*Original Article*

# Quality Assurance of External Beam Radiotherapy and Results of Participation in IAEA/WHO TLD Inter-Comparison Program for Radiotherapy Level Dosimetry at Khwaja Yunus Ali Medical College & Hospital in Bangladesh

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## Abstract

***Background:*** *The outcome of the radiotherapy is highly dependent on how precisely dose is delivered to the tumor and should not exceed±5% of the prescribed dose including all types of uncertainties involved in the treatment procedure.* ***Objectives:*** *This manuscript describes the comprehensive Quality Assurance (QA) program for two linear accelerators by ensuring Percentage Depth Dose (PDD), Quality Index (QI), Beam Flatness and Symmetry, and beam output consistency at Khwaja Yunus Ali Medical College and Hospital, Sirajganj, Bangladesh. The program is designed according to the policy of the center and by the guidelines of Bangladesh Atomic Energy Regulatory Authority.* ***Materials and Methods:*** *The adopted QA procedure at our centre included daily, weekly, monthly, and yearly checks, as well as individual treatment verifications and participation in IAEA/WHO TLD inter-comparison Program.* ***Results:*** *The results of the study showed reproducibility in all QA procedures with an average photon for monthly beam output 0.988±0.011, 0.989±0.010 and 1.005±0.006 for 4 MV, 6 MV and 15 MV respectively. The maximum variation of calibration factors of the chambers for last five years between the manufacturer values and the average calibration coefficient lies within -0.298 to 0.47% with an uncertainty of ±1.8% (k=1). The results of IAEA/WHO TLD inter-comparison program of dose measurement shows the ratio of IAEA to KYAMCH values was 1.009±0.018.* ***Conclusion:*** *The above result shows an excellent agreement of calibration coefficient of ionization chambers and dosimetry with the international standard system.*

***Keywords:*** *Radiotherapy, Quality Assurance.*

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## Introduction

Maximum control of tumors with minimum normal tissue complications depends on various factors especially on the accuracy of absorbed dose.[1] Clinical data consideration lead to generally agreed recommendations on the required accuracy in clinical dosimetry for radiotherapy procedures being given in ICRU report-24 (1976) for at least an accuracy of ±5 % in the delivery of absorbed dose to the target volume of the treated tumor.[2-3] Brahme[4] also proposed a tolerance value of accuracy in dose delivery of ±3.5 % at one standard deviation level. In radiobiology, the dose response relationship for tumor cell killing follow the sigmoidal curves at high dose which implies that the tumor control can only be achieved with a very high precision dose delivery. Quality Assurance procedures ensure a consistent and safe fulfillment of prescribed dose to the target tumor volume with minimal dose to normal tissues. A comprehensive program of quality assurance is necessarily important for accurate dose delivery to the patient in radiation therapy. The Cancer Center of Khwaja Yunus Ali Medical College and Hospital (KYAMCH) was started on the 1st April 2005 as the first private Cancer Center with outdoor facilities for treatment of cancer patients with facilities that includes two modern medical linear accelerators Elekta Synergy (4 MV, 6 MV, 15 MV photon beam) and Elekta Platform (6 MV and 15 MV Photon beam), modern and updated imaging facilities, treatment planning

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software and dosimetry software to provide 3DCRT, IMRT, IGRT and Brachytherapy for the first time in Bangladesh. A quality management system was established at KYAMCH from the beginning of operation. The Effective QA Program ensures that the machine characteristics do not vary significantly from their original values achieved at the time of acceptance and commissioning. The Specific QA protocols have been adapted from the American Association of Physicists in Medicine Task Group (AAPM TG-40), TRS-398 and Elekta recommended user checks for the LINAC (Elekta Synergy and Elekta Platform) which were commissioned at KYAMCH cancer center. Quality Assurance (QA) is the overall process which is supported by quality control activities. The purpose of the QA program is to identify and minimize the sources of uncertainties and errors, increases the probability that they will be recognized and corrected as early as possible, thereby reducing their consequence for patient treatment. This article describes the QA program, results and performance evaluation presented over years of operational period. We ensure daily, weekly, monthly and yearly QA for all radiotherapy, dosimetry and imaging equipments and patient specific QA has been done properly, precisely and sincerely with sets of sophisticated device and software. The program is designed according to the policy of the center as well and the guideline of Bangladesh Atomic Energy Regulatory Authority (BAERA). The absorbed dose to water measurement plays a very important part of the dose delivery to the patient. Hence, as a part of QA, the ionization chambers were calibrated once a year from SSDL, Bangladesh. To ensure accurate dose measurement, the best available procedure is the participation ininter-comparison program with international system. In this regard, we participated in the IAEA/WHO TLD inter-comparison program for hospital level measurement with cooperation of Secondary Standard Dosimetry Laboratory (SSDL), Bangladesh.

