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Short Communication

Medium-Term Stability of the Photon Beam Energy of An Elekta Compact™ Linear Accelerator Based on Daily Measurements of Beam Quality Factor

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Abstract

Introduction
In this study, we aimed to assess the medium-term energy stability of a 6MV Elekta Compact™ linear accelerator. To the best of our knowledge, this is the first published article to evaluate this linear accelerator in terms of energy stability. As well as investigating the stability of the linear accelerator energy over a period of several weeks, the results will be useful for estimation of the required tolerance values for the beam quality factor (BQF) of the PTW QUICKCHECK webline™ (QCW) daily checking device.

Materials and Methods
Over a 13 week period of routine clinical service, 52 daily readings of BQF were taken and then analyzed for a 10×10 cm^2 field.

Results
No decreasing or increasing trend in BQF was observed over the study period. The mean BQF value was estimated at 5.4483 with a standard deviation (SD) of 0.0459 (0.8%). The mean value was only 0.1% different from the baseline value.

Conclusion
The results of this medium-term stability study of the Elekta Compact linear accelerator energy showed that 96.2% of the observed BQF values were within ±1.3% of the baseline value. This can be considered to be within the recommended tolerance for linear accelerator photon beam energy. If an approach of applying ±3 SD is taken, the tolerance level for BQF may be suggested to be set at ±2.5%. However, further research is required to establish a relationship between BQF value and the actual changes in beam energy and penetrative quality.

Keywords: Radiotherapy, Linear accelerator, Quality control, Photons, Beam, Energy

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1. Introduction

There is a growing need for a substantial increase in the number of radiotherapy devices in most under-resourced communities and developing countries. Design of linear accelerators that meet the needs of these communities is a major step in the right direction towards reducing geographical variations in cancer care [1].

Given the limited access to accelerators, support services, and maintenance engineers in under-resourced regions, dosimetric stability is regarded as one of the most desirable characteristics of linear accelerators. One of the dosimetric parameters of interest is photon beam energy, which affects beam penetration and consequently, the dose to the target.

In the present study, we aimed to assess the medium-term energy stability of an Elekta Compact^{TM} linear accelerator (Crawley, United Kingdom), which has been designed and marketed as a relatively simple device, producing only 6 MV photons. This study is of particular interest, as this device is the first Elekta accelerator with a standing wave waveguide. Although several studies have been conducted on the stability of linear accelerator beams [2-15], only a limited number have focused on beam energy. We checked the energy stability of this accelerator using the beam quality factor (BQF) obtained from a QUICKCHECK webline^{TM} (QCW) (PTW Freiburg, Germany) daily checking device. To the best of our knowledge, this is the first published paper, investigating the energy stability of this type of linear accelerator. The results will provide information on the energy stability of the linear accelerator over a period of several weeks. They will also help in estimating the required tolerance values for the beam energy index (BQF) of this daily checking device for this or other linear accelerators.

2. Materials and Methods

Multi-detector daily-checking devices are effective tools for performing quick and convenient quality assurance tests to determine several useful quantities, e.g., central-axis radiation dose, penetrative quality, beam flatness and symmetry, wedge angle, and field size of linear accelerators. Figure 1 presents an image of QCW with a daily measurement setup on an Elekta Compact linear accelerator.

Figure 1. The QCW setup for daily measurements on the Elekta Compact^{TM} linear accelerator

QCW consists of 13 vented ionization chambers. Readings of nine chambers are used for calculating the central-axis dose, flatness, wedge angle and symmetry. The QCW also calculates a BQF as an energy index. Measuring the energy is carried out by the other four chambers, where the reading of one of these energy chambers is used for calculating the BQF. There are different absorbing material thicknesses above these four chambers [16].

Based on the beam energy selected in the measurement menu, the appropriate detector is read out by the system. The chamber used for photon beams is called E1. The E1 chamber reading, together with the reading of the central-axis chamber, are then automatically put into in a polynomial relationship to calculate the BQF value, displayed to 4 decimal places [16]. The details of this polynomial function are proprietary information and not available to users.

Over 13 weeks of routine clinical service, 52 daily readings of BQF were obtained on the Elekta Compact linear accelerator installed in our radiotherapy department. The measurements were performed in the mornings immediately after the warm-up procedure that is recommended by the linear accelerator manufacturer. As specified in the QCW user manual, a 10×10 cm^2 field size was used to obtain BQF values [16]. The usual source-to-surface distance (SSD) for QCW setup (97.3 cm) was also applied. The linear accelerator was not re-calibrated during this period.

3. Results

Figure 2 demonstrates the daily measurements of BQF values. The mean BQF value was estimated at 5.4483 with a standard deviation (SD) of 0.0459. The mean value was only 0.1% higher than the reference (baseline) value. The percentage differences between each daily BQF measurement and the baseline value are plotted in Figure 3. The results showed maximum deviations of +1.5% and -2.5%.

