Verification and evaluation of radiation-beam parameters of high-energy linear accelerator with gantry rotation

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Abstract. The radiation beam from a linear accelerator originates from the acceleration of the electrons in the accelerating structure. As the gantry rotates together with the accelerating structure, it is at different orientations with respect to the magnetic field of Earth. The deviations in the path of the electron beam due to the changes in the magnetic fields are corrected by steering coils surrounding the accelerating structure. In the present investigation, all deviations in photon and electron beam parameters of a high energy linear accelerator with gantry rotation are checked. The central axis dose is measured using a parallel-plate ionization chamber placed in the fabricated phantom via parallel-plate chamber holder. To measure the beam flatness and symmetry, a dosimetric plate designed to hold a radiosensitive film is used. The evaluation performed using the fabricated phantom confirms the accuracy of the dose delivered to patients at various gantry angles.

1. Introduction
Radiation therapy using iso-centrically mounted linear accelerators is one of the most common methods of treating malignancy. The radiation beam from a linear accelerator originates from the acceleration of the electrons in the modified circular waveguide (accelerating structure). As the gantry rotates, together with the accelerating structure, it is at different orientations with respect to the magnetic field of Earth. The deviations in the path of the electron beam due to the changes in the magnetic fields are corrected by steering coils surrounding the accelerating structure. The input to the steering coils is a calibration lookup table for the gantry angle with respect to the current, which is created during the installation of the accelerator. The outcome of the treatment depends on the accuracy with which the prescribed dose of radiation is delivered to the tumor region. The accuracy of the dose delivery depends on the mechanical accuracy of the rotating structure and other parameters such as the radiation-beam flatness, homogeneity, field width and field penumbra. Taking confidence in the mechanical stability of the installed accelerator, the present study checks the dose stability of the linear accelerator using the indigenously developed phantom [1].

2. Materials and Methods
In the present investigation all deviations in the photon and electron beam parameters of a high-energy linear accelerator with gantry rotation are checked. The phantom is fabricated using Poly methyl meth acryl ate (PMMA) with dose plates which can hold various dosimeters. The central axis dose is measured
using a parallel-plate ionization chamber placed in the fabricated phantom via a parallel-plate chamber holder [2]. The dosimetric plate and the detector that it holds can be rotated about the stand of the fabricated phantom and fixed at desired orientations in 10° intervals [3]. Figure 1 shows the schematic representation of the phantom and the measurement setup in the linear accelerator.

For the dose measurement, the phantom is positioned on the treatment table and aligned using treatment setup lasers. The parallel-plate ionization chamber (NACP02, Scanditronix) is positioned on the phantom using the parallel-plate chamber holder of the fabricated phantom. Buildup is provided over the parallel plate chamber depending on the energy used.

To verify the stability of the dose across a homogeneous radiation field at different gantry angles with respect to that at the reference gantry angle, as per the Quality Control of Medical Electron Accelerators Recommendations No. 11, 2013 [4], profiles are measured along the major beam axes at different gantry positions for all energies, and the variations in the profiles with respect to the baseline measurements at the reference gantry angle are evaluated. The suggested set-up conditions are: the maximum field size (limited by the linac or the measuring device used); source to diaphragm distance = 100 cm; d = reference depth, d_{ref} (or depth of dose maximum, d_{max} if “in air” measurements are performed); and gantry angles of 0°, 90°, 180°, and 270°. The frequency and tolerance have maximum up to 3% deviation from base-line measurements (within the flattened area) [4,5].

To correct for influences of the temperature and atmospheric pressure on the ionization-chamber reading, the temperature and atmospheric pressure are recorded throughout the experiment.

Figure 1. Schematic representation of the fabricated phantom and measurement setup in Varian Clinac 2100 CDHX Linear Accelerator (Electron Measurements)

2.1. For photon beams
A buildup of 5.6cm is used, with 6- and 18- MV photons. The machine isocenter is set at the center of the surface of the parallel-plate chamber. Dose measurements are recorded for 100 MU with a field size of 10×10 cm².