## Materials and Methods

The adopted QA procedure at our centre included daily, weekly, monthly, and yearly checks, as well as individual treatment verifications. The daily QA includes delivery of 100 MU per photon energy as morning LINAC warm-up with SSD of 100cm. The weekly QA includes measuring dosimetric outputs for photon and electron beams. The monthly QA involves a measurement in terms of dosimetry, mechanical/optical and safety aspects. The annual QA includes a sum of monthly QAs, beam characteristics, planned maintenance (PM), measurement instrument calibration from SSDL with all saved QA sheets. The basic QA tasks performed with their tolerances are summarized in Table I.

## Daily QA

Elekta recommends that the LINAC should be warmed up prior to daily use. To follow this, we checked our machines every morning before the treatment started. The tolerances levels for both set of lasers [sagittal, horizontal and vertical wall sides] are within ±1 mm at our center. The optical distance indicator (ODI) is also checked at SSD with a tolerance of 1 mm. The door interlocks and audiovisual monitors are also part of the daily QA. The QA procedure also checks on the mechanical system, the image-forming and image detection system, accuracy of cross wires, light/radiation field coincidence, door interlocks, optical distance indicator accuracy and emergency stop buttons.

## Weekly QA (dosimetry)

The dosimetry has been performed with dosimetric equipment (ionization chamber and electrometer) including water phantom, slab phantom, barometer and thermometer for weekly QA for both linear accelerators Elekta Platform dual energy (6MV and 15 MV) and Elekta Synergy (4MV, 6MV and 15 MV). It consists of beam and mechanical alignment test, the output of the LINAC using a calibrated chamber for 1cGy/MU (delivered dose for 100MU) is delivered to the isocenter. The dosimetry is done as per IAEA dosimetry protocol TRS-398.[5]

The absorbed dose to water measurement by TRS-398 protocol at reference point $D_{W,Q}$ ($Z_{ref,w}$) for high energy photon beam can be calculated by the Equation-1 given below;

$$D_W(Z_{ref,W}) = M_Q N_{D,W} k_{Q,Q_0}$$
$$\text{where, } M_Q = m_u \cdot k_{tp} \cdot k_{elec} \cdot k_{pol} \cdot k_s \qquad \text{(Equation: 1)}$$

Where, $m_u$be the charge rate in nC/min corrected for the ambient conditions, $k_{t,p}$ (pressure and temperature), correction factors for electrometer $k_{elec}$, ($k_{elec}$=1) if the chamber was calibrated with the same electrometer), polarity, $k_{pol}$ and $k_s$, ion recombination, $N_{D,W}$ be the calibration factor of the ionization chamber for Q_0 quality, and k_(Q,Q_0 ) is the beam quality correction factor (in case of $^{60}$Co, $k_{Q,Q0}$ =1 as the chamber is calibrated in terms of $^{60}$Co beam). The details of the ambient correction $k_{tp}$, polarity correction factor $k_{pol}$, and ion-recombinationcorrection factor (k_s) are described elsewhere .[5]

## Annual QA: Calibration of ionization chambers

The ionization chamber is calibrated from Secondary Standard Dosimetry Laboratory in terms of absorbed dose to water for $^{60}$Co radiation quality. The chamber was protected by a PMMA sleeve of 1 mm wall thickness, and is positioned in the water phantom, so that its reference point is on the central axis of the beam. The distance from the source to the reference point of the chamber is 1 m. The reference point of the chamber is placed at 5 cm inside water phantom for a field size of 10 cm X 10 cm at the reference plane. The absorbed dose to water was measured with standard ionization chamber by Equation-2 for reference condition. The chamber to be calibrated is placed at the same position with the same electrometer inside the IAEA water phantom of size 30cm X 30cm X 30cm. The chamber calibration factor ($N_{D,W}$) is then calculated by Equation -2 given below;

$$N_{D,W} = \frac{D_W(Z_{ref})}{M_Q} \text{ (Gy/C)} \qquad \text{(Equation: 2)}$$

