IS ATTENUATION TECHNIQUE SENSITIVE ENOUGH TO BE USED TO MAKE A DISTINCTION BETWEEN FLATTENING FILTER AND FLATTENING FILTER FREE SPECTRUM OF A THERAPY LINAC

by

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The purpose of this study was to check if attenuation analysis is sensitive enough to make a distinction between photon energy spectra of standard accelerators and accelerators operating without a field flattening filter. Attenuation measurements were performed in two operating modes of a medical linear accelerator: with a flattening filter and without it, at nominal energy of 6 MV. Numerical and Laplace transform pair methods were used for spectra reconstruction. Although the difference between two attenuation curves is very small, as expected both reconstruction techniques produce slightly softer spectra at flattening filter free mode. The most important conclusion of this pilot study is that attenuation analysis can be a sensitive tool which is able to detect spectral differences between photon beams of an accelerator operating in two regimes.

Key words: photon spectrum, attenuation analysis, flattening filter, flattening filter free

INTRODUCTION

The knowledge of bremsstrahlung spectra of medical linear accelerators can be of great importance. Direct (in beam) measurement of the photon spectra of medical linear accelerators with NaI(Tl) or HpGe is not possible mostly due to high intensities of photon beams and difficulties in determining detector efficiency in high energy regions. Therefore, several indirect methods were developed to determine the photon spectra: attenuation analysis [1-8], Compton spectroscopy [9-11], photoactivation analysis [3, 4], spectral unfolding from depth-dose measurement [12] and Monte Carlo simulation [13]. Most of the developed indirect techniques are quite complicated to be routinely performed in clinical environment and they also have some disadvantages. Attenuation analysis is the most practical method among the aforementioned methods, since it employs standard dosimetry equipment available in most radiotherapy departments (plus some additional attenuators). In this method, the dose is measured after the beam passes through different thicknesses of a chosen attenuator. The energy spectra of therapy beam can be reconstructed by using the obtained attenuation curve.

The photon beam that does not pass through the flattening filter has different dosimetric characteristics. The intensity of the dose is higher due to the lack of absorption and the field profile is not homogeneous, as could be expected. However, a difference in the spectra of filtered and unfiltered beams can have an impact on dosimetric properties. Attenuation analysis can be used to determine the spectrum of the flattening filter free (FFF) photon beam due to its simplicity and convenience.

The subject of this paper is to check if attenuation analysis is sensitive enough to make a distinction between photon energy spectra of standard accelerators and accelerators operating without field flattening filters recently introduced into medical practice. Therefore, attenuation measurements were performed in two operating modes of a medical linear accelerator: with a flattening filter (FF) and without it. Two different reconstruction techniques were used to check

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whether small differences in the attenuation curve can reveal differences between FF and FFF spectra.

MATERIALS AND METHODS

Therapy beam contains photons in the energy range from zero to E_{max}, which corresponds to the incident energy of electrons that hit the target. When the beam passes through attenuators having different thickness denoted as x, the relative dose transmission can be calculated as follows

$$T(x) \quad \frac{1}{D_0} \quad \overset{E_{max}}{\underset{0}{}} R(E)\mu_{air}(E)E \;\; \Phi(E)e^{\;\mu_A(E)x}\mathrm{d}E \qquad (1)$$

where $R(E)$ is the response function of ionisation chamber, $\mu_{air}(E)$ – the mass energy absorption coefficient of air, $\Phi(E)$ – the photon fluence, and $\mu_A(E)$ – is the attenuation coefficient of the absorber material. D_0 denotes dose rate measured in air

$$D_0 \quad \overset{E_{max}}{\underset{0}{}} R(E)\mu_{air}(E)E\Phi(E)\,\mathrm{d}E \qquad (2)$$

The obtained relative transmission curve $T(x)$ was used to reconstruct $\Phi(E)$. Two different methods were used:

– The numerical method, where the photon spectra $\Phi(E)$ can be represented by Schiff function $F_S(E)$ [14] multiplied by a correction function F_c of seven variables. The following form of the correction function was determined to be good enough for this pilot study

$$F_c(E) \quad u\mathrm{e}^{\;t \;\; \frac{a}{E^n} \;\; \frac{b}{E^k} \;\; c} \qquad (3)$$

where a, b, c, n, k, t, u are parameters that have to be determined by attenuation analysis. This function is robust enough to describe all attenuation effects of the emitted bremsstrahlung: in the target itself and in the filters used to tailor beam properties according to therapy requirements in both modes of accelerator operation FF and FFF. A detailed description of this method is given in Krmar *et al*. [3]

– The Laplace transform pairs. It has been determined before [5-8] that the relative transmission curve $T(x)$ and photon spectra $\Phi(E)$ can be presented as Laplace transform pairs by applying proper mathematical transformations. This also allows the transformation of the transmission function obtained by attenuation measurements in photon spectra as follows

$$\Phi_E \quad \frac{1}{ER(E)\mu_A(E)} \quad \frac{\mathrm{d}\mu_A(E)}{\mathrm{d}E} \; \mathcal{L}^{\;1}[T(x)] \qquad (4)$$

where E is the photon energy and $\mathcal{L}^{-1}[T(x)]$ – the inverse Laplace transform of the function describing the obtained transmission data. Relative transmission curve was approximated by the following function

$$T(x) \quad \frac{a}{(x \quad b)^c}\mathrm{e}^{\;dx} \qquad (5)$$

where x is the attenuator thickness and a, b, c, d are parameters. This function, slightly simplified in comparison with the one described by Archer and Wagner [5], was a good choice to describe the attenuation curve for the used maximum photon energy.

