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Effect of a flattening filter on the surface and build-up doses for high-energy photons produced with a varian TrueBeam STx linear accelerator

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ABSTRACT

Background: The aim of thise study was to measure and determine the surface and build- up region doses at different field sizes on the central axis of 6 and 10 MV with flettening filter (FF) and without flettenin filter (FFF) high-energy photon beams, which are commonly used in clinical radiotherapy applications, and to reveal the difference between FF and FFF beams. ***Material and Methods:*** The dose measurements were made using a parallel-plate ion chamber and a water-equivalent solid water phantom for a field size of 5 × 5, 10 × 10, and 20 × 20 cm^2, with a source skin distance of 100 cm. ***Results:*** The relative surface doses for 6 MV FF high-energy photons are 10.9% ±0.007%, 16.4%±0.010% and 26.9%±0.014% for field sizes of 5x5, 10x10 and 20x20 cm^2. For 6 MV FFF they are 14.7%±0.010%, 19.7%±0.010% and 27.2±0.009% respectively. The relative surface doses for 10 MV FF high-energy photons are 6.3% ±0.010%, 12.0%±0.007% and 23.7%±0.010% for field sizes of 5x5, 10x10 and 20x20 cm^2. For 10 MV FFF they are 9.7%±0.010%, 13.8%±0.007% and 20.1%±0.007% respectively. ***Conclusion:*** It was observed that the relative surface doses increased in FFF for 6MV compared to FF photon beams, and increased in 5x5 and 10x10 cm^2 field sizes and decreased in 20x20 cm^2 field size for 10MV photon beam. These results may have important implications in radiotherapy applications where skin dose is important.

INTRODUCTION

High-energy photon beams produced by linear accelerators have been used in radiotherapy for more than half a century (1). In recent years, classical high-energy photon beams obtained using a flattening filter (FF) have begun to be replaced by high-energy photon beams obtained without a flattening filter (FFF). The dose rates of high-energy photon beams obtained without a flattening filter are higher than those obtained with a classical flattening filter (2, 3). This feature enables the treatment to be completed in a shorter time in treatments performed with FFF rays (4). The short treatment time makes it easier to control involuntary organ movements that occurs during treatment (intrafraction movements). It also reduces uncertainty in target volume and critical organ doses (5). The success of the treatment is possible by giving the desired dose to the target volume with absolute accuracy. The advantages of irradiation with FFF are obvious, especially in hypofractionated irradiations using fewer fractions than conventional radiotherapy such as stereotactic radiosurgery and stereotactic body radiotherapy (6, 7).

The use of advanced radiotherapy techniques such as intensity modulated radiotherapy and volumetric modulated arc therapy in radiotherapy has reduced the use of high-energy electron beams in the treatment of superficial tumors. Today, only linear accelerators that produce high-energy FF and FFF photon beams have begun to be used (2, 5). In the treatment of surface tumors and tumors just below the surface, the surface and build-up region doses are important and play a decisive role in the success of the treatment (8). In high-energy photon beams, surface and build-up region doses are directly related to energy level and the collimator design of the linear accelerator. The absence of a flattening filter on high-energy beams reduces collimator scatter radiation and the out-of-field dose compared to FF beams. Reducing the out-of-field dose reduces the risk of radiation-induced secondary cancer (9).

Although researchers have compared the dose characteristics of FF and FFF photon beams, such as depth dose and dose profile, there has been limited comparison of the surface dose and build-up region doses. The rapid change in these doses makes it difficult to measure them accurately; ideally, an extrapolation ion chamber should be used to measure these doses. When this device is not available, a parallel-plate ion chamber can be used; however, it presents an overresponse in the surface and build-up regions due to secondary electron scattering from the sidewall of the chamber (8, 10). It is necessary to

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correct this measured overdose. Gerbi's overresponse correction factors can be used for all types of fixed parallel-plate chambers. These factors are specific to the chamber properties, volume, plate separation, and guard size (11, 12).

