Unflattened photon beams from the standard flattening filter free accelerators for radiotherapy: Advantages, limitations and challenges

Medical electron linear accelerators (linacs) are the most commonly used beam delivery devices for radiation therapy of varieties of cancer cases. For high energy photon beam therapy, three different types of medical linacs, namely standard linac (C-arm linacs of Elekta, Siemens, and Varian), helical linac (Hi-Art Tomotherapy), and robotic linac (Accuray Cyber knife) are used in clinics. A large number of standard linacs are used worldwide and their number is increasing rapidly in radiation beam management of increasing cancer cases. A standard linac uses a flattening filter (FF) in photon mode operation while helical and robotic linacs do not have flattening filters. The FF in a standard linac is located between the primary collimator and the monitor chamber and its main role is to make the photon beam dose distribution uniform at reference depth within the allowed variations. The flat dose profiles with a homogenous dose variation across the beam provide the ease in patient dose calculation during treatment planning. The FF is made up of high Z materials and is usually conical in shape to flatten the forward peaked bremsstrahlung spectrum of megavoltage photons. The presence of the FF in the linac substantially reduces the photon beam dose rate and is also thought to be the major source of head scattered photons which causes the variation of in-air output with field size and the exchange effect of secondary collimators. The characteristics of photon beams from FF linac with jaw collimators and multileaf collimators (MLCs) have comprehensively been studied in the last five decades and all the aspects related to its clinical applications have been standardized.

The advent of advanced beam therapy techniques, such as stereotactic radiosurgery/radiotherapy (SRS/SRT) where inhomogeneous dose distributions are applied and intensity-modulated radiotherapy (IMRT) where varying fluence pattern across the beam are delivered, have stimulated the increasing interest in operating standard linac in a flattening filter free (FFF) mode.[1] A standard linac can therefore be used for generating photon beams either with flattening filter (FF beam) or without flattening filter (FFF beam). A number of Monte Carlo and experimental studies dealing with characteristics, dosimetric aspects, and radiation protection issues of FFF photon beams generated by mechanically removing the flattening filter of existing standard linacs of different makes and models have been reported in the recent past.[2-15] Studies related to treatment planning and dose delivery of various clinical cases using FFF beams demonstrate their clinical suitability and superiority over FF photon beams. A review of the properties of FFF photon beams summarizing the findings of different investigators has also been published recently.[1] Very recently, Hrbacek *et al.*[16] reported the measured dosimetric characteristics of unflattened photon beams generated by a new model of a standard linac (TrueBeam STx, Varian Medical Systems) capable of generating both flattened and unflattened clinical photon beams.

It is well known that the flattening filter in a standard linac acts as an attenuator, the beam hardener and the scatterer. Obviously, the removal of the FF results in an increase in dose rate, softening of the x-ray spectra, reduction in head scattered radiation, and the nonuniform beam profile. The reported dose rate of FFF beams is about 2 - 4 times higher than that of the FF beams, i.e., FFF linac can typically be operated at a dose rate higher than 10 Gy/min under the normal operating conditions applied for FF linac. The increased dose rate decreases the dose delivery time, especially for hypofractionated SRT, and is thought to be useful in managing the intrafractional target motion. The softening of the x-ray spectra affects the depth as well as lateral dose distribution at all depths and results in increased surface dose and slight shifting of the depth of maximum dose toward the surface. The lateral transport is reduced, which may result in greater control over gradients with the field and at target boundaries. The head scatter variation for an unflattened beam is typically about 1.5% as against about 8% of the flattened beam for the field sizes in the range of 3×3 to 40×40 cm^2. As a result a simple model for dose calculation of irregular treatment fields would be sufficient for the FFF beam. Moreover, due to the absence of the collimator exchange effect, it would not be necessary to account whether the upper or lower secondary

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collimator is defining the long side of the rectangular beam. The decreased head scatter and hence the reduced head leakage also results in decreased far field peripheral dose (PD) to the patient. The near field PD is also less due to the combined effects of softer photon beam spectra, increased dose per pulse, and reduced collimator transmission.

