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Original article

# Mathematical parameterization of dosimetry quality index checking of the photon beam based on IAEA TRS-398 protocol

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A R T I C L E I N F O

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A B S T R A C T

The quality is essential for radiation use in medicine and the beam quality index is the basic parameter to periodically check the normal functioning of Linac head in radiotherapy treatment. It is recommended by IAEA protocols TRS-398 based on absorbed dose in water. The PDD method is used as a basis of the parameterization of the photon beam quality for predicting its variation with beam energy and field size. The objective of this work is to establish a mathematical law for predicting and checking the beam dosimetry quality index according to field size and beam energy based on IAEA TRS-398 protocol.

For an easier and more reliable procedure determination of the beam quality based on TRS 398, two empirical laws were therefore established with an accuracy better than 2%. They can serve the basic floor to medical physicist to verify and to control the dosimetry output quality at arbitrary field size. Our findings aim to facilitate the dosimetry quality control that set in use according to current conditions for checking out the radiotherapy efficiency and the safety inside the treatment room.



## 1. Introduction

The quality of radiation used in medicine is taken seriously by International Atomic Energy Agency (IAEA), International Commission on Radiation Units and measurement (ICRU), American Association of Physicist in Medicine (AAPM) and International Electrotechnical Commission (IEC) in many publications and protocols (IAEA, 2004a; AAPM, 2009a; ICRU, 2006; IEC, 2016). They were introduced the parameters in many methods to assess the beam quality for checking the functioning of a medical device as dosimeters, linear accelerators (Linac), measure channels ... etc. In external beam radiotherapy, the quality dosimetry investigation aims to check out any unexpected changes in dosimetry output of the Linac head and to proceed to resolve any technical problem and it should be at the Linac commissioning and thereafter on a fixed period for assessing the quality assurance for radiation treatment of cancer (IAEA, 2004b).

The quality control is based on many protocols are established for well monitoring the dosimetry deliverance and its quality for checking the radiotherapy treatment efficiency according to beam energy under specific reference conditions of temperature, pressure and humidity (Md Tofiz Uddin, 2012). The procedure implementation of one method can introduce uncertainties that vary from one protocol to another.

The IAEA TRS 398 protocol recommends evaluating the beam quality index based on TPR parameter for field size of $10 \times 10\ \text{cm}^2$ as a quotient of dose at a depth of 20 cm to dose of a depth of 10 cm (IAEA, 2004b). For determination facility, the percentage depth dose (PDD) method is introduced which is as a quotient of PDD at a depth of 20 cm to PDD of a depth of 10 cm (Song et al., 2016). The quality control improvement aims always to ensure high radiotherapy quality of cancer treatment (AAPM, 1994b). The quality procedure determination should be easier, reliable and inclusive according to current conditions as that we have previously introduced to assess the beam quality based on PDD fragmentation (Bencheikh et al., 2018). In this work, we are focused on beam dosimetry quality index as one parameter to evaluate the dosimetry quality in radiotherapy treatment based on IAEA technical report series (TRS) 398. The objective of this study is to extend the beam quality index procedure to arbitrary field size and to establish an easier procedure by introducing a

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mathematical law according to field size and beam energy driving the dosimetry quality.

The dosimetry quality is not new in our works; we have previously worked on photon dosimetry quality using Monte Carlo method (Bencheikh et al., 2017a, 2017b). We have also studied the impact of removing flattening filter and the different particles, which are into the produced beam on dosimetry quality (Bencheikh et al., 2017c). In this work, we will establish two mathematical laws to predict the beam dosimetry quality based on IAEA TRS 398 protocol by handling the PDD measurements of Varian Clinac 2100.

## 2. Materials and methods

### 2.1. Dose measurements

In this study, the dose measurements are performed for two photon beam energies of 6 MV and 18 MV, produced by Varian Clinac 2100 (Varian, Palo Alto, CA), which are the most commonly used in our clinical practice. The measurements were performed, for a source to surface distance SSD of 100 cm, in a water phantom of a volume of $40 \times 40 \times 40\ cm^3$ in respect to recommendations of the Swiss Society of Radiobiology and Medical Physics (SSRMP) (SSRMP, 2000).