Guy *et al.* (13) conducted the first study on the surface dose of 6 and 10 MV FFF photon beams. They measured the surface doses by using the Markus parallel-plate ion chamber with different field sizes from 2 × 2 cm^2 to 30 × 30 cm^2. They found that compared with 6 MV FF photon beams, the surface dose when using 6 MV FFF photon beams is 45% higher for the 2 × 2 cm^2 field and 13% higher for the 20 × 20 cm^2 field size. Compared with 10 MV FF photon beams, the surface dose when using 10 MV FFF photons beams is 63% higher for a 2 × 2 cm^2 filed size and 2% lower for a 20 × 20 cm^2 field size. Although the authors measured the surface doses within the build-up region, they did not assess dose variation at different depths within that region. In a related study, Sigamani *et al.* (14) measured the surface and build-up region doses with a parallel-plate ion chamber and Gafchromic film. Specifically, they examined 6 MV FF photon beams and 7 MV FFF photon beams. They reported minimal differences in the surface and build-up region doses between FF and FFF photon beams. More recently, Yani *et al.* (15) conducted dosimetric comparisons using the DOSXYZnrc code on a virtual heterogenous phantom. They found higher doses on the phantom surface when using FFF photon beams due to electron contamination present in FF photon beams.

Although there has been extensive investigation on FF photon beams (16-20) there is limited information available on FFF photon beams. Among the available studies, Guy *et al.* (13) observed substantial differences in surface doses between FF and FFF photon beams, whereas Sigamani *et al.* (14) reported only minimal differences. The discrepancy between these findings, along with the overall lack of research in this area, underscores the need for additional studies to better understand the dosimetric characteristics of FFF photon beams. Hence, this study aimed to address this gap by measuring and analyzing the surface and build-up region doses at various field sizes along the central axis for 6 and 10 MV FF and FFF photon beams, which are commonly used in clinical radiotherapy. We quantified and compared the differences between FF and FFF photon beams.

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MATERALS AND METHODS

Equipment

Varian TureBeam STx linear accelerator

Measurements were made in the Varian TureBeam STx linear accelerator (Varian Medical System, Palo Alto, CA, USA) was used to produce the 6 and 10 MV FF and FFF photon beams. This device has 120 leaves. The innermost 32 pairs of leaves are 2.5 mm wide at the isocenter, and the outermost 28 pairs are 5 mm wide. Irregular fields up to 40 cm wide and 22 cm long can be created. The dose rate is 5-600 monitor unit (MU)/min for 6 MV FF photon beams, 400-1400 MU/min) for 6 MV FFF photon beams, 5-600 MU/min for 10 MV FF photon beams and 400-2400 MU/min for 10 MV FFF photon beams. To minimize statistical uncertainty in the measurements, 400 MU was used for all beams.

Markus parallel-plate ion chamber

This study employed a Markus parallel-plate ion chamber (PTW 23343, PTW Freiburg, Freiburg, Germany). Figure 1 shows a diagram of this device. The physical effective point of measurement for this device was defined as 0.023 mm, at the inner surface of the proximal collecting plate. The plate separation is fixed at 2 mm, and the sidewall-to-collector distance is 0.35 mm.

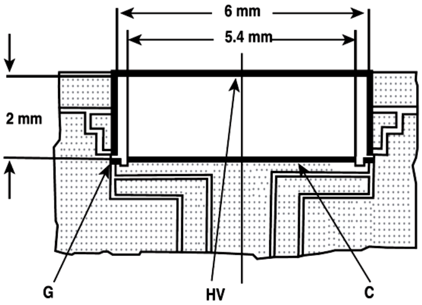

Figure 1. Diagram of a Markus parallel-plate ion chamber. Abbreviations: HV: high voltage, C: collector electrode, G: guard ring.

Electrometer

A Unidos electrometer (PTW Freiburg, Germany) was used for dose measurements. Its use is appropriate for of high-energy photon and electron beams at 100–240 V and 5/60 Hz.

Water-equivalent slab phantom

This study used an RW3 water-equivalent slab phantom (made of Goettingen White Water; PTW Freiburg). This phantom acts as water for photon energy ranging from cobalt-60 to 25 MV, and for electron energy ranging from 4 to 25 MeV. The physical density of this phantom is 1.045 g/cm^3. It consists of 30 × 30 cm^2 slabs of various thicknesses ranging from 1 to 10 mm, with a thickness tolerance of ± 0.1 mm. It can be adapted for use in different ion chambers.