The magnitude of contaminating electrons of FFF beam is relatively small and as a consequence the depth of dose maximum shows weak dependence on field size variation. Lateral dose profiles of FFF beam differ significantly from the FF beam. The central peak in the lateral profiles of FFF beam is pronounced only for medium to large field sizes. The higher the energy the more pronounced is the central peak. The shape of the lateral beam profile of a FFF beam changes slightly with depth due to a significantly reduced off-axis softening effect and hence the depth--dose characteristic remains almost constant across the field even for large field sizes.

The photo-neutron fluence per monitor unit (MU) produced by the high-energy FFF beam is relatively less in comparison to that produced by the FF beam. The dose-normalized neutron fluence reduction is even greater for the real treatment plans (e.g., IMRT for prostate) because of higher dose per MU in the FFF beam. Hence, operating the accelerator in the FFF mode will benefit both the patient and the radiation therapy technologist. However, the benefit of decreased neutron dose for FFF beams at high x-ray energies (15, 18 MV) needs to be critically examined giving due consideration to their clinical use over low X-ray energies (6, 8 MV). Due to reduced average energy, treatment head leakage, and fractional neutron dose, the concrete thickness required for the FFF linac vault is also relatively less. Thus, the existing linac vault can safely be used for operating FFF linac at reduced occupational exposure and while constructing a new shielded vault there will be saving of space and cost.

In addition, the phosphor screen of the electronic portal imaging device (EPID) shows increased sensitivity to low energy photons present in the spectra of the FFF beam.[17] It was also reported that the EPID-measured profile changes minimally with increasing phantom thickness due to small energy variation across the profile. Portal dosimetry using existing EPID of standard linac is therefore a possible option for patient-specific quality assurance in the FFF beam.

While treating the patients by SRT and stereotactic body radiotherapy (SBRT) with a 6 MV FFF beam, the integral dose to nearby healthy tissue and the whole-body integral dose respectively were found significantly higher than the FF beam and the use of higher FFF beam energy was suggested as the remedy of the problem (e.g., using 8 MV instead of 6 MV).[1] This is due to the fact that 8 MV unflattened depth dose characteristics are similar to those for a 6 MV flattened beam. The use of a FFF beam over a FF beam is a natural choice for IMRT treatments. However, leaf travel time for creating a large number of optimized segments for static IMRT and the leaf speed for the dynamic and rotational IMRT are the limiting factors in dose delivery efficiency by IMRT. Hence, for effective and efficient use of the FFF beam, the technology of current MLC needs to be modified. Further, the intensity of the FFF beam abruptly decreases with the off-axis distance for large open fields ($\geq 10 \times 10$ cm^2) which necessitates the off-axis distance-dependent modulation for delivering uniform dose to the tumor. While executing the off-axis distance-dependent modulation by dynamic MLC larger monitor units are required which increase the gross head leakage and lessen the advantage of using the FFF beam. This effect is significant in dynamic IMRT of off-axis targets and large volume targets and while dealing with such clinical cases a modified FFF beam is required.

The current dosimetry protocols which are followed for output measurement of photon beams from medical linac requires a beam quality correction factor. This beam quality correction factor is related to the quality index [%DD(10) or TPR_{10}^{20}] of the photon beam. As the reference conditions for measuring the quality index of the photon beam is given with reference to the FF beam it cannot be directly applied for the FFF beam. There is a need to revise the existing dosimetry protocols for the FFF beam. The conventional definition of beam penumbra is not applicable to the FFF beam requiring a modification in the definition. The primary electrons have been reported to penetrate through the high Z thin targets used for generating bremsstrahlung photons posing a potential risk for producing high surface doses if not removed. In the case of FF linac, the electrons penetrating through the thin bremsstrahlung targets are efficiently removed by the FF. In a FFF linac, an additional thin metal plate in front of the monitor chamber is used to remove the primary electrons penetrating through the bremsstrahlung target. The material and the thickness of this plate need to be optimized maintaining the advantage of the FFF beam and giving due consideration to the incidence of bremsstrahlung target breaks.

