QUALITY CONTROL OF MODERN LINEAR ACCELERATOR: DOSE STABILITY LONG AND SHORT-TERM

Md Tofiz Uddin, National Institute of Cancer Research and Hospital, Dhaka, Bangladesh

Abstract

Quality Control (QC) data of modern linear accelerators, collected by National Institute of Cancer Research and Hospital, Dhaka, Bangladesh between the years 2006 and 2010, were analyzed. Three Linear Accelerators is included in this work. The goal was to provide information for the evaluation and elaboration of QC of accelerator outputs and to propose a method for QC data analysis. Short- and long-term drifts in outputs were quantified by fitting empirical mathematical models to the QA measurements. Normally, long-term drifts were well (≤1.5%) modeled by either a straight line or a single-exponential function. A drift of 2% occurred in 18 ± 12 months. The shortest drift times of only 2–3 months were observed for some new accelerators just after the commissioning but they stabilized during the first 2–3 years. The short-term reproducibility and the long-term stability of local constancy checks, carried out with a sealed plane parallel ion chamber, were also estimated by fitting empirical models to the QC measurements. The reproducibility was 0.3–0.6% depending on the positioning practice of a device. Long-term instabilities of about 0.3%/month were observed for some checking devices. The reproducibility of local absorbed dose measurements was estimated to be about 0.4%. The proposed empirical model fitting of QC data facilitates the recognition of erroneous QC measurements and abnormal output behavior, caused by malfunctions, offering a tool to improve dose control.

INTRODUCTION

Quality Control is the regulatory process through which the actual quality performance is measured, compared with existing standards, and the actions necessary to keep or regain conformance with the standards. Quality control forms part of quality system management [3]. Quality Control is concerned with operational techniques and activities used: To check that quality requirements are met and to adjust and correct performance if requirements are found not to have been met. The most important aim for good dose accuracy is the maintenance of a narrow deviation in the radiation production of an accelerator. The radiation production is called 'output' and it is defined as the dose absorbed at a reference point in a beam per a monitor unit (MU) measured by accelerator monitoring chamber (Gy/MU). Shift of the output level results in changes of the doses received by all patients. The maintenance of good dosimetric accuracy in treatments depends on the stability of an accelerator, reproducibility of QC measurements and the ability of the used QC procedure in the detection of true drifts in the beam parameters. The output is measured at regular time intervals accurately in a water tank by using a very stable reference instrument. The measurements are carried out with relatively long time intervals since they are workful and time consuming.

Approximated constancy checks (CC) of output are carried out more often by using by fast and easily movable equipment. A CC device may not be very stable requiring regular calibrations against the local reference instrument [4]. The use of an appropriate QC procedure for output should maximize the detection of both 'normal' and unexpected changes in output levels. QC programs given by different international or national authorities have recommended considerable variable time intervals for the output measurements ranging from one week to even one year. Intuitively it is safer to have short output measurement intervals but too redundant measurements waste resources and time that could be used for treatments [2]. The RT centres have to choose their QC program intuitively without quantitative data of the efficacy of the use of the chosen program on the overall accuracy of dose. The elaboration and optimization of a local QC program would require the knowledge of normal time pattern in output level to estimate output stability and suitable time intervals for the measurements. Such knowledge might also facilitate the detection of potential malfunctions and measurement errors. The knowledge of measurement reproducibility is crucial in the choice of appropriate action levels for the measurements and in the evaluation of appropriate remedying actions for measured output changes. Due to relatively long output measurement time intervals, the reproducibility of the approximate CCs should be sufficient in the detection of output changes of only a few per cent with very few check repetitions. Moreover, long-term stability of a CC device should be sufficient (or known) with respect to the chosen output measurement time interval. All the factors mentioned above may depend on accelerator and dosimetric equipment types.

METHODOLOGY

The Quality Control data collected by the Department of Radiation Oncology, National Institute of Cancer Research and Hospital, Dhaka, Bangladesh between 2006 and December 2010 were analyzed to determine short- and long-term time trends in accelerator outputs and the reproducibility of the output measurements and the CCs of outputs. The data had been collected for photon external beams of three linear accelerators, including one Varian Clinac 2100 C (6 and 10MV), DHX3186(6 and 23 MV), and one DHX3041 (6 and 15 MV). All these three Accelerators are from Varian Medical System. The output measurements had been carried out by the support of all experienced hospital physicists at the depth of 10 cm in a 10×10 cm^2 beam at maximal time intervals of 6 months

ISBN 978-3-95450-115-1

by using a 0.6 cc open ionization chamber type NE 2571 and NE Farmer 2570 electrometer (NE Technology Ltd, Reading, UK). The CCs of the outputs had been carried out two or three times a week by the RT technologists by using four sealed plane parallel ionization chambers of type PTW-Linacheck T42010 (PTW, Freiburg, Germany). One device was used per two accelerators. The CC devices had been calibrated in connection with the output measurements. Relative dosimetry comprehending the checks of beam profiles and depth dose (QI) was carried out before each output measurement by using a 0.13 cc open ionization chamber (Wellhöfer IC15, Scanditronix-Wellhöfer, Uppsala, Sweden) and a Wellhöfer WP700 scanning water tank with Dosimetrie WP700 software (Wellhöfer Dosimetrie, Schwarzenbruck, Germany)