Measurements

A Markus parallel-plate ionization chamber was used to measure the surface dose. The polarity effect of the chamber was taken into account and the readings were corrected using equation (1).

$$Qavg = (Q+ + Q-) / 2 \qquad (1)$$

Where $Qavg$ is the average charge used for relative ionization $Q+$ and $Q-$ are the charges measured under positive and negative polarities, respectively (21).

All measurements were conducted at a fixed source skin distance (SSD) of 100 cm. For each measurement, 100 MU were used. The set-up of the ionization chamber remained unchanged across different depths measurements. Because the photon flux from a point source follows the inverse square law, a fixed source-to-chamber distance was used to eliminate distance-related errors. Distance corrections were applied to account for SSD variations at different depths.

Measurements were performed for both 6 and 10 MV photon beams, with and without flattening filters (FF and FFF photon beams), across three field sizes: 5× 5, 10× 10 and 20×20 cm^2. Surface and build-up region doses were measured at multiple depths along the central axis:0(surface), 1, 2, 5, 7, 10, 12, 13, 14, 15, 16 and 17 mm for 6MV photon beams and 0 (surface), 1, 2, 5, 7, 10, 12, 14, 16, 20, 22, 23, 24 and 25 mm for 10 MV photon beams. The maximum dose for the 10x10cm^2 field size was 15mm (6MV FF), 14mm (6MV FFF), 24mm (10MV FF), and 23 mm (10MV FFF). All dose were normalized to 100% at the maximum depth. To correct for the over-response of the parallel-plate chamber in the build-up region, the measured percenaget depth dose (PDD) was adjusted using Gerbi's method (11). Each measurement was repeated five times to calculate the standard deviation. Figure 2 illustrates the setup geometry and surface dose measurement configuration.

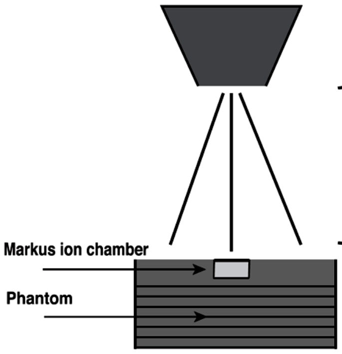

Figure 2. Diagram showing the measurement of the surface and build-up region doses. Abbreviation: SSD, source skin distance.

Data analysis

SPSS (v.22) Statistics (IBM Corp., Armonk, NY, USA) was used for data analysis. The Wilcoxon signed -rank test was used for statistical comparison, with p<0.05 considered to indicate a significant difference.

RESULTS

Figure 3 shows the relative surface and build-up region doses of the FF and FFF photon beams at a SSD of 100 cm for a field size of 5 × 5 cm^2. The relative surface dose was 10.9% ± 0.007% for 6 MV FF photon beams and 14.7% ± 0.010% for 6 MV FFF photon beams (p = 0.041), and 6.3% ± 0.010% for 10 MV FF photon beams and 9.7% ± 0.010% for 10 MV FFF photon beams (p = 0.025). At a depth of 2 mm, the relative dose was 57.2% ± 0.007% for 6 MV FF photon beams and 65.1% ± 0.015% for 6 MV FFF photon beams (p = 0.042), and 45.5% ± 0.007% for 10 MV FF photon beams and 47.3% ± 0.010 for 10 MV FFF photon beams (p = 0.025). At a depth of 5 mm, the relative dose was 83.0% ± 0.010% for 6 MV FF photon beams and 88.3% ± 0.010% for 6 MV FFF photon beams (p = 0.034), and 67.8% ± 0.007% for 10 MV FF photon beams and 71.6% ± 0.007% for 10 MV FFF photon beams (p = 0.025). Finally, at a depth of 10 mm, the relative dose was 98.3% ± 0.007% for 6 MV FF beams and 99.1% ±0.007% for 6 MV FFF beams (p = 0.039), and 86.2% ± 0.007% for 10 MV FF beams and 90.2% ± 0.007% for 10 MV FFF beams (p = 0.034).