2.2. For electron beams
A 1.6 cm thick poly methyl methacrylate plate is added above the detector (buildup) for 6- and 9- MeV electrons, and a 2.6 cm thick plate is added for 12-, 16- and 20- MeV electrons, the maximum dose points specific to the linear accelerator. The machine isocenter is set at surface at the center of the chamber. Dose measurements are recorded for 100 MU at a field size of 10×10 cm², with a 10×10 electron cone mounted at gantry angles in the range of 0-360° at 20° intervals. However, the gantry angle is restricted to 100° in the clockwise direction and 260° in the counterclockwise direction for electron beams owing to the constraints of rotating the gantry with the electron cone.
2.3. Evaluation of Beam Flatness and Symmetry

To measure the beam flatness and symmetry, a dosimetric plate designed to hold a radiosensitive film is used. This plate is made of opaque PMMA and can hold an 18×18-cm² film at the center of the phantom. This loaded with the film is attached as part of the phantom. The field cross lines are matched to the reference marking on the cassette with a 0° gantry and collimator angle. The film-holder thickness is 1cm. The gantry and the phantom are rotated to the desired orientation, and the film is exposed for 250 MU. Cross line references are marked on the Gafchromic EBT2 (ISP Technologies) film using pin impressions. The exposed films are scanned using an EPSON film scanner and analyzed using the OmniPro IMRT² software [6]. This is repeated for photon energies with 90° gantry-angle intervals. The OmniPro IMRT² software supports multiple user-defined protocols for calculation of the flatness and symmetry. The International Electrotechnical Commission (IEC) protocols [7] are used to determine the flatness and symmetry as shown in equations (1) and (2) respectively [8].

\[
Flatness = 100 \times \frac{d_{\text{max}}}{d_{\text{min}}}
\]

The maximum dose \(d_{\text{max}}\) is anywhere in the radiation field and the minimum dose \(d_{\text{min}}\) is within the flattened area is defined as follows for varying field widths (FW). The region calculated over varies by FW - 2 × 1 cm if 5 ≤ FW ≤ 10; FW - 2 × (0.1 × FW) if 10 < FW ≤ 30 and FW - 2 × 3 cm if 30 < FW for main axes and FW - 2 × 2 cm if 5 ≤ FW ≤ 10; FW - 2 × (0.2 × FW) if 10 < FW ≤ 30 and FW - 2 × 6 cm if 30 < FW for diagonals.

The symmetry was determined according to the point difference quotient (IEC) method. The maximum quotient for a dose between points, equal distances from the central axis within the flattened area, is defined as follows. The region calculated over varies by FW - 2 × 1 cm if 5 ≤ FW ≤ 10; FW - 2 × (0.1 × FW) if 10 < FW ≤ 30 and FW - 2 × 3 cm if 30 < FW for main axes and FW - 2 × 2 cm if 5 ≤ FW ≤ 10; FW - 2 × (0.2 × FW) if 10 < FW ≤ 30 and FW - 2 × 6 cm if 30 < FW for diagonals. When Point L and Point R are points on the left and right side of the profile equidistant from the central axis within flattened area defined as the 80% of the field width,

\[
Symmetry = 100 \times \text{Max} \left( \frac{|\text{Point L}|}{|\text{Point R}|} \right)
\]

2.4. Gafchromic EBT2 film

A Gafchromic EBT2 dosimetry film (ISP Technologies) is used [9-11]. It is a high-spatial resolution and highly sensitive dosimetric film that can be used in the dose range of 0.01-40 Gy. The active part of the film is a single sensitive layer approximately 30μm thick with a thin topcoat made on a clear 175μm thick polyester substrate. The active layer is coated with a polyester layer (50 μm thick) and a pressure-sensitive adhesive layer 25μm thick. The film is a near-tissue equivalent with effective atomic no. \(Z_{\text{eff}}\) = 6.84. The un-irradiated EBT2 film has a yellow color, and the irradiated film undergoes polymerization, becoming greenish in color. It exhibits real-time density changes that stabilize rapidly after exposure.

2.5. Scanner

An EPSON Dual Lens Perfection V700 desktop scanner is used for scanning the EBT2 films [12]. This scanner is equipped with a white cold cathode fluorescent lamp and is capable of scanning in the transmission and reflection modes. Films are scanned using the EPSON software in the “professional mode.” A scan resolution of 300 dots per inch (dpi) and 16-bit gray scale are used. A preview is performed before each scan in order to define the area to scan. The scanned images obtained with the aforementioned settings are saved as TIFF image files.
3. Results

3.1. Measurements with photons

Figure 2 shows the photon dose normalized to a 0° gantry angle. The measured readings for photons with different gantry orientations indicate that the beams deliver stable readings for all gantry angles.

![Figure 2. Dose to d_{max} normalized to a 0° gantry angle for photon measurements](image)

The dose at d_{max} for 6- MV photon beam with different gantry angles varies from 0.9964 to 1.002. For 18- MV photons, it varies from 0.9973 to 1.001. Here, the dose is normalized to a 0° gantry angle.

3.2. Measurements with electrons

Figure 3 shows the electron dose normalized to a 0° gantry angle. The measured readings for electrons with different gantry orientations indicate that the beams deliver stable readings for all gantry angles.

