on a code of practice for radiotherapy accelerators to reinforce the quality assurance in the radiotherapy treatment.[11] The quality management aims to ensure a high radiotherapy quality for cancer treatment.[12,13] The dosimetry quality control allows the medical physicist to check the normal functioning of Linac head and, especially, the beam dosimetry monitors.

The purpose of this work is to extend the photon beam dosimetry quality control and to establish one more that is reliable

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and easier under the current conditions by covering all sub-PDD regions. Therefore, we have introduced the PDD rate variation as a basic parameter that varies its function according to the depth and photon beam energy.

2. Materials and methods

The dose measurements were performed as recommended by the Swiss Society of Radiobiology and Medical Physics (SSRMP, 2000) using the PTW 30013 chamber (Physikalisch Technische Werkstätten (PTW) Freiburg, Freiburg, Germany) for the PDD measurements of both 6 MV and 18 MV photon beams. Mephysto software was also used to drive the ion chamber for data acquisition of an increment of 2.5 mm in-depth. Inside the radiotherapy department, all PDD measurements are taken at temperature of 20 °C, pressure of 101.3 Pa and humidity of 50%. The water phantom consists of pure water put in a tank of a volume of 40 × 40 × 40 cm^3.

2.1. Percent depth dose rate determination

The knowledge of absorbed dose distribution within a patient is based on its measurements in water in terms of (PDD) and the beam dose profiles or off-axis ratio (OAR). In the quality determination protocols, the dosimetry quality index was evaluated beyond the depth of 10 cm to avoid electron contamination of the photon beam.[14]

In this work, the dosimetry quality is examined based on the measured PDDs as a function of field size and photon beam energy. The normalization of the PDD variation with field size enables us to check out the beam quality with irradiation field size to extend the beam quality index which is recommended by IAEA and not to be limited to 10 × 10 cm^2 by including the dosimetric properties of all PDD sub-regions.

The PDD rate was determined according to the following formula (1):

$$\text{PDD rate} = \frac{\text{PDD}_{d_2,d_1}}{a} \quad (1)$$

where a is the side of the square irradiation field and

$$\text{PDD}_{d_2,d_1} = \frac{\text{PDD}_{d_2}}{\text{PDD}_{d_1}} \quad (2)$$

where d_1 and d_2 are depths on central beam axis and $d_1 < d_2$.

The formula (2) is extended form the field size of 3 × 3 cm^2 to the field size of 25 × 25 cm^2. This extension aims to demonstrate the importance of including the depth dose regions below 10 cm in the beam quality control.

2.2. Uncertainty of PDD measurements

The accuracy of absorbed dose measurements could be improved significantly if the uncertainty of the measurements carried out in the user's beam could be reduced. According to IAEA protocols,[1] the overall uncertainty of the absorbed dose measurements – in our study – is 2%, gathering five factors: long-term stability of user dosimeter, establishment of reference conditions, dosimeter reading related to the beam monitor, correction for influence quantities and human manipulation deficiencies.

3. Results and discussion

3.1. Percent depth dose PDD

The PDD varies with photon beam energy and irradiation field size for a source to surface distance (SSD) of 100 cm. Fig. 1 shows the PDD variation inside the irradiation field size of 10 × 10 cm^2 as a function of depth in the water phantom for photon beam energies of 6 MV and 18 MV.

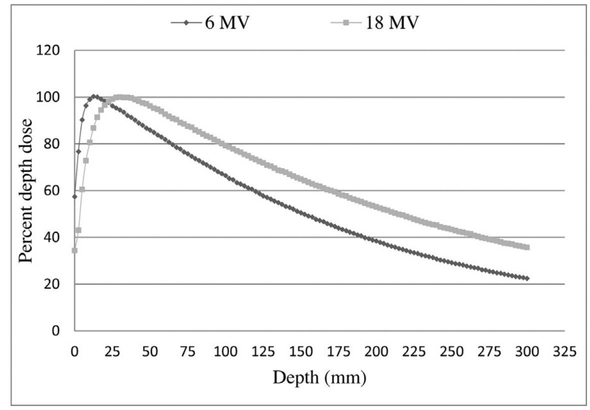

Fig. 1. PDD variation as a function of depth for both photon beam energies 6 MV and 18 MV.s.

We notice from Fig. 1 that the depth of the maximum dose (D_{max}) increased according to photon beam energy. The depth of the maximum dose is 15 mm for 6 MV and 30 mm for 18 MV (Fig. 1).