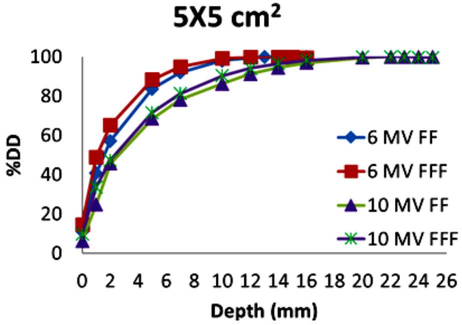

Figure 3. The relative surface and build-up doses for a 5 × 5 cm² field size and 6 and 10 MV high-energy photon beams with a flattening filter (FF) and without a flattening filter (FFF). The doses are normalized to a depth of 15 mm for 6 MV FF, 14 mm for 6 MV FFF, 23 mm for 10 MV FF, and 24 mm for 10 MV FFF. Each measurement was repeated five times and the standard deviation between the measurements was ≤ 0.02. Abbreviation: %DD, percentage depth dose.

Figure 4 shows the relative surface and build-up region doses for a field size of 10 × 10 cm^2 at an SSD of 100 cm. The relative surface dose was 16.4% ± 0.010% for 6 MV FF photon beams and 19.7% ± 0.010% for 6MV FFF photon beams (p = 0.039), and 12.0% ± 0.007% for 10 MV FF photon beams and 13.8% ± 0.007% 10 MV FFF photon beams (p = 0.025). At a depth of 2 mm, the relative dose was 60.0% ± 0.007% for 6 MV FF photon beams and 67.1% ± 0.007% for 6 MV FFF photon beams (p = 0.039), and 42.9% ± 0.010% for 10 MV FF photon beams and 49.7% ± 0.007% for 10 MV FFF photon beams (p = 0.039). At a depth of 5 mm, the relative dose was 83.7% ± 0.012% for 6 MV FF photon beams and 89.0% ± 0.015% for 6 MV FFF photon beams (p = 0.034), and 68.5% ± 0.007% for 10 MV FF photon beams and 73.3% ± 0.007% for 10 MV FFF photon beams (p = 0.025). Finally, at a depth of 10 mm, the relative dose was 98.3% ± 0.010% for 6 MV FF photon beams and 99.1% ± 0.007% for 6 MV FFF photon beams (p = 0.041), and 88.5% ± 0.010% for 10 MV FF photon beams and 91.0% ± 0.010% for 10 MV FFF photon beams (p = 0.034).

Figure 5 shows the relative surface and build-up

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region doses for a field size of 20 × 20 cm² at an SSD of 100 cm. The relative surface dose was 26.9% ± 0.014% for 6 MV FF photon beams and 27.2% ± 0.009% for 6MV FFF photon beams ($p = 0.039$), and 23.7% ± 0.007% for 10 MV FF photon beams and 20.1% ± 0.010% 10 MV FFF photon beams ($p = 0.039$). At a depth of 2 mm, the relative dose was 66.8% ± 0.007% for 6 MV FF photon beams and 70.5% ± 0.007%for 6 MV FFF photon beams ($p = 0.039$), and 52.8% ± 0.010% for 10 MV FF photon beams and 54.2% ± 0.007% for 10 MV FFF photon beams ($p = 0.025$). At a depth of 5 mm, the relative dose was 88.7% ± 0.012% for 6 MV FF photon beams and 90.8% ± 0.015% for 6 MV FFF photon beams ($p = 0.034$), and 75.2% ± 0.007% for 10 MV FF photon beams and 76.4% ± 0.007% for 10 MV FFF photon beams ($p = 0.025$). Finally, at a depth of 10 mm, the relative dose was 99.0% ± 0.007% for 6 MV FF photon beams and 99.5% ± 0.007% for 6 MV FFF photon beams ($p = 0.025$), and 88.5% ± 0.007% for 10 MV FF photon beams and 91.0 % ± 0.007% for 10 MV FFF photon beams ($p = 0.025$).