![Figure 3. Dose to z_{max} normalized to a 0° gantry angle for electron measurements](image)

For 6-, 9-, 12-, 16-, and 20- MeV electron beams, the dose at depth of maximum dose z_{max} varies from 0.9873 to 1, 0.9851 to 1, 0.9936 to 1.010, 0.990 to 1.004, and 0.9737 to 1.004 respectively. The dose is normalized to a 0° gantry angle.

3.3. Flatness and Symmetry
The variations in the flatness and symmetry of the incident photon beams are checked using Gafchromic EBT2 films for a 10×10 cm² field size at a 5 cm depth for both 6- and 18- MV photons. The exposed films at various gantry angles are scanned using a 16- bit gray scale- resolution (300 dpi) EPSON scanner. The films are scanned in the transmission mode, and the images are saved as TIFF files. The TIFF images are transferred to the Omnipro IMRT software for analysis. The films are aligned according to the pin impression on them, which represent the field axis. The symmetry and flatness of the field are measured in both the X- and Y- axis directions in various regions of the field using the software. Figure 4 shows the film analysis. The symmetry and flatness for each gantry angle are normalized to a gantry angle of 0°.

![Figure 4. Omnipro software used for film analysis to measure the beam flatness and symmetry](image)

The flatness and symmetry measured using a radiation field analyzer (RFA) for a 6-MV photon beam with 10×10- cm² field size at the depth of d_max are 101% and 100.9%, respectively, and those for 18-MV photons are 100.9% and 101.4%, respectively. The flatness and symmetry with the film at the depth of d-max for 6-MV photons are 101.46% and 100.83%, respectively, and that for 18-MV photons are 100.95% and 101.46%, respectively.

4. Discussion
The observed mean dose variation; mean(standard deviation) at d_max for different gantry angles normalized to a 0° gantry angle for a 6-MV photon beam is 0.9992(0.002), and that for an 18-MV photon beam is 0.9986(0.002). The observed mean dose variation at z_max for different gantry angles normalized to a 0°gantry angle for 6-, 9-, 12-, 16-, and 20-MeV electrons is 0.9922(0.004), 0.9906(0.005), 1.003(0.005), 0.9985(0.004), and 0.9976(0.004) respectively. The variations found are within 3%. The standard deviation in measurements with 6 and 18-MV photons is 0.002 and the maximum standard deviation observed in measurements with electrons is 0.005.

The film analysis shows that the symmetry and flatness for different gantry angles at a depth of 5 cm are within acceptable limits for both 6- and 18- MV photon beams. The evaluation performed using the fabricated phantom confirms the accuracy of the dose delivered to the patients at various gantry angles.
References
[1] ICRU 1989 Tissue substitutes in radiation dosimetry and measurement. Bethesda, MD.
[2] Saju B, Santhosh V S, Babu B R S, Raghukumar P, RaghuRam K N, Divya K T, et al. 2007 Design and Fabrication of Dosimetric Phantom for Radiotherapy Conf. of Indian Society of Radiation Physics and the Saha Institute of Nuclear Physics, (Kolkata)
[3] Saju B 2008 Design and development of devices for radiation dosimetry [Ph. D Thesis] Kerala: University of Calicut.
[4] Swiss Society of Radiobiology and Medical Physics 2013 Quality Control of Medical Electron Accelerators Recommendations No. 11.
[5] Technical Report Series. 2000 Absorbed Dose Determination In External Beam Radiotherapy: An International Code of Practice For Dosimetry. TRS 398. VIENNA, IAEA.
[6] OmniPro- IMRT software (V 1.5) Treatment verification for IMRT, IGRT and rotational therapy; Iba Dosimetric Systems, Germany.
[7] International Electro-technical Commission 2007 IEC 60976, Edition 2, IEC, Geneva.
[8] Eclipse treatment planning systems manual. Varian Medical Systems, Palo Alto, CA, USA.
[9] Zeidan O A, Stephenson S A L, Meeks S L, Wagner T H, Willoughby T R, Kupelian P A, et al. 2006 Med. Phys. 33:4064-72
[10] Huet C, Dagois S, Derreumaux S, Trompier F, Chenaf C, Robbed I. 2012 Radiation Measurements 47. 40-49.
[11] Arjomandy B, Tailor R, Anand A, Sahoo N, Gillin M, Prado K, et al. 2010 Med.Phys. 37:5.
[12] Devic S, Seuntjejens J, Sahm E, Podogorsak E B, Schmidttein C R, Kirov A S, et al. 2005 Med. Phys. 32. 2245-53.