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Assessment of Monitor Units and Gamma Pass Rate for 6 MV and Flattening Filter Free (FFF) Beams in Volumetric Modulated Arc Therapy (VMAT)

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Abstract

Background: In linear accelerators, the treatment field's uniform intensity is achieved by including a flattening filter in the beam. However, to produce more conformal dose distributions, contemporary radiotherapy practice now frequently uses fluence and aperture modifying techniques, such as volumetric modulated arc therapy. In these circumstances, the flattening filter in the beam manufacturing process is no longer required. It is therefore necessary to compare the monitor units of 6 MV and flattening filter free plans and how it influences the gamma pass rates to determine which is best for treating cervical cancer with pelvic lymph node metastasis. **Methods:** VMAT plans for fifteen patients with cervical cancer with pathological pelvic lymph node metastasis were included in this study. Each patient had two VMAT plans using conventional 6 MV beam with flattening filter and one with flattening filter free beam (FFF). The VMAT plans were made using two arcs, and then recalculated to give the planned dose distribution to the detectors in a Delta4 phantom. The VMAT plans were irradiated on the Delta4 phantom using an Elekta linear accelerator (6 MV). **Results:** The mean monitor unit for the 6 MV plans was 506.3 MU and a standard deviation of 48.6 while that of the FFF plans had a mean MU of 701.5 with a standard deviation of 87.6. The total monitor units (MUs) for the FFF plans were significantly greater than the 6 MV plans ($p = 6.1 \times 10^{-5}$). **Conclusion:** Flattening filter free (FFF) plans require more numbers of monitor units in comparison to conventional 6 MV filtered beams for external radiation of cervical cancer with pelvic lymph nodes involvement.

Keywords

Monitor Units, Gamma Pass Rate, Flattening Filter Free, Multileaf Collimator

1. Introduction

Intensity-modulated radiation techniques such as volumetric modulated arc therapy (VMAT) are intended to increase dose sparing and conformance, but they also include the delivery of more monitor units (MU) [1]. Volumetric modulated arc therapy is a technique based on a simultaneous variation of MLC position, gantry angle and dose rate to improve dose sparing and shorten the treatment time [2]. A higher risk of secondary malignancies is associated with the rise in MU because it results in larger secondary radiation exposure.

The goal of volumetric modulated arc therapy (VMAT) is to increase dose sparing and reduce treatment duration by simultaneously varying the multileaf collimator (MLC) location, gantry angle, and dose rate. The total MU of a plan may be significantly impacted by parameters like leaf or gantry speed in modulated procedures where the total MU is not linearly connected to the intended dose [3].

A monitor unit (MU) is a measure of machine output from a clinical accelerator for radiation therapy such as a linear accelerator or an orthovoltage unit [4]. Monitor units are measured by ionization chambers that measure the dose delivered by a beam and are built into the treatment head of linear accelerators [5]. The output from a linear accelerator is measured as charges in the ionization chamber. Monitor unit is affected by beam energy, source surface distance (SSD), tissue-phantom ratio/tissue maximum ratio, percentage depth dose (PDD), output factor (OF), wedge factor (WF) and calibration factor [6].

The use of flattening filter free (FFF) beams was intended to decrease the long delivery treatment time since removing the flattening filter raises the dose rate by a factor of two to four [7]. Stereotactic body radiation therapy (SBRT) procedures benefit most from the higher intensity associated with FFF beams, however it may be effective in a variety of other fields and treatments [8]. FFF beams differ significantly from traditional photon beams in several ways. In addition to having a distinct photon energy spectrum and varied head-scatter characteristics, they also have a different beam profile and a higher dose rate [9]. As a result, FFF beams have special beam characteristics such as a sharper penumbra, less head scatter, lower out-of-field dosage and dosimeter response such as higher ion recombination [10].

The aim of the study was to assess the monitor units and the gamma pass rates for conventional 6 MV beams and flattening filter free beams in a volumetric modulated arc therapy (VMAT) of cervical cancer with pelvic lymph node metastasis.

2. Materials and Method

2.1. Elekta Linear Accelerator

An Elekta Versa HD linac (manufactured and installed in 2017) which produces both photon and electron beams of various energies and has the ability to perform VMAT treatment was used for the study (see **Figure 1**). The 160-leaf multi-leaf collimating mechanism on this linac enables accurate beam shaping to the treatment volume. Additionally, it features a megavoltage (MV) electronic imaging device and a 4D cone beam CT. The photon beam energies used are 6 MV and 6 MV flattening filter free (FFF).

2.2. ScandiDos Delta4 Phantom

A 2014 Delta4 phantom from ScandiDos (Sweden) was also used (see **Figure 1**). This phantom covers the whole cross-section of any beam direction with two crossing arrays in a fixed cylindrical configuration. Each detector separately calculates the 4D dose-picture by measuring the dose, pulse, and pixel [11]. With a resolution of 50 nGy, Delta4 measures the dose with high density in the high gradient zone [12].

2.3. Method

The study comprised VMAT plans for fifteen cervical cancer patients with pelvic lymph node metastases. For each patient, VMAT plans for both 6 MV and 6 MV FFF beams were created using the RayStation treatment planning system (RaySearch Laboratories AB Sweden) giving a total of thirty plans for the fifteen patients. Two arcs were used to create each plan. The dose constraints for the primary tumour and lymph node volumes were met for both the 6 MV and FFF beams.

The treatment setup lasers were used to align the Delta4 phantom on the treatment couch at its isocenter (see **Figure 1**). It was then connected to both the computer running the ScandiDos Delta4 and the linac. The VMAT plans were then exposed to radiation on the phantom, and using the Delta4 program, dose discrepancies between the measured and calculated plans were recorded at each measured site on the phantom. The gamma pass rate, dose deviation, and distance to agreement were calculated by the Delta4 software.

The clinical criteria for the pass rate was a gamma pass rate of at least 90% with a dose variation of less than 3% and 3 mm. This criteria is based on the departmental protocol. Plans that achieved pass rates of 90% or more were deemed successful, while those that achieved pass rates of less than 90% were deemed unsuccessful. If the 3%/3 mm requirement is met for each measured point, the local gamma index (GI) is lower or equal to unity [13]. The combined mechanical and dosimetric uncertainty contribution to the observed dosage is the foundation of the 3 percent/3 mm requirement [13].