The PTW 30013 chamber (Physikalisch Technische Werkstätten (PTW) Freiburg, Germany) was used for the PDD measurements of both 6 MV and 18 MV photon beams. MEPHYSTO software (PTW, Freiburg, Germany) was used to drive the ion chamber for data acquisition at increment of 2.5 mm in depth. All PDD measurements were carried out under conditions of temperature of 20° C and the pressure of 101.3 Pa and the humidity of 50%. The uncertainty of PDD measurements was less than 2% and this included all the uncertainties of experimentation and the uncertainty of devices measurements used.

### 2.2. Beam quality index

The beam quality index is evaluated based on phantom tissue ratio (TPR) parameter that is a measure of the effective attenuation coefficient describing the exponential decrease of photon depth dose curve beyond the depth of the maximum dose ($D_{max}$). The TPR appears too much complicated to be measured inside the radiotherapy department and to override this technical problem, it can be related to measured $PDD_{20,10}$ using the empirical following relationship (Podgorsak, 2005):

$$TPR_{20,10} = 1.2661\ PDD_{20,10} - 0.0595 \tag{1}$$

where $PDD_{20,10}$ is the ratio of PDD at a depth of 20 cm to PDD at a depth of 10 cm for a field of $10 \times 10\ cm^2$ and SSD of 100 cm. Fig. 1 presents the beam quality index determination depth interval as recommended by IAEA TRS 398:

## 3. Results and discussion

### 3.1. Percentage depth dose PDD

PDDs vary with beam energy, irradiation field size and depth for a SSD of 100 cm. Fig. 2 presents PDD variation with depth for both photon beam energies 6 MV and 18 MV inside an irradiation field size of $10 \times 10\ cm^2$.

The depth of maximum dose increases with photon beam energy. For 6 MV, the depth of maximum dose is 15 mm, and for 18 MV, the depth of maximum dose is 30 mm (Fig. 2). Beyond the depth of maximum dose, we notice that PDD curve of 18 MV is above to PDD curve of 6 MV. In this region of the PDD curve, the dosimetry quality is determinable and it therefore can be evaluated to check the dosimetry dependence on photon beam energy.

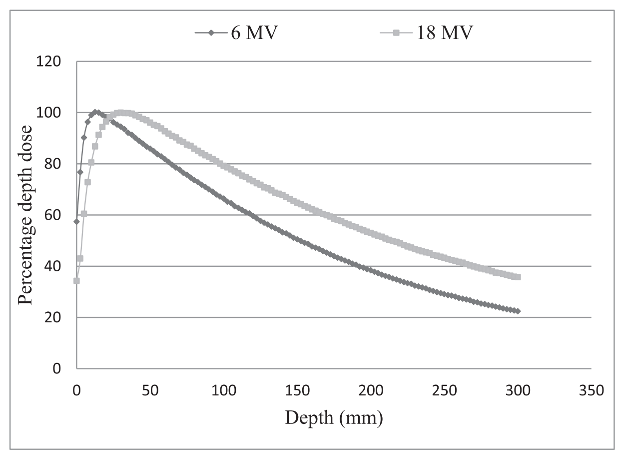


**Fig. 2.** PDD variation as a function of depth.

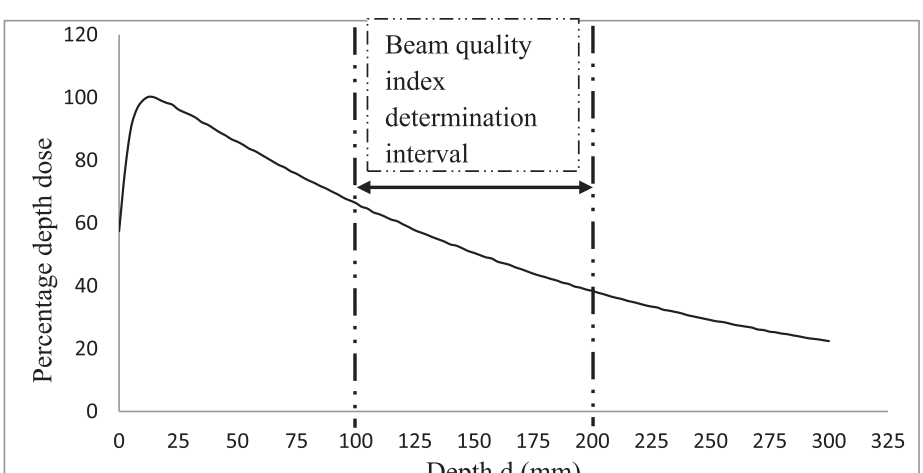


**Fig. 1.** Percentage depth dose variation as a function of depth and depths interval of beam quality index determination.