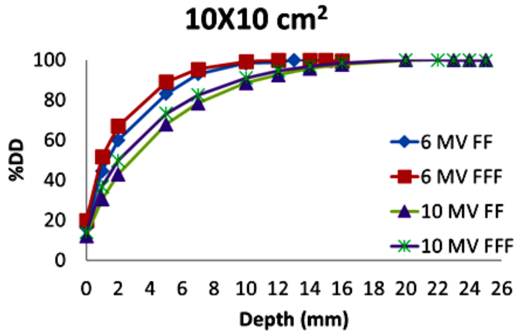

Figure 4. The relative surface and build-up doses for a 10 × 10 cm² field size and 6 and 10 MV high-energy photon beams with a flattening filter (FF) and without a flattening filter (FFF). The doses are normalized to a depth of 15 mm for 6 MV FF, 14 mm for 6 MV FFF, 23 mm for 10 MV FF, and 24 mm for 10 MV FFF. Each measurement was repeated five times and the standard deviation between the measurements was ≤ 0.02. Abbreviation: %DD, percentage depth dose.

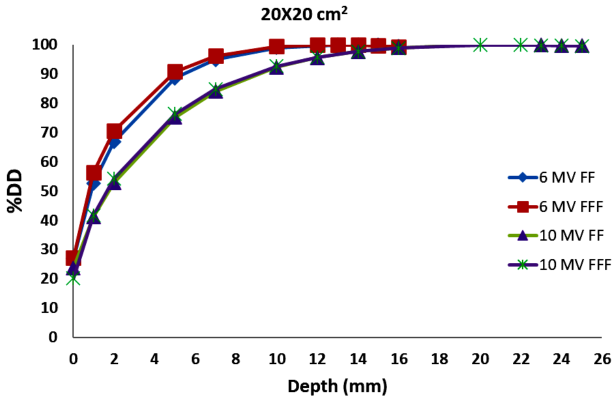

Figure 5. The relative surface and build-up doses for a 20 × 20 cm² field size and 6 and 10 MV high-energy photon beams with a flattening filter (FF) and without a flattening filter (FFF). The doses are normalized to a depth of 15 mm for 6 MV FF, 14 mm for 6 MV FFF, 23 mm for 10 MV FF, and 24 mm for 10 MV FFF. Each measurement was repeated five times and the standard deviation between the measurements was ≤ 0.02. Abbreviation: %DD, percentage depth dose.

Figure 6 presents a summary of the relative surface doses of the 6 MV FF, 6 MV FFF, 10 MV FF, and 10 MV FF high-energy photon beams for the 5 × 5, 10 × 10 and 20 × 20 cm² field sizes at an SSD of 100 cm. The relative surface doses of all beams increased as the field size increased. The relative surface doses of 6 MV FFF photon beams were higher than those of 6 MV FF photon beams. The relative surface doses of 10 MV FF photon beams were higher for the 5 × 5 and 10 × 10 cm² field sizes, while they were lower for the 20 × 20 cm² field size. The difference was significant ($p < 0.05$).

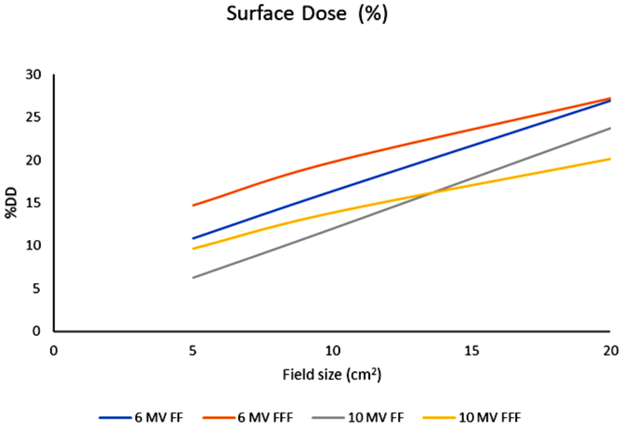

Figure 6. The relative surface doses for the different field sizes of the 6 and 10 MV high-energy photon beams with a flattening filter (FF) and without a flattening filter (FFF). The doses are normalized to a depth of 15 mm for 6 MV FF, 14 mm for 6 MV FFF, 23 mm for 10 MV FF, and 24 mm for 10 MV FFF. Each measurement was repeated five times and the standard deviation between the measurements was ≤ 0.02. Abbreviation: %DD, percentage depth dose.