DOSE MEASUREMENT

The determination of absorbed dose within a patient is based on the measurement of absorbed dose in water, since mean electron density of soft tissues is close to that of water. The correction factor is given in the dosimetric code of practice and is based on the value of a beam quality index (QI). Finally, the dose absorbed in water for radiation of quality Q is given as

$$D_{W,Q} = M.k_{TP}.k_s.k_{pol}.k_{elec}.N_{W,Q}\,, \qquad (1)$$

where M is reading of an electrometer and correction factors k_{TP}, k_s, k_{pol} and k_{elec} are for conversion of actual measurement conditions to reference conditions, for recombination of ion pairs before they are collected, for polarity of collecting voltage and for sensitity of electrometer, respectively. $N_{w,Q}$ is the calibration coefficient of the chamber for dose absorbed in water for radiation of quality Q [3].

For the QI, the TRS-398 recommends measurement of tissue phantom ratio (TPR_{20}^{10}, ratio of doses at depths of 20 and 10 cm) or ratio of depth ionizations at depths 10 and 20 cm ($J_{20}^{10} \equiv$ J10/J20) for the field size of 10x10 cm^2. According to TRS-398 this quantities are empirically related to

$$TPR_{20}^{10} = \frac{1.2661}{J_{20}^{10}} - 0.0595\,. \qquad (2)$$

According to IAEA (2000) [3], overall uncertainty of clinical absorbed dose measurements is 1.5% (1SD) and a measurement procedure carried out in user's beam gives the most significant contribution to this being even 1.4% (1SD). The latter is divided into 5 factors: 1) long-term stability of user dosimeter 0.3%, 2) establishment of reference conditions 0.4%, 3) dosimeter reading relative to beam monitor 0.6%,4) correction for influence quantities (k beam quality correction 1.0%. The accuracy of absorbed dose measurements could be significantly improved if the uncertainty of the measurements carried out in the user's beam could be reduced.

DOSE CALCULATIONS

Dose calculations for the dose delivery measured by the STUK were carried out by a hospital physicist. The number of monitor units (MUs) for an isocentric central axis dose delivery of 2 Gy at the depth of 10 cm in water (SAD=100 cm, SSD=90 cm) were calculated for the following FSs (XxY): 5x5, 7x7, 10x10, 15x15, 20x20, 30x30, 40x40, 5x30 and 30x5 cm^2.

RESULTS

Short-term Behaviour of an Output Level

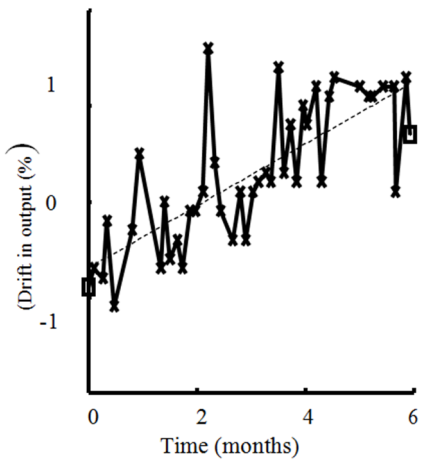

Figure 1: According to the constancy checks ('x's with a solid line), a systematic short-term drift in an output level was assumed linear (dashed line) between two successive output measurements (squares).

Long-term Behaviour of an Output Level

A 'free' cumulated systematic long-term (time period of more than two successive output measurements) drift in an output level, which most likely would have occurred without any dose adjustments, was estimated for each accelerator and photon energy.[2] This was done by arranging consecutively the linear short-term trends formed by two successive output measurements.

Short-term Output

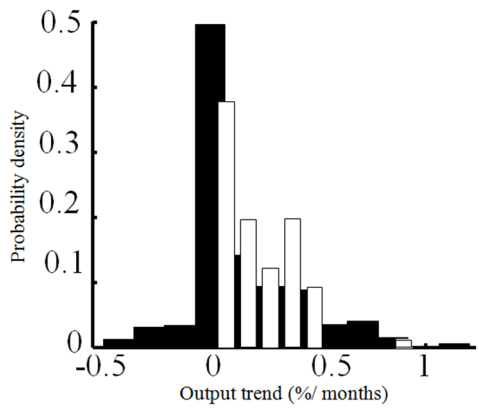

Figure 2: [5] The empirical probability distributions of linear short-time output trends constructed from the quality control data collected for 6 MV (black bars) and

ISBN 978-3-95450-115-1

for 15-18 MV (white bars). For 6 MV, the mean ± SD of the output trends, weighted by their relative durations, were 0.05 ± 0.27%/month. For 15-18 MV, the corresponding values were 0.15 ± 0.19%/month.