Attenuation measurements were performed at the Institute for Pulmonary Diseases of Vojvodina, Sremska Kamenica, Serbia. Elekta Versa HD linear accelerator was used in the measurements. All measurements were performed by using 6 MV photon beam. Two sets of measurements were performed: one in the standard FF mode operation and the other in FFF regime of irradiation. The experimental set-up is presented in fig. 1.

Plates made of electrolytic Cu (density 8.920 gcm^{-3}) were used in the measurements. The maximum thickness of attenuator plates was 4.8 cm. The field size was 2 cm   2 cm at 100 cm and the delivered photon dose was exactly 500 MU. Since Elekta Versa HD operating at 6 MV in FF mode delivers 6 Gy min^{-1} (600 MU min^{-1}) (Elekta Versa HD automatic dose rate) and in FFF mode it delivers 14 Gy min^{-1} (1400 MU min^{-1}), the measuring time in FF mode was 0.8 min and in FFF mode 0.35 min.

The dose was measured with IBA Dosimetry CC-04 (S/N 14152 CC04) ionization chamber and IBA Dose 1 electrometer. Nickel-Silver build-up cap with 13.6 mm diameter was used for all the measure-

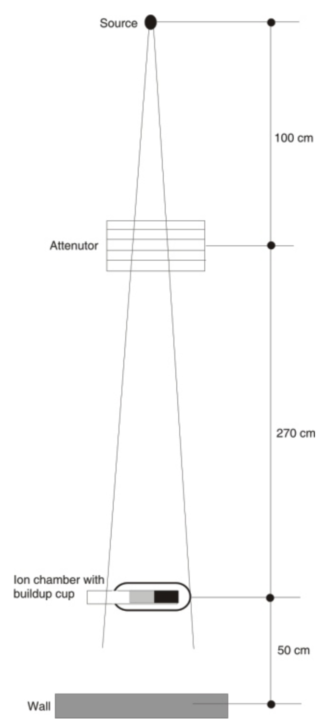

Figure 1. Experimental set-up of attenuation measurements

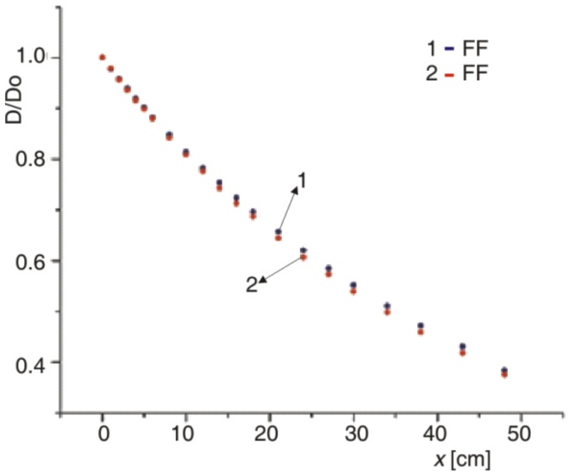

Figure 2. Relative transmitted data through Cu

ments. For each attenuator thickness three measurements were made and the mean value was used. By out of beam dose measurement it was determined that radiation scattered from the wall contributes less than 2 % to the total dose. The uncertainty of measurements was 1.5 % when calculated according to IAEA guidelines. Unfortunately the error bars are not visible in fig. 2. The scatter of measured doses did not exceed the IAEA estimation. It was assumed that the energy response of the dosimetry system is uniform. In that case the unfolded quantity is the product $R(E)\Phi(E)$ [3]. However, considering that the objective of this paper is to check if attenuation analysis is sensitive enough to differentiate between FF and FFF modes, this approximation was acceptable.

RESULTS AND DISCUSSION

Relative transmission data is presented in fig. 2. Evidently the difference between the two curves is very small.

Figure 3(a) shows the normalized photon spectra reconstructed by numerical technique and the results obtained by Laplace pair technique are shown in fig. 3(b). By using PDD* technique in water it has already been measured that energy spectra in FFF mode should be slightly softer [14, 15]. As it can be seen in figs. 3(a) and 3(b) both methods produce slightly softer spectra at FFF mode as it was expected, but the difference is very small.