3.2. Beam dosimetry quality analysis

For beam dosimetry quality investigation, the PDD curves (Fig. 1) are subdivided into three regions: build-up dose, electronic equilibrium and exponential decay. We have selected two depth intervals for the first two regions and three depth intervals for the third region, the results are discussed below.

3.3. Build-up dose

The build-up dose region is subdivided into two intervals:

- The first interval (A): from depth d_1 = 0 mm to depth d_2 = 15 mm for 6 MV and from depth d_1 = 0 mm to depth d_2 = 30 mm for 18 MV.
- The second interval (B): from depth d_1 = 5 mm to depth d_2 = 15 mm for 6 MV and from depth d_1 = 10 mm to depth d_2 = 30 mm for 18 MV.

Fig. 2 gives PDD rate variation in proportion to field size for build-up dose region.

We notice from Fig. 2 that PDD rate increases with photon beam energy while it decreases with irradiation field size. The gap between the PDD rate curves of 6 MV and 18 MV photon beam energies decreases with irradiation field size (Fig. 2) and when the length of the interval decreased that is to say when the depth d_1 comes near the depth of the maximum dose d_2.

3.4. Electronic equilibrium

The electronic equilibrium region is bordering between two depths:

- The first border interval (A): from depth d_1 = 12.5 mm to depth d_2 = 17.5 mm for 6 MV and from depth d_1 = 25 mm to depth d_2 = 35 mm for 18 MV.
- The second border interval (B): from depth d_1 = 10 mm to depth d_2 = 20 mm for 6 MV and from depth d_1 = 22.5 mm to depth d_2 = 37.5 mm for 18 MV.

Fig. 3 gives the PDD rate variation according to field size for the electronic equilibrium region.

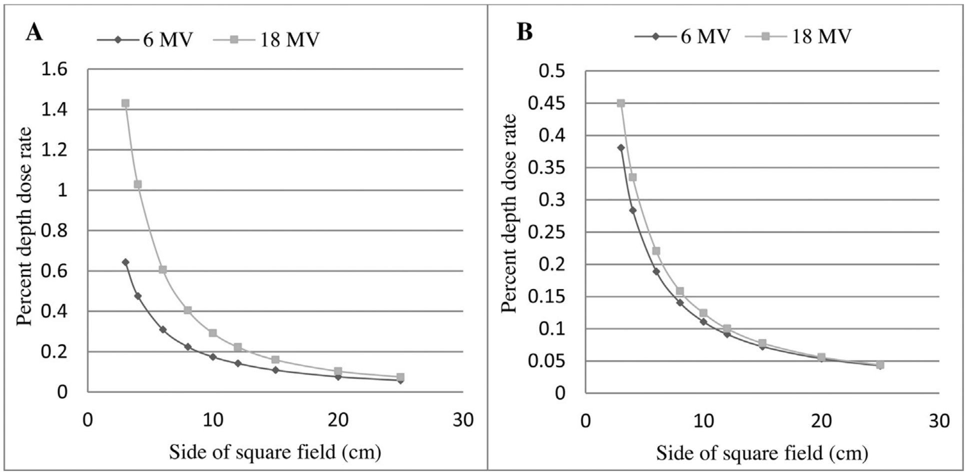

Fig. 2. PDD rate variation as a function of field size for build-up dose region.

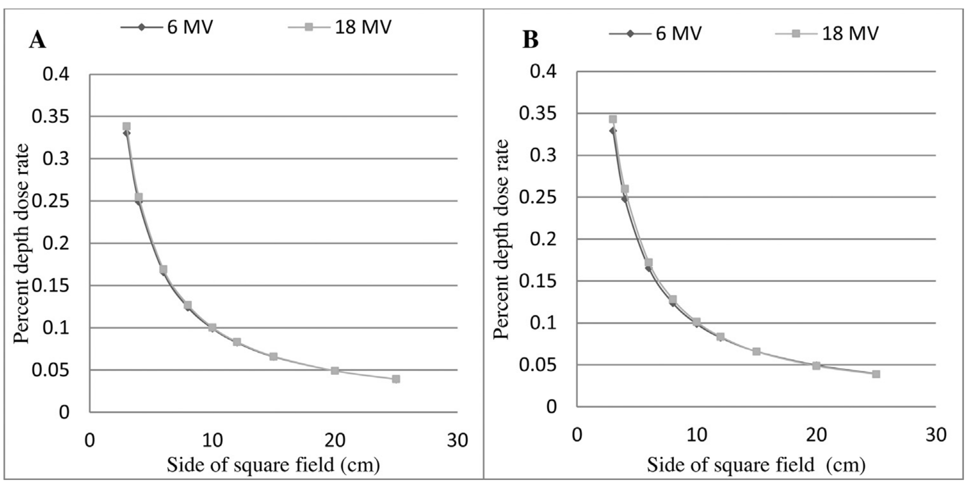

Fig. 3. PDD rate variation as a function of field size for the electronic equilibrium region.