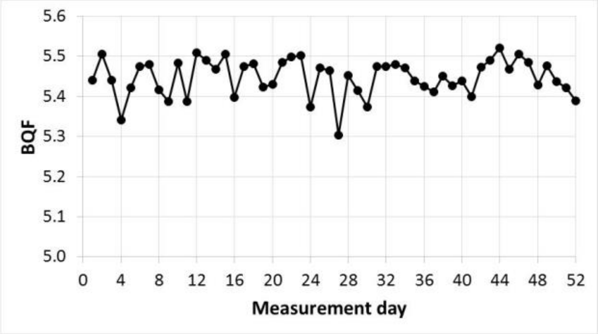

Figure 2. The daily measurements of beam quality factor (BQF)

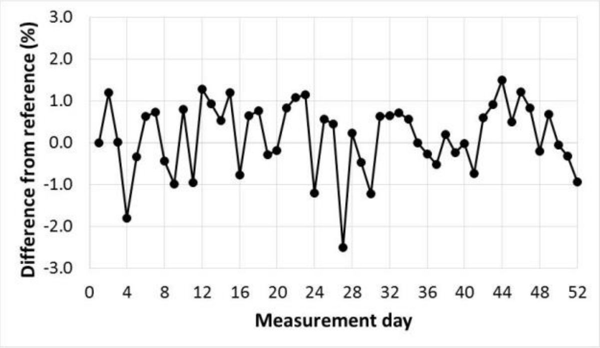

Figure 3. Daily percentage variations from the reference beam quality factor (BQF) value over the measurement period

4. Discussion

Specifications of the nominal energies of linear accelerators are based on standard percentage depth dose (PDD) tables, such as those presented in the British Journal of Radiology, Supplement 25 [17]. During acceptance testing, the energy of this linear accelerator was found to be within the manufacturer's specified level, i.e., PDD at a 10 cm depth in water for a 10×10 cm^2 field and 100 cm SSD within ±2.0% of 67.0%. [18].

In the present study, the mean daily BQF measurements over the observation period were found to be only 0.1% different from the baseline value. Moreover, no decreasing or increasing trend in BQF was observed during the study period. The gradient of the fitted straight line to the data was almost zero (0.0001) and, therefore, showing negligible systematic trend; so, the observed fluctuations in BQF could be considered to be random. The impact of such random fluctuations on patient treatment is much less significant than systematic errors, as small random daily variations in dose can cancel out over a number of days.

In the present study, with the exception of two days when BQF values were found to be -2.5% and -1.8%, respectively, the values fell within a ±1.3% range; also, SD, expressed as a percentage of the mean value, was 0.8%. As one of the criteria for setting tolerance levels for quality assurance is the actual behavior of the accelerator itself, such measurements could be helpful in selecting an appropriate BQF tolerance level that is neither too lax nor too strict (causing unwarranted interruptions in the use of linear accelerators).

In this regard, Ritter et al., by assuming a normal distribution, suggested setting ±3 SD as the lower and upper tolerance levels to cover 99.7% of the readings and avoid too many false-positive test results [14]. This approach would set the tolerance levels for BQF at ±2.5% (range: 5.3042-5.5762) in our linear accelerator.

It has been previously suggested that for maintaining 6MV PDD within ±2% of the baseline, the energy of the linear accelerator can have a tolerance level as much as ±10%, equivalent to ±1 MV energy variations [14]. On the other hand, limiting the acceptable PDD variation to ±1% has been also proposed and shown to be achievable [13].

As mentioned earlier, to the best of our knowledge, no paper has been published on the energy stability of the linear accelerator evaluated in the present study; therefore, a direct comparison between our findings and previous research is impossible. However, a study by Peng et al. on another type of Elekta linear accelerator showed that the energy remained within a ±2% range [7].

Several national and international organizations have made recommendations on the energy stability of linear accelerator beams, e.g., the report by Task Group 40 of the American Association of Physicists in Medicine [19]. It should be mentioned that recommendations such as those on energy specification (penetrative quality) are based on standard-setup, in-water measurements. However, under typical circumstances in busy radiotherapy clinics, daily measurements that require time-consuming phantom setup, cannot be performed. Instead, dedicated daily checking devices are used to speed up morning evaluations. Therefore, daily assessment of energy variation is based on the constancy of an energy index, derived from the readings by the daily checking device.

Ideally, a 1% change (for instance) in the daily energy index should be equivalent to a 1% change in beam energy, or even better, a 1% change in PDD (indicative of the dose at the prescription point); however, this may or may not be the case. Here, the problem arises as how to translate the acceptable variation in PDD values in the standard setup to the observed changes in the energy index (BQF in our case).

The BQF values reported in the present study most probably represent an acceptable level of energy stability for the studied linear accelerator in terms of classic quality indices, pertaining to water phantom PDDs or tissue-phantom ratios. However, this cannot be stated categorically and requires further research on BQF behavior with regard to energy. We are currently investigating this, as well as other important factors such as beam output, flatness and symmetry.

5. Conclusion

The evaluation of medium-term energy stability of Elekta Compact linear accelerator showed that 96.2% of BQF values were within ±1.3% of the baseline value. This can be considered to be within the recommended tolerance range for photon beam energy fluctuations of the linear accelerator. If an approach of applying ±3 SD is taken, our data suggest a tolerance level of ±2.5%, i.e., BQF ranging from 5.3042 to 5.5762. However, further research is required to establish a relationship between BQF value and the actual changes in beam energy and penetrative quality.

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