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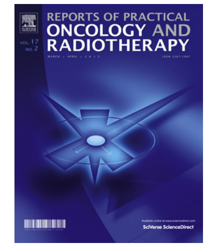

Original research article

Analysis of physical parameters and determination of inflection point for Flattening Filter Free beams in medical linear accelerator

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ABSTRACT

Background: Medical Linear accelerators manufactured without flattening filters are increasing popular in recent days. The removal of flattening filter results in increased dose rate, reduced mean energy, reduction in head leakage and lateral scattering, which have shown advantageous when used for special treatment procedures.
Aim: This study aims to analyze physical parameters of FFF beams and to determine the inflection point for standardizing the beam flatness and penumbra.
Materials and methods: The beam profiles and depth dose patterns were measured using Radiation Field Analyzer (RFA) with 0.13 cc cylindrical ion chamber. The beam energy characteristics, head scatter factor (Sc) were obtained for 6FFF and 10FFF beams and compared with 6 MV and 10 MV photons, respectively. The symmetry and stability of unflattened regions were also analyzed. In addition, the study proposes a simple physical concept for obtaining inflection point for FFF beams and results were compared using the Akima spline interpolation method. The inflection point was used to determine the field size and penumbra of FFF beams.
Results: The Sc varied from 0.922 to 1.044 for 6FFF and from 0.913 to 1.044 for 10FFF with field sizes from 3 cm × 3 cm to 40 cm × 40 cm which is much less than FF beams. The obtained value of field size and penumbra for both simple physical concept and Akima spline interpolation methods is within the ±1.0 mm for the field size and ±2 mm penumbra. The results indicate that FFF beams reduce Sc compared with FF beams due to the absence of a flattening filter.
Conclusion: The proposed simple method to find field size and penumbra using inflection point can be accepted as it is closely approximated to mathematical results. Stability of these parameters was ascertained by repeated measurements and the study indicates good stability for FFF beam similar to that of FF beams.

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1. Background

Low LET photon irradiation with linear accelerators has become a standard of care in the management of cancers at various sites. Conventionally, the useful radiation beam passes through a beam homogenization filter or beam flattening filter (FF) resulting in a flat beam profile. It is introduced into the path of the beam to reduce excess radiation intensity of bremsstrahlung radiations originating from the transmission target.[1,2]

In the recent past, linear accelerators have been manufactured without flattening filters as additional option known as Flattening Filter Free (FFF) beams. The removal of a flattening filter results in increased dose rate, reduced mean energy, reduction in head leakage and lateral scattering, which have all shown advantageous in special treatment procedures.[3] Different vendors have different target and beam transport designs to suit the need of customers. The beam profiles generated from these linacs vary in output pattern. The different types of variation in physical parameters encountered are variable intensity profiles, variable energy profiles, change in output factors and change in depth doses relating to their differences in collimator settings. When a flattening filter is removed and the beam becomes an FFF beam, then there are no beam hardening effects. The virgin bremsstrahlung beam has slightly reduced the central axis percentage depth dose (CADD) pattern, which is again field size dependent. Georg et al.[5] in their review brought out the pattern of spectra for FF and FFF X-ray beams, indicating two effects – (1) increase in photon energy fluence for FFF beams associated with increased dose/pulse and (2) off axis spectra are not much different from that of the central axis for the FFF beam in contrast to a significant shift in spectrum due to the introduction of the flattening filter. Intensity of the FFF beam is analyzed by measuring intensity patterns available from different linear accelerators with respect to nominal field sizes and inhomogeneity patterns. The theoretical estimates of beam intensity patterns have been reported in the literature.[4–6] Kragl et al. have investigated the effect of surface dose.[7] According to their study, for field sizes smaller than 15 cm^2, surface doses at d_{max} increase for unflattened beams with maximum differences of 7% for 6 MV and 25% for 10 MV. For a 30 cm × 30 cm field, surface dose decreased by about 10% for FFF beams. As the diverging beam gets collimated by primary, secondary and tertiary collimators, they project an entrance field outline on the skin of the patient, defined as a radiation field size. In determining the penumbral widths of unflattened beams, the concept of spatial distance between 80% and 20% dose values used for conventional beams is no longer valid.[8] To overcome this problem, Ponisch et al.[4] introduced a normalization method that allows the calculation of the penumbra of an unflattened beam as well as a direct comparison with those of flattened profiles. More specifically, unflattened beam profiles were rescaled according to the ratio of the dose values at the inflection points in the penumbral region. FFF beams are commonly used to treat many malignancies including reirradiation.[9]

2. Aim

The earlier studies have not determined field size and stability of physical parameters of FFF beams. To acquire this knowledge, we studied the properties of flattened and unflattened beams of 6 and 10FFF photon fields, and a simple physical concept for obtaining inflection point (IP) for FFF beams is proposed. The results were compared using the Akima spline interpolation method. The obtained results of inflection point were then used to determine the field size and penumbra of FFF beams.

3. Materials and methods

The installed linear accelerator (True Beam^{TM} from Varian Inc., USA) has (a) flattening filter (FF) beam photon energies of 6, 10, and 15 MV, (b) FFF photon energies of 6 and 10FFF MV, and (c) 7 electron energies of 4, 6, 9, 12, 15, 18, and 22 MeV. The beam profiles and depth dose patterns were measured using a Radiation Field Analyzer (RFA) from IBA, Germany with 0.13 cc cylindrical ion chamber for both reference and filed measurements. For the determination of symmetry, stability of the beam, field size and penumbra, dose profiles were scanned for a field size (FS) of 20 cm × 20 cm, 10 cm depth and Source to Chamber Distance (SCD) 100 cm.

4. Beam energy characteristics

4.1. *Quality index*

The purpose of measuring the quality index is to ensure that radiation energy has not changed significantly. By measuring the tissue–phantom ratio (TPR), it is possible to assess the photon beam quality. Three exposures (100 MU each) are made with gantry angle 0°, Source to Axis Distance (SAD) 100 cm and FS 10 cm × 10 cm using a calibrated 0.6 cc ionization chamber positioned at the isocenter at depths of 10 and 20 cm in a water phantom. The ionization ratio at the depth of 20 cm to that of 10 cm is known as quality index. The quality index is dependent on beam energy and it increases linearly with photon beam energy. The measurement was done for both FF and FFF photons (6 and 10 MV).

4.2. *Percentage depth dose at 10 cm*

The percentage depth dose value at 10 cm in a 10 cm × 10 cm photon beam with a Source to Skin Distance (SSD) of 100 cm, $\%DD_{10}$ is considered as a beam quality indicator and is endorsed in absolute dose measurement in AAPM TG51 protocol. In this study, we analyzed %DD(10) for both FF and FFF of 6 and 10 MV photon beams using 0.6 cc cylindrical chamber.

4.3. *Depth of dose maximum (d_{max})*

Depth of dose maximum (d_{max}) depends on the beam energy and beam field size. Nominal values for d_{max} ranges from 0 to 5 cm (orthovoltage X-ray beams to 25 MV photon beams) were