Where $D_W$ ($Z_{ref}$) is the measured absorbed dose to water (Gy/min) at reference position by reference ionization

chamber, and $M_Q$ be the measured charge (nC/min) collected by the electrometer. The correction factor for ambient condition, polarity and ion recombination is taken in the consideration given elsewhere.[5]

### Participation in IAEA/WHO TLD inter-comparison Program

A set of three TLDs, one of them a control (capsulated LiF powder), was irradiated for 2 Gy of absorbed dose to water, measured by dosimetry system at KYAMCH. A special type of holder feasible to set with phantom size of 40 × 40 × 40 cm3 was used in this study. The irradiations were carried at a depth of 10 cm for a field size of 10 × 10 cm2 at source to surface distance (SSD) 100 cm for various photon energies from Elekta Platform and Elekta Synergy linear accelerators. The Elekta Platform has 6 MV and 15 MV whereas the Elekta Synergy has 4MV, 6 MV and 15 MV.

The dose for irradiation is fixed at 2 Gy of absorbed dose to water because this value is approximately equal to the dose to the patient at each fractionation of treatment. The deviations ? of reported and measured absorbed dose were calculated according to the formula (Equation 3) recommended by the IAEA.

$$\Delta = \frac{D_{KYAMCH} - \overline{D_{IAEA}}}{\overline{D_{IAEA}}} \qquad (Equation: 3)$$

Where, $D_{IAEA}$ is the absorbed dose measured by the TLD system of IAEA and $D_{KYAMCH}$ is the absorbed dose measured by the irradiated TLD in the present study.

## Result and Discussion

The daily QA parameters that affect patient positioning and therefore the registration of the radiation field and lasers, ODI, patient dose (output constancy) and safety (door interlock and audiovisual contact) are included. Table I describes an overview of the daily, weekly and monthly QC checks performed in accordance with these QA procedures. The details are given in Table I. From Table I, all these parameters are regularly checked and found within the acceptable limits and in good working condition. Collimator and gantry isocenters which could affect dosimetric outcome both had an average deviation of 0.1 mm from reference values. Weekly dosimetric QA checks were performed with a calibrated ionization chamber to confirm the radiation outputs for each photon energy. For monthly QA we include more refined testing of parameters which will either have a smaller impact on the patient (e.g., treatment co9auch indicators) or have lower likelihood of changing over a month (e.g., light and radiation field or beam flatness). The maximum difference between dosimetric QA values and reference values is about 1% for photon beams. This was to validate the absolute dose calibrations of megavoltage photon and electron beams using the International Atomic Energy Agency (IAEA) technical report series (TRS 398). Using Medphysto software, the flatness and symmetry of the various beams and energies were obtained using TRS-398 protocols. The results of the study showed reproducibility in all QA procedures with an average photon output 0.988±0.011, 0.989± 0.010 and 1.005±0.006 for 4 MV, 6 MV and 15 MV respectively. A typical dose consistency for 6 MV photon beams of Elekta Platform and Elekta Synergy are given in Fig.1 and Fig 2. Beam profiles for (a) 6MV photon, and (b) 15MV photon for Elekta Platform and Elekta Synergy are shown in Fig.3 and Fig 4. All the monthly and yearly beam flatness and symmetry were within set tolerance values. The daily QA3 device is used for quick daily checks and was operating within prescribed tolerances of 3%. A custom-built LAS VAGAS QA Phantom was used in analyzing the image forming and detection system. Digital images were obtained and the number of holes at every row and columns apart were evaluated using the iView software tool. Monthly analysis of all the images produced an optimum image quality. The images were also observed for distortions.