As shown in Fig. 3, the gap between the PDD rate curves of 6 MV and 18 MV photon beam energies was independent of the interval length of the region bordering the electronic equilibrium (Fig. 3A and B). The PDD rate variation is between 0.039 and 0.35 for both bordering regions A and B. The dosimetry variation on the electronic equilibrium region is independent of the depth and photon beam energy while it varied also according to the irradiation field size.

The electronic equilibrium region cannot allow us to check the dosimetry quality according to photon beam energy and depth as it is used to check the dosimetry quality with irradiation field size.

3.5. Exponential decay

The exponential decay region is subdivided into three depth intervals:

- The first interval (A): from depth d_l = 50 mm to depth d_2 = 100 mm for 6 MV and 18 MV photon beams.
- The second interval (B): from depth d_l = 100 mm to depth d_2 = 200 mm for both photon beams.
- The third interval (C): from depth d_l = 200 mm to depth d_2 = 300 mm for both photon beams.

Fig. 4 shows PDD rate variation according to field size for the exponential decay region.

Fig. 4 shows that the PDD rate increases slightly with an increasing photon beam energy while it decreases according to irradiation field size. The gap between the PDD rate curves of 6 MV and 18 MV photon beam energies decreases with depth and irradiation field size while it increases when d_1 becomes far from depth of dose (Fig. 4). It, therefore, depends on the sub-region according to its position over the exponential decay region.

In the protocols mentioned above, the dosimetry quality control aimed to check the beam dependence on the beam energy based on the PDD on the exponential decay region that varied with field size, depth and photon beam energy. This region is not appropriate for an accurate evaluation procedure of the dosimetry quality. In protocols IAEA TRS-398, the depths of the exponential decay sub-region (case B) are used to assess the beam quality index. The dosimetry quality, however, is not clearly provided by those sub-regions and it is not overall. The global information about dosimetry quality is stated according to the overall PDD variation from skin dose (0 mm) to exit dose (300 mm). This confirms the necessity to find a way to evaluate the beam dosimetry quality through the whole PDD variation with depth in the water phantom.

3.6. Total PDD

The whole PDD region corresponds to the entire PDD curve variation that is to say the interval from depth d_l = 0 mm to depth d_2 = 300 mm for both photon beam energies 6 MV and 18 MV. It