DISCUSSION

High-energy photon beams are widely used in radiotherapy. They have a skin protective effect (1) that increases as the energy increases. In classical linear accelerators, high-energy photons formed in the target material create secondary electrons by passing through structures such as an FF, monitor ion chambers, and collimator jaws until they reach the surface of the patient (22). These secondary electrons affect the surface and build-up region doses, which are clinically important and sometimes dose limiting. The surface doses and build-up region doses depend on the energy of the photons and the gantry design of the linear accelerator, including whether the gantry section includes an FF (23).

Recent years, high-energy FFF photon beams have started to be used in clinical applications. This approach increases the dose rate up to 4 times compared with a classical linear accelerator. It is especially preferred in hypofraction irradiation because the treatment ends in a shorter time (6). While the literature contains abundant information about the surface and build-up region doses of high-

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energy FF photon beams produced by classical linear accelerators, there is less information about these doses when FFF photon beams are delivered.

It is not easy to measure the surface and build-up region doses accurately because the doses change rapidly in this region. The best device to measure surface and build-up region doses is an extrapolation ion chamber, although a parallel-plate ion chambers can be used with Garbi's overdose correction (11). The use of radiochromic film for surface dosimetry has alleviated some problems with conventional radiation dosimetry. Specifically, radiochromic films have high spatial resolution and low spectral sensitivity, so they are suitable for measuring regions with a steep dose gradient (24, 25).

In our study, as the field size increased, the relative surface and build-up region doses also increased for all high-energy photon beams. While the maximum dose depth with the 10 × 10 cm^2 field size was 15 mm with 6 MV FF photon beams, it decreased to 14 mm with 6 MV FFF photon beams. Similarly, the maximum dose depth was 24 mm for 10 MV FF photon beams and 23 mm for 10 MV FFF photon beams. The surface and build-up region doses increased with 6 MV FFF photon beams compared with 6 MV FF photon beams, and this increase became less pronounced as the field size increased. At the largest tested field size (20 × 20 cm^2), the relative surface dose was 26.9% for 6 MV FF photon beams and 27.2% for 6 MV FFF photon beams, a difference of approximately 1.1% (this difference was significant p:0.039). For the same field size, the relative surface dose was 23.7% for 10 MV FF photon beams and 20.1% for 10 MV FFF photons, a difference of approximately 18% (this difference was also significant p:0.039). The surface and deposition doses of 10 MV FFF photon beams are higher than those of 10 MV FF photon beams for 5 × 5 and 10 × 10 cm^2 field sizes, but lower for 20 × 20 cm^2 field size

Relative dose values showed similar trends at depths of 2, 5, and 10 mm in the build-up region. For a 20×20 cm^2 field size, the relative dose at a depth of 10 mm was 99.0% with 6 MV FF, while it was 99.5% with 6 MV FFF photon beams. It was 92.9% with 10 MV FF and 92.7% with 10 MV FFF. The effect of the flattening filter decreased, and the relative dose values approached the photon beams obtained with the flattening filter. The absence of a flattening filter for high-energy photons eliminates secondary electrons from the flattening filter. However, the absorption of secondary electrons coming from the monitor ion chamber and collimator jaws is not also eliminated. This is interpreted as an increase in the doses on the surface and build-up region without the flattening filter compared to the filtered high-energy photons, since the amount of secondary electrons absorbed by the Flattening filter is greater than the secondary electrons created by the flattening filter. Its decrease as the field size increases can be explained by the fact that the secondary electrons coming from the collimator jaws can reach the field center in small fields, but not in large areas. Cashmore (3). investigated the surface doses in 6 MV - 10 MV FF and FFF photon beams, at different field sizes and source-to-skin distances, in the presence of a mounting tray and motorized wedge. In his study, he reported that surface doses increased similarly with FFF photon beams at 6 and 10 MV, decreasing in larger fields (40×40 cm^2) and decreasing by 5% at 10 MV. In our study, a 3.6% decrease was found for a 20×20 cm^2 field size with 10 MV FFF photon beams.