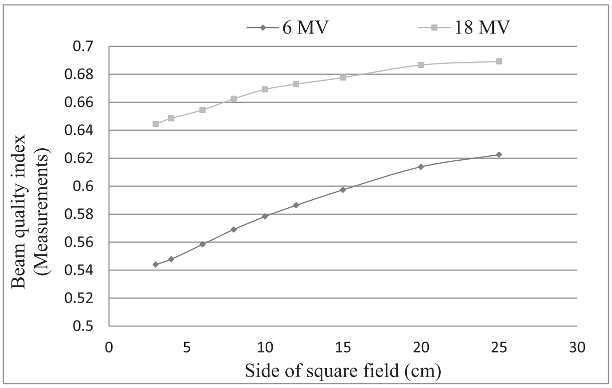


**Fig. 3.** Beam quality index variation as a function of field size.

### 3.2. Beam quality analysis

Based on the IAEA IRS 398 protocol, the beam quality index is determined on exponential decay of PDD cure (Fig. 1). Fig. 3 presents the beam quality index as $PDD_{20,10}$ variation with field size.

The gap between beam quality index curves of 18 MV photon beam and 6 MV photon beam decreases with field size (Fig. 3). Using the mathematical fit method, we have thereafter established two empirical laws governing the variation of beam quality index according to photon beam energy and field size.

Formula 2 gives the mathematical expression of beam quality index (QIL):

$$QIL = a + bx + cx^2 \tag{2}$$

where

*x* is the side of square irradiation field which expressed in cm

*a*, *b* and *c* are coefficients which depend just the photon beam energy *E* which is expressed in MV.

The expressions of *a*, *b* and *c* are the following:

$$a = 89.210^{-4}E + 47.1510^{-2} \tag{3}$$

$$b = -15.0410^{-5}E + 71.4310^{-4} \tag{4}$$

$$c = 54.9710^{-8}E - 9610^{-6} \tag{5}$$

Fig. 4 gives comparison between quality index measurement and QIL and the committed error.

The QIL reproduces the measured quality index as a function of field size with a committed error under 1% (Fig. 4). The established law is therefore reliable and accurate to predict the dosimetry quality index variation according to beam energy when ion chambers are calibrating at arbitrary field size and it can serve as a basic law for quality control that is easy to return for checking the dosimetry quality based on IAEA TRS 398 protocol.

### 3.3. Beam quality index rate

Beam quality index rate is a ratio of beam quality index divided by the side of irradiation square field. Fig. 5 gives the variation of beam quality index rate for both photon beam energies 6 MV and 18 MV.

The quality index rate decreases with photon beam energy and field size and it is between 0.027 and 0.22 for both photon beam energy (Fig. 5).

Using the same mathematical technique, the beam quality index rate law (QIRL) is established according to field size and photon beam energy. Formula 6 gives the expression of QIRL:

$$QIRL = ax^{-b} \tag{6}$$

where

*x* is side of irradiation square field which expressed in cm

*a* and *b* are coefficients which depend only on photon beam energy E which is expressed in MV.

The expressions of *a* and *b* are the following:

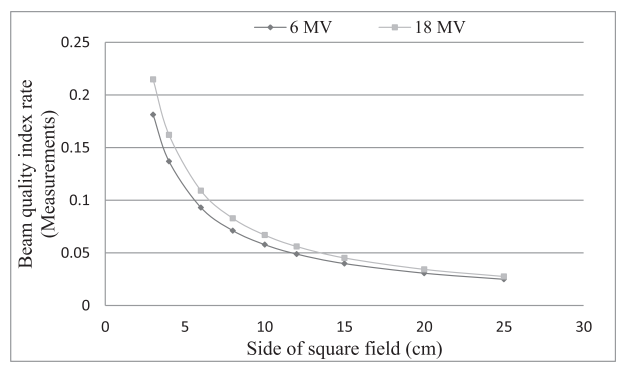


**Fig. 5.** Beam quality index rate variation as a function of field size.

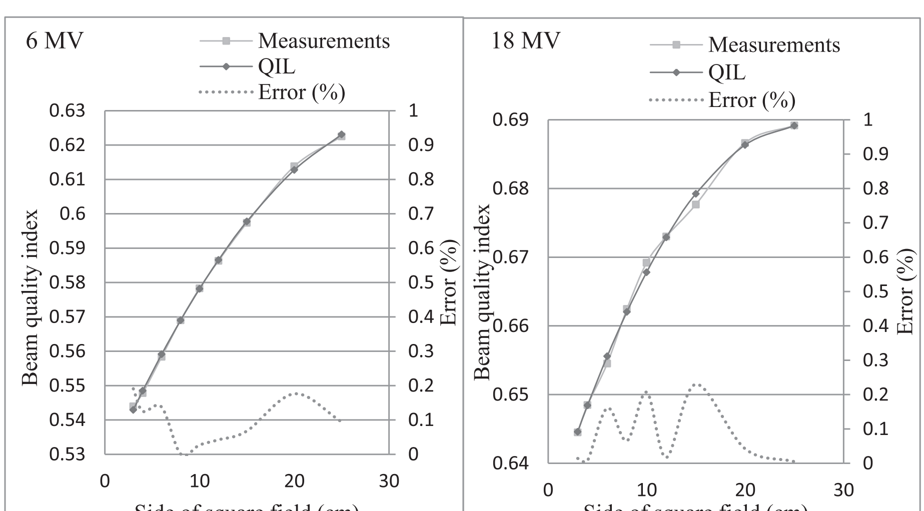


**Fig. 4.** Beam quality index law (QIL) and committed error variation as a function of field size.

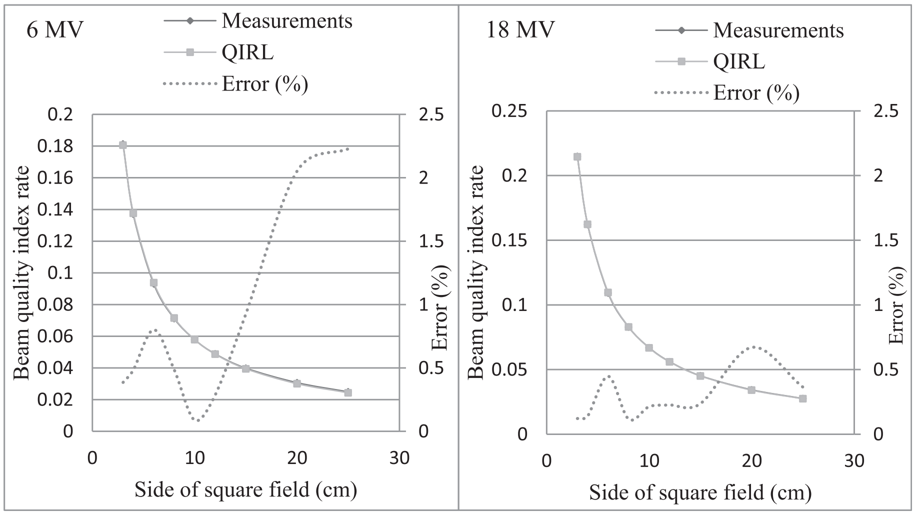


**Fig. 6.** Beam quality index rate law (QIRL) and committed error variation as a function of field size.

$$a = 93.6310^{-4}E + 45.410^{-2} \quad (7)$$

$$b = 20.310^{-4}E + 93.3010^{-2} \quad (8)$$

Fig. 6 gives comparison between measured quality index rate and QILR and the committed error.

The measured quality index rate is reproduced by QIRL with a committed error less than 1% for photon beam energy of 18 MV and less than 2% for photon beam energy of 6 MV for field size smaller than $20 \times 20\,\text{cm}^2$ (Fig. 6). In perspective, we will correct this error for being less than 2% for field size greater than $20 \times 20\,\text{cm}^2$.

The 2% is the acceptability limit recommended by IAEA as an uncertainty for taking in action a parameter in radiotherapy treatment (active parameter) [5].

## 4. Conclusion

The dosimetry quality index is up to now a crucial parameter to check out for high external beam radiotherapy quality, which is related to photon beam energy and irradiation field size for ensuring high radiotherapy efficiency.

According to current reference conditions, two mathematical laws are established to predict the dosimetry quality index variation with photon beam energy and irradiation field size. These mathematical laws regenerate the quality index with accuracy better than 2% and are therefore reliable and accurate. In perspective, we will study the quality index for flattening filter free (FFF) Linac configuration in continuation of our previous works on flattening filter design quality (Bencheikh et al., 2017d, 2017e; Hugo, 2012).

## Declaration of Competing Interest

The authors have not a conflict of interest about this article.

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