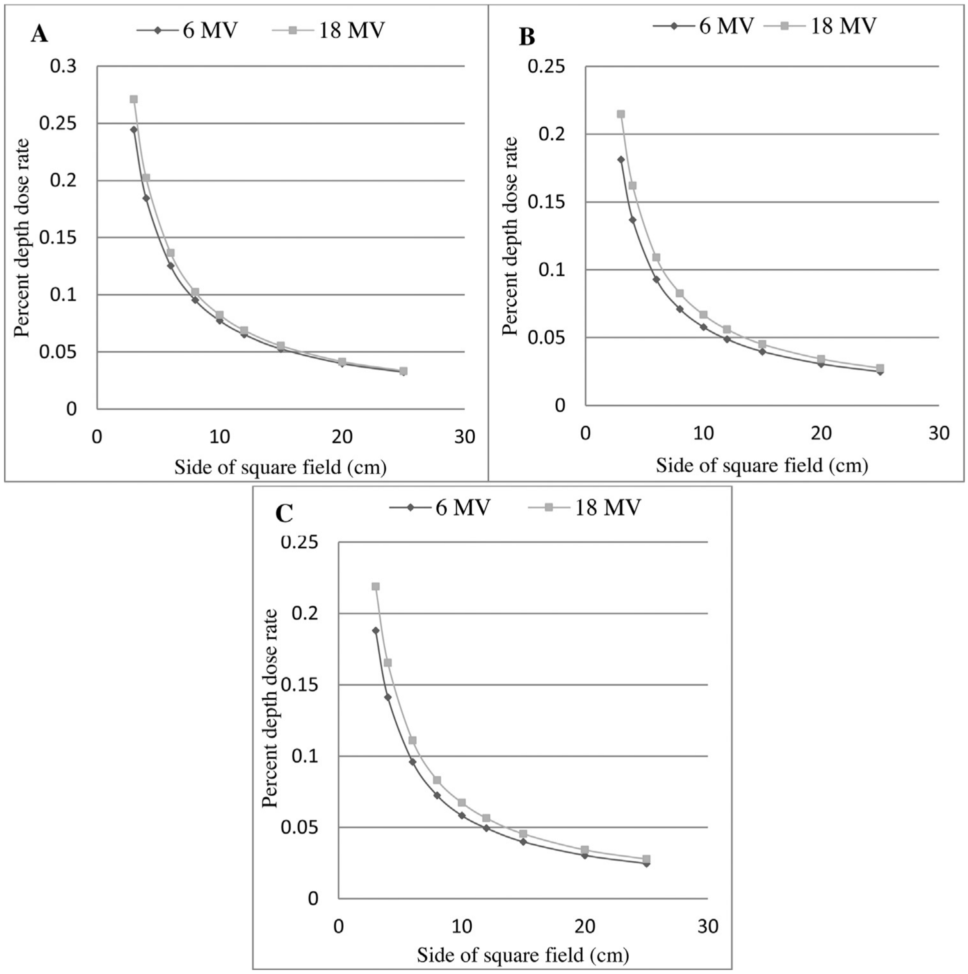

Fig. 4. PDD rate variation as a function of field size for exponential decay region.

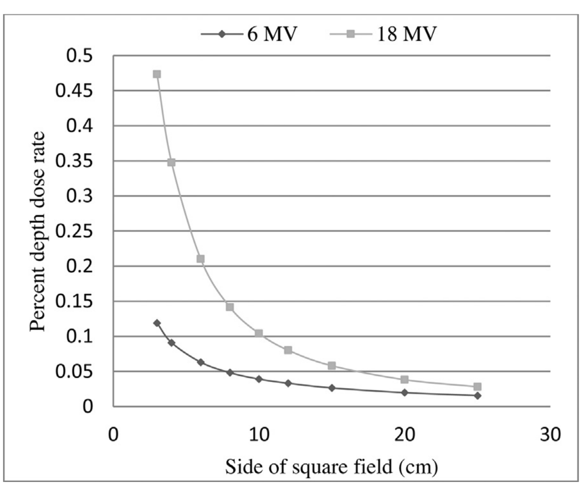

Fig. 5. PDD rate variation as a function of field size for the whole PDD.

includes all PDD sub-regions studied above and has the global information about the beam dosimetry quality. Therefore, we have proceeded to investigate the dosimetry quality by covering the PDD variation by determining its rate with field size for both photon beam energies.

Fig. 5 gives PDD rate variation according to field size for the whole PDD region.

Fig. 5 illustrates that the discrepancy between the PDD rate curves of 6 MV and 18 MV photon beams is clearly displayed. We observe also that the dosimetry quality is easy to state at any field size less than $25 \times 25\,cm^2$. Based on results of this study, the dosimetry quality control becomes easier for Linac head calibration.

In this work, many deficiencies of the beam quality index protocol has shown as the quality determination that is limited to the field size of $10 \times 10\,cm^2$ cm on exponential decay region at depths of 10 cm and 20 cm.[15,14] Previously, we studied the beam quality based on PDD fragmentation.[16]

4. Conclusion

This work is an experimental study of dosimetry quality according to photon beam energy and irradiation field size. The quality management is inclusive in such determination procedure inside the radiotherapy department. We have presented the necessity to include all PDD sub-regions and all dosimetric particularities in the dosimetry quality procedure, such as electron contamination and low photon energy. The presented approach allows us to assess the quality based on the PDD variation in an easier and reliable way. At any field size under $25 \times 25\,cm^2$, on the exponential decay region, the beam quality is assessed to examine the radiotherapy treatment efficiency with photon beam energy while on the build-up region, it is assessed to check the dosimetric properties of the particles contamination and its impact on the radiotherapy quality. In these PDD regions, the PDD rate of 18 MV is above that of 6 MV.

This discrepancy can serve to check this quality of the photon beam according to the energy and irradiation field size.

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Conflict of interest

None declared.

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