If we compare the results of both reconstruction methods shown in figs. 3(a) and 3(b), it can be seen that photon spectra obtained by these two different methods differ significantly. The shape of the spectra obtained by Laplace transform pairs depends on the function chosen to fit the transmission data [6]. This means that if some other choice of the function was made, the difference between the two methods might have been smaller. However, it is more important that both methods showed similar trends if FF and FFF spectra were compared. It can be seen in both figures that FF and FFF spectra are similar at high energies and that a certain difference arose at lower energies. In both cases the energy spectrum has slightly more abundant low-energy part for FFF mode of operation. This could be expected due to the absence of FFF results in the presence of low-energy component which is usually removed by filtration in flattening filters. Instead of a detailed analysis of the impact of a measurement error on the results obtained, a simple test was performed. The calculation procedures were repeated with a set of data where each value was first increased for the estimated measurement error and then decreased. This operation did not have any impact on the general trend shown in fig. 3.

CONCLUSION

The most important conclusion of this experiment is that attenuation analysis can be a sensitive tool which is able to detect spectral differences between photon beams of an accelerator operating in two regimes: with a flattening filter and without it. The transmission curves obtained by measurements when using Cu

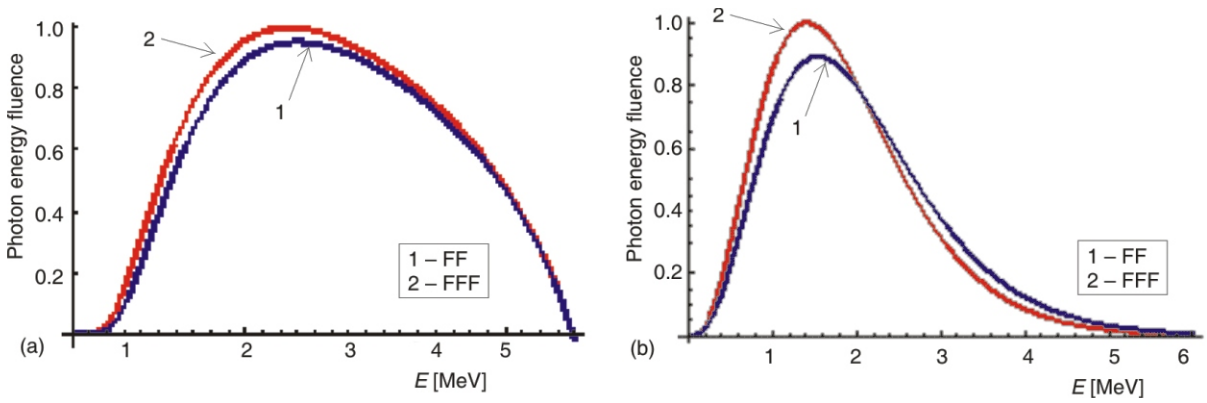

Figure 3. Normalized photon energy spectra reconstructed by (a) numerical technuque and (b) Laplace pair technique

* PDD means percentage depth dose defined as the quotient, expressed as a percentage, of the absorbed dose at any depth, *d*, to the absorbed dose at a fixed reference depth, d_0, along the central axis of the beam

attenuators in simple narrow geometry of FF and FFF beams do not differ significantly. However, even these small differences can make visible distinctions in photon energy spectra. Many factors that influence spectral reconstruction from transmission data were analyzed [1, 2], so there is still room for improvement of the quality of results obtained in this paper, after this very first and very encouraging attempt to compare FF and FFF photon spectra by using the attenuation technique.

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AUTHORS' CONTRIBUTIONS

The idea for this paper was suggested by M. Krmar, Measurements were made by A. A. Toth, N. V. Ignjatov and L. D. Dragojlović. Data analysis and spectra reconstruction was performed by M. Mikalački, A. A. Toth, and M. Krmar. The article was written by A. A. Toth and M. Krmar.

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ДА ЛИ ЈЕ АТЕНУАЦИОНА ТЕХНИКА ДОВОЉНО ОСЕТЉИВА ДА БИ СЕ КОРИСТИЛА ЗА РАЗЛИКОВАЊЕ СПЕКТРА ТЕРАПИЈСКОГ АКЦЕЛЕРАТОРА СА И БЕЗ ХОМОГЕНИЗАЦИОНОГ ФИЛТЕРА

Намена овог рада је да провери да ли је атенуациона техника довољно осетљива да направи разлику између фотонског спектра стандардних акцелератора и акцелератора који раде без хомогенизационог филтера. Атенуациона мерења изведена су при два начина рада акцелератора, са хомогенизационим филтером и без хомогенизационог филтера, за номиналну енергију од 6 MV. За реконструкцију спектра коришћена је нумеричка метода као и метода Лапласових трансформација. Иако је разлика међу атенуационим кривама веома мала, обе технике за реконструкцију дају мекши спектар у раду без хомогенизационог филтера, као што смо и очекивали. Најбитнији закључак ове пилот студије јесте да атенуациона анализа може бити довољно осетљив алат како би се детектовала разлике међу спектрима за два различита начина рада акцелератора.

Кључне речи: спектар фотона, атенуациона анализа, хомогенизациони филтер, безхомогенизациони филтер