The relative build-up region doses showed similar trends at a depth of 2, 5, and 10 mm. For a 20 × 20 cm^2 field size, the relative dose at a depth of 10 mm was 99.0% for 6 MV FF photon beams, 99.5% for 6 MV FFF photon beams, 92.9% for 10 MV FF photon beams, and 92.7% for 10 MV FFF photon beams. Although the absence of an FF eliminates the generation of secondary electrons from the FF, secondary electrons from the monitor ion chamber and collimator jaws are not eliminated. The surface and build-up region doses for the FFF photons increased compared with the FF photons because the amount of secondary electrons absorbed by a FF is greater than the secondary electrons created by an FF. The decrease as the field size increases can be explained by the fact that the secondary electrons coming from the collimator jaws can reach the field center in small field sizes, but not in large field sizes. Cashmore (3) investigated the surface doses of 6 and 10 MV FF and FFF photon beams at different field sizes and SSDs in the presence of a mounting tray and motorized wedge. The author repoted that the surface dose increased in 6 FFF photon beams compared to 6 FF photon beams, while it increased in small field sizes and decreased in large field sizes for 10 MV FFF photon beams (a 5% decrease in the 40 × 40 cm^2 field size). In our study, similarly the surface dose increased in the 6 FF photon beam compared to the 6 FF photon beam, increased in the 5×5 and 10×10 cm^2 field sizes in the 10 MV FFF photon beam, and decreased in the 20×20 cm^2 field size.

Apipunyasopon *et al.* (26) measured the surface and build-up region doses of 6 MV FF photon beams produced with a Varian linear accelerator by using a Markus ion chamber and compared them with the results they obtained from a Monte Carlo simulation model they created with the DOSXYZnrc code. They reported the following measured relative surface doses 10.5% for the 5 × 5 cm^2 field size, 16.04% for the 10 × 10 cm^2 field size, and 21.74% for the 15 × 15 cm^2 field size. The Monte Carlo simulation and measurement results were similar. Akbas *et al.* (10) measured the relative surface and build-up region doses of 6 MV FF photon beams produced with a Varian linear accelerator by using a Markus ion chamber, radiochromic film, and metal oxide semiconductor field effect transistor dosimeters in a water-equivalent solid phantom. They reported the following relative surface doses: 10.8% for the 5 × 5 cm^2 field size, 16.6% for the 10 × 10 cm^2 field size, and 28.1% for the 20 × 20 cm^2 field size. We recorded a remarkably similar relative surface dose in 6 FF photon beams for field sizes of 5 × 5 cm^2 (10.9% ± 0.007%) and 10 × 10 cm^2 (16.4% ± 0.010%).

Siganami *et al.* (14) measured the relative surface and build-up region doses at different field sizes for 6 –10 MV FF and FFF photon beams produced with the Varian True Beam instrument. They used a parallel-plate ion chamber (NACP-02, IBA) and Gafchromic film. They reported higher surface and build-up region doses for FFF photon beams compared with FF photon beams, with a more pronounced increase with a smaller field size.

Imae *et al.* (12) measured the relative surface and build-up doses of 6 MV FF and FFF photon beams produced with an Elekta device in a water-equivalent solid water phantom and a Markus ion chamber. They reported the following relative surface doses: for a 2 × 2 cm^2 field size, 6.56% for 6 MV FF photon beams and 8.48% for 6 MV FFF photon beams; for a 10 × 10 cm^2 field size, 14.86% for 6 MV FF photon beams and 16.40% for 6 MV FFF photon beams. Overall, they found small differences between FF and FFF photon beams for all field sizes

The skin is a target organ in the radiotherapy of some cancers, including breast cancer (27, 28). Treatment planning systems cannot accurately calculate surface and subsurface (build-up) doses (29). Therefore, it is important to verify surface doses using measurement methods. The differences found between surface doses, particularly in studies using unfiltered radiation, highlight the need for further research on this topic.

CONCLUSION

High-energy photons without a flattening filter have higher surface dose and build-up region doses than photons with a flattening filter exept for large fields. This may not have much impact in clinical practice. However, it is important in situations where surface dose is important, such as breast radiotherapy. It is important to eliminate the uncertainty in surface doses from high-energy photons without a flattening filter.

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Ethical considerations: This study does not require ethical consideration. No human
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Author contribution: Study concept/study design: F.A., H.B.B; statistical analysis and manuscript writing: F.A., H.B.B., C.K.A.; data acquisition: F.A., H.B.B., S.C.K., C.K.A.

AI usage: AI was not used in this study.

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