Long-term Output

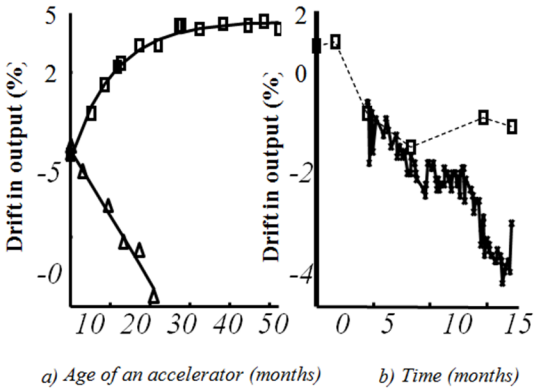

Figure 3: [1] Systematic cumulated long-term drifts in output levels. Accelerators with sealed monitoring chambers: a) Example of both an exponentially increasing level (output measurements illustrated with squares) and a linearly decreasing level (output measurements illustrated with triangles). The proposed models (solid lines) describe well the constructed drifts. An accelerator with an unsealed monitoring chamber: b) According to CCs (stars with a solid line) and output measurements (squares with a dashed line), a periodic behaviour (period about a year) due to environmental conditions was observed [5]. Differences between the output and CC measurements increase significantly with time demonstrating great systematic long-term drift in the stability of the CC device (regular recalibrations removed). It should be reminded that the constructed output drifts do not describe dose errors in treatments because of dose adjustments.

SUMMARY AND CONCLUSION

The aspects investigated in this thesis have an impact on the accuracy of absorbed dose in radiation therapy. These are reproducibility of dosimetric quality control (QC) measurements, stability of accelerator radiation output, effectiveness of a chosen dosimetric QC program, accuracy of beam data used to configure dose calculation algorithm suggestions and criteria were proposed to improve dose accuracy and to optimize workload related to dosimetric QC. The developed method revealed that appropriate choice of a dosimetric QC program should take into account the measurement reproducibility and output stability. A method based on empirical model fitting of QC measurement results was found suitable for the quantification of these factors. The change of measurement action levels was shown to have more prominent relative effect than the change of measurement time interval.

The proposed model fitting facilitated identification and reduction of random measurement errors enabling the lowering of measurement action levels. As a consequence, workload of dosimetric measurements can be significantly reduced by prolonging output measurement interval from 1 month to even 6 months while maintaining treatment quality. Alternatively, by maintaining the workload, dose accuracy can be improved by even about 3 %. The method can be easily incorporated in the electronic archives of QC results. The resources spend on QC measurements can be further optimized if individual measurement time intervals are used for the accelerators instead of a common measurement interval. Frequent checks were reasoned for some accelerators just after the commissioning but these accelerators seemed to stabilize with time. The proposed empirical model fitting was found suitable for the evaluation of individual measurement time intervals.The importance of QC for beam data used for the dose calculations was demonstrated by showing errors of up to about 3% in such data. The magnitude of these errors was comparable to the benefit obtainable by using a short output measurement time interval. Robust reference beam data sets were constructed for the Varian Clinac 2100 CDs.

ACKNOWLEDGMENT

This thesis is based on work done in National Institute of Cancer Research and Hospital, Dhaka, Bangladesh between the years 2006 and 2010. Both of these institutions are greatly acknowledged. Especially I wish to express my gratitude to Proferssor Dr Sheikh Golam Mostofa Head of the Department of Radiation Oncology, for the opportunity to work in the Hospital.

REFERENCES

[1] E. Aird, P. Mayles and C. Mubata, “Quality control of megavoltage equipment,” in *Handbook of Radiotherapy Physics, Theory and Practice*, P. Mayles, A. Nahum and J.C. Rosenwald (Eds.), New York, NY, USA, (Taylor&Francis; 2007), p. 831.

[2] J. Aguirre, R. Tailor, G. Ibbott et al., “Thermoluminescence dosimetry as a tool for the remote verification of output for radiotherapy beams: 25 years of experience,” Proceeding of the International Symposium on Standards and Codes of Practice in Medical Radiation Dosimetry, IAEA-CN-96/82, Vienna, Austria, IAEA; 2002, p. 191-199.

[3] International Atomic Energy Agency (IAEA), “Absorbed dose determination in external beam radiotherapy. Code of practice for high energy photon beams,” TRS-398. Vienna, Austria, IAEA; 2000.

[4] A. Ahnesjö and M.M. Aspradakis, “Dose calculations for external photon beams in radiotherapy,” Phys. Med. Biol. 44 (1999) R99-R155.

[5] H. Bouchard and J. Carrier, “Reducing the frequency of linac output check: a statistical model of linac output fluctuation based on a 3 year history to evaluate new tolerances as a function of test frequency for 12 linear accelerators,” Med. Phys. 34 (2007) 2612.