The primary important parameter of QA involves in the accuracy and reliability of absorbed dose measurement that mainly includes; (i) calibration of ionization chamber as per international recommendation. The used international protocols TRS-398 (IAEA) recommends for absorbed dose to water determination are based on the calibration factor of the ionization chamber in-terms of $N_{D,W}$ with $^{60}$Co quality. The calibration of ionization chamber in terms of absorbed dose to water ($N_{D,W}$) is conducted at reference condition (FS: 10 cm X10 cm, 5 cm depth in water phantom). The measured calibration factors are compared with the manufacturer's values which are given in Table II. The calculated combined uncertainties of Type A and Type B were within 1.8% for coverage factor of *k=1*. The percentage of deviations between measured and manufacturer's calibration coefficients $N_{D,W}$ were calculated according to the formula recommended by the IAEA. From Table II, the average variation of calibration factors of the chambers for last five years between the manufacturer values and new calibration coefficient lies within -0.34 to 0.47% with an uncertainty of ±1.8% (*k=1*). The result shows an excellent agreement of calibration coefficient of ionization chamber which have a good consistency.

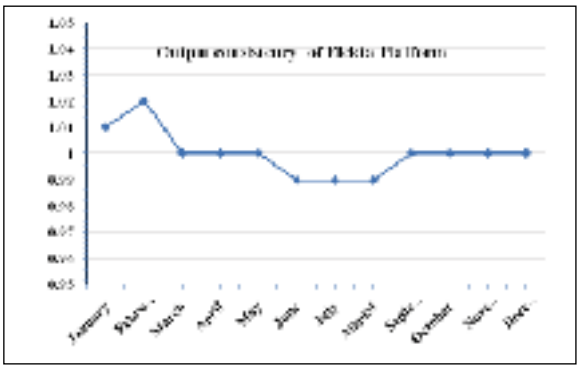


**Fig-1** Monthly output average dose consistency per MU of Elekta Platform in 2017 for 6 MV

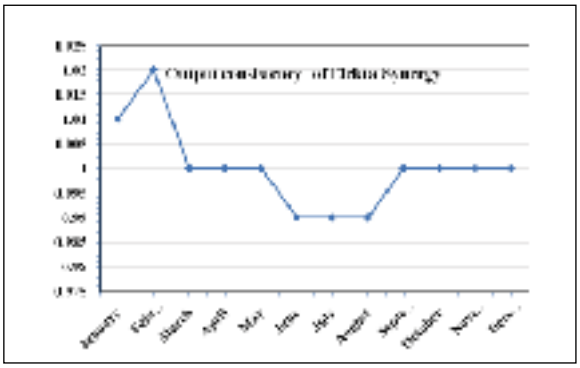
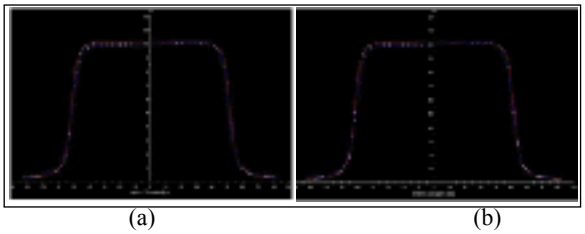
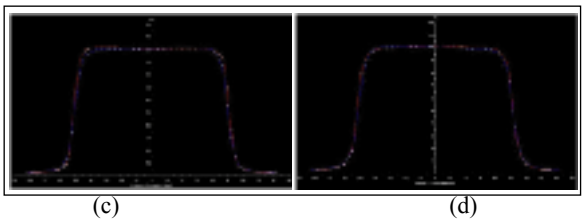


**Fig-2** Monthly output average dose consistency per MU of Elekta Synergy in 2017 for 6 MV photon beam



(a) (b)

**Fig-3** Beam profile of (a) 6 MV and (b) 15 MV photon beam of Elekta Platform Medical LINAC.



(c) (d)

**Fig-4** Beam profile of (c) 6 MV and (d) 15 MV photon beam of Elekta Synergy Medical LINAC.

The postal dose inter-comparison program organized by IAEA/WHO every alternate year, found the deviation of stated dose to measured dose for photon beams 4 MV, 6 MV (2 beams) and 15 MV (2 beams) lies between 0-3.3%with an uncertainty of ±1.8% (*k=1)* which are within limit. The results obtained by the participation in inter-comparison program are given in Table 3. The average value of dose ratios between IAEA and KYAMCH were 1.009 0.018which are in good agreement with other literature values Nisbetet al.[6] 1.002 0.012, Rassiahet al.[7] 1.027 0.031, Izewskaet al.[8] 1.007 0.037, Rahman et al.[1] 1.004 0. 043.This shows an excellent agreement of traceability of dosimetry performed by KYAMCH which has a good consistency.