In summary, although there are a number of advantages of using a FFF beam especially for advanced radiotherapy techniques there are a few limitations (e.g., using relatively higher energy photon beam for SRT, limited speed of current MLCs, and off-axis distance-dependent modulation in IMRT) and challenges (e.g., criteria for beam quality evaluation and penumbra, establishment of dosimetry methods, and consequences of photon target burn-up) which need to be addressed for establishing this beam as an alternate to the FF beam.

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References

1. Georg D, Knoos T, McClean B. Current status and future perspective of flattening filter free photon beams. Med Phys 2011;38:1280-93.
2. Vassiliev ON, Titt U, Kry SF, Ponisch F, Gillin MT, Mohan R. Monte Carlo study of photon fields from a flattening filter-free clinical accelerator. Med Phys 2006;33:820-7.
3. Ponisch F, Titt U, Vassiliev ON, Kry SF, Mohan R. Properties of unflattened photon beams shaped by a multileaf collimator. Med Phys 2006;33:1738-46.
4. Cashmore J. The characterization of unflattened photon beams from a 6 MV linear accelerator. Phys Med Biol 2008;53:1933-46.
5. Parsai EI, Pearson D, Kvale T. Consequences of removing the flattening filter from LINACs in generating high dose rate photon beams for clinical applications: A Monte Carlo study verified by measurement. Nucl Instrum Methods Phys Res B 2007;261:755-9.
6. Kragl G, Wetterstedt S, Knausl B, Lind M, McCavana P, Knoos T, *et al*. Dosimetric characteristics of 6 and 10 MV unflattened photon beams. Radiother Oncol 2009;93:141-6.
7. Dalaryd M, Kragl G, Ceberg C, Georg D, McClean B, Wetterstedt S, *et al*. A Monte Carlo study of a flattening filter-free linear accelerator verified with measurements. Phys Med Biol 2010;55:7333-44.
8. Titt U, Vassiliev ON, Ponisch F, Kry SF, Mohan R. Monte Carlo study of backscatter in a flattening filter free clinical accelerator. Med Phys 2006;33:3270-3.
9. Georg D, Kragl G, Wetterstedt S, McCavana P, McClean B, Knoos T. Photon beam quality variations of a flattening filter free linear accelerator. Med Phys 2010;37:49-53.
10. Kry SF, Howell RM, Titt U, Salehpour M, Mohan R, Vassiliev ON. Energy spectra, sources, and shielding considerations for neutrons generated by a flattening filter-free Clinac. Med Phys 2008;35:1906-11.
11. Sawkey DL, Faddegon BA. Determination of electron energy, spectral width, and beam divergence at the exit window for clinical megavoltage x-ray beams. Med Phys 2009;36:698-707.
12. Kry SF, Titt U, Ponisch F, Vassiliev ON, Salehpour M, Gillin M, *et al*. Reduced neutron production through use of a flattening-filter-free accelerator. Int J Radiat Oncol Biol Phys 2007;68:1260-4.
13. Kry SF, Howell RM, Polf J, Mohan R, Vassiliev ON. Treatment vault shielding for a flattening filter-free medical linear accelerator. Phys Med Biol 2009;54:1265-73.
14. Vassiliev ON, Titt U, Kry SF, Mohan R, Gillin MT. Radiation safety survey on a flattening filter-free medical accelerator. Radiat Prot Dosimetry 2007;124:187-90.
15. Tsechanski A, Krutman Y, Faermann S. On the existence of low-energy photons (<150 keV) in the unflattened x-ray beam from an ordinary radiotherapeutic target in a medical linear accelerator. Phys Med Biol 2005;50:5629-39.
16. Hrbacek J, Lang S, Klock S. Commissioning of photon beams of a flattening filter-free linear accelerator and the accuracy of beam modeling using an anisotropic analytical algorithm. Int J Radiat Oncol Biol Phys 2011. doi:10.1016/j.ijrobp.2011;80:1228-37.
17. Tyner E, McClean B, McCavana P, Wetterstedt S. Experimental investigation of the response of an a-Si EPID to an unflattened photon beam from an Elekta Precise linear accelerator. Med Phys 2009;36:1318-29.

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