**Table I:** QA tasks with tolerance and average data from our center

| Frequenc | Procedure | AAPM TG-40 Tolerance level.[9] | KYAMCH Action Level |
|---|---|---|---|
| Daily | Dosimetry | | |
| | Photo and Electron Consistency | ±3% | ±1% |
| | Mechanical | | |
| | Localization Laser | 2mm | 0.2mm |
| | Gantry & Collimator rotation with central axis | 2mm | 0.1mm |
| | Optical Distance Indicator (ODI) | 2mm | 0.1mm |
| | Safety | | |
| | Door Inter-lock | Functional | Functional |
| | Audio-Visual Monitor | Functional | Functional |
| Weekly | Dosimetry | | |
| | Photon output consistency | ±3% | 0.55% |
| | Mechanical | | |
| | Gantry Angle Isocenter | 2mm | 0.1mm |
| | Collimator Isocenter | 2mm | 0.1mm |
| | Beam /Field Size Alignment | 2mm | 0.3mm |
| | Localization Laser | 2mm | 0.2mm |
| | Safety | | |
| | Door Interlock | Functional | Functional |
| | Audio-Visual Monitor | Functional | Functional |
| Monthly | Dosimetry | | |
| | Photon and electron output constancy | ±2% | ±1% |
| | Photon and electron beams flatness constancy | ±3% | ±1% |
| | Photon and electron beams symmetry | ±3% | ±1% |
| | Mechanical | | |
| | Gantry/Collimator angle readout | 1 degree | 0.3degree |
| | Optical Distance Indicator | 2mm | 0.1mm |
| | Field Size Indicator | 2mm | 0.1mm |
| | Treatment couch position indicator | 2mm/1 degree | 0.1mm and 0degree |
| | Localizing Laser | 2mm | 0.20mm |
| | Light and Treatment Field Coincidence | 2mm | 0.5mm |
| | Imaging System QA | Optimum Quality | Optimum Quality |
| | Safety | | |
| | Emergency off Switch | Functional | Functional |
| | Door Interlock | Functional | Functional |
| | Audio/Visual Monitor | Functional | Functional |

**Table II:** Comparison of $N_{D,W}$ factors between current measurement by SSDL, Bangladesh and manufacturer values for five consecutive years for ionization chambers used for dosimetry at KYAMCH.

| Ionization Chamber | Year of Calibration | Manufacturer Values (PTB, Germany): Absorbed dose to water Calibration Factor, $N_{D,W}$ (Gy/C) | Uncertainty (k=1) | SSDL, BAEC Values Absorbed dose to Water Calibration Factor, $N_{D,W}$ (Gy/C) | Uncertainty (k=1) | Percentage of Deviation (%) |
|---|---|---|---|---|---|---|
| TW30013-04774 | 2013 | $5.408 \times 10^7$ | ±2.2% | $5.339 \times 10^7$ | ±1.8% | 1.28 |
| | 2014 | | | $5.435 \times 10^7$ | | -0.50 |
| | 2015 | | | $5.405 \times 10^7$ | | 0.06 |
| | 2017 | | | $5.325 \times 10^7$ | | 1.53 |
| | 2018 | | | $5.415 \times 10^7$ | | -0.13 |
| | Average | | | 5.384 $10^7$ | | 0.45 |
| TW31010-2211 | 2013 | $2.882 \times 10^8$ | ±2.2% | $2.825 \times 10^8$ | ±1.8% | 1.98 |
| | 2014 | | | $2.916 \times 10^8$ | | -1.18 |
| | 2015 | | | $2.861 \times 10^8$ | | 0.73 |
| | 2017 | | | $2.874 \times 10^8$ | | 0.28 |
| | 2018 | | | $2.866 \times 10^8$ | | 0.56 |
| | Average | | | 2.868 $10^8$ | | 0.47 |
| TW31010-1888 | 2013 | $3.013 \times 10^8$ | ±2.2% | $2.973 \times 10^8$ | ±1.8% | 1.33 |
| | 2014 | | | $3.082 \times 10^8$ | | -2.29 |
| | 2015 | | | $3.016 \times 10^8$ | | 0.10 |
| | 2017 | | | $3.024 \times 10^8$ | | -0.36 |
| | 2018 | | | $3.021 \times 10^8$ | | -0.27 |
| | Average | | | 3.023 $10^8$ | | -0.30 |

**Table III:** Results of participation of the IAEA/WHO TLD intercomparison program for radiotherapy level dosimetry of (KYAMCH), Sirajganj, Bangladesh.

| IAEA/WHO TLD Intercomparison program: Year of Participation | Photon Beam MV | KYAMCH Stated Dose (Gy) | IAEA Measured Dose (Gy) | % of relative to IAEA mean Dose | Ratio: IAEA mean Dose to KYAMCH Stated Dose |
|---|---|---|---|---|---|
| 2013 | 4 | 1.99 | 2.02 | -1.2 | 1.01 |
| | 6 | 1.99 | 2.05 | -2.9 | 1.03 |
| | 6 | 1.98 | 2.05 | -3.3 | 1.03 |
| | 15 | 1.98 | 2.02 | -1.9 | 1.02 |
| | 15 | 1.95 | 1.95 | 0.0 | 1.00 |
| 2015 | 4 | 2.00 | 2.05 | -2.6 | 1.03 |
| | 6 | 2.00 | 2.00 | 0.2 | 1.00 |
| | 6 | 2.00 | 2.01 | -0.7 | 1.01 |
| | 15 | 2.03 | 2.06 | -1.6 | 1.02 |
| | 15 | 2.00 | 2.04 | -1.8 | 1.02 |
| 2017 | 4 | 2.00 | 1.96 | 1.9 | 0.98 |
| | 6 | 2.00 | 1.95 | 2.3 | 0.98 |
| | 15 | 2.00 | 1.98 | 1.1 | 0.99 |
| | | Average | | | 1.009 0.018 |

# Conclusion

The QA procedures were structured to maintain the accuracy for achieve optimum treatment. For consistent performance of teletherapy unit within accepted tolerance level, Quality Assurance (QA) and Quality Control (QC) activities are highly required. This is a multidisciplinary team effort for reduction of errors and uncertainties in every step of the radiotherapy process. From this stem the need to perform stringent and regular QC checks, in terms of dose accuracy, for the Linear accelerators to deliver specific doses to the tumour. For the preparation of this manual, it was decided to rely as much as possible on well established published national and international guidelines[1] as well as the Elekta recommended checks. The beam output obtained by using actual dosimetry over the period of years when compared to expected output, shows deviation within permissible limit i.e.:±1% which reflects the accuracy and reproducibility of the treatment plans generated and the accurate delivery of dose. The traceability obtained by our participation in the IAEA/WHO inter-comparison program by TLD postal dose quality audit were found to be within the IAEA acceptance limit of ±5%.

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# References

1. Rahman MS, Kim GN, et al. TLD Postal Dose Quality Audit Inter-comparison for Megavolts Photon Beam of Radiotherapy Centres in Bangladesh. Jour. Nucl. Sci. Tech 2008;2:260-263.
2. ICRU. Determination of absorbed dose in patient irradiated by means of X or gamma rays in radiotherapy procedures, Report-24, Bethesda MD: ICRU, 1976.
3. Brahme A, Chavaudra J, Landbergetal T. Accuracy requirements and quality assurance of external beam therapy with photon and electron. Acta. Oncol.1988;1:27.
4. Brahme A. Dosimetric precision requirements in radiation therapy. Acta. Radiol. Oncol. 1984;23: 379-391.
5. International Atomic Energy Agency, Absorbed dose determination external beam radiotherapy: An international code of practice for dosimetry based on standards of absorbed dose to water. Technical Report Series No. 398, IAEA, Vienna, 2000.
6. Nisbet A, et al. A dosimetric inter-comparison of kilovoltage X-rays, megavoltage photons and electrons in the Republic of Ireland. Radiother. Oncol.1998;48:95-101.
7. Rassiahet P, et al. A thermoluminescence dosimetry postal dose inter-comparison of radiation therapy centres in Malaysia. Australian Physical & Engineering Sciences in Medicine, 2004;27:25-29.
8. Izewska J, et al. Postal dose audits for radiotherapy centres in Latin America and the Caribbean: trends in 1969-2003, Rev. Panam Salud Publica. 2006;20:161-172.
9. Kutcher GJ, Coia L, Gillin M, et al. Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40. Med Phys. 1994;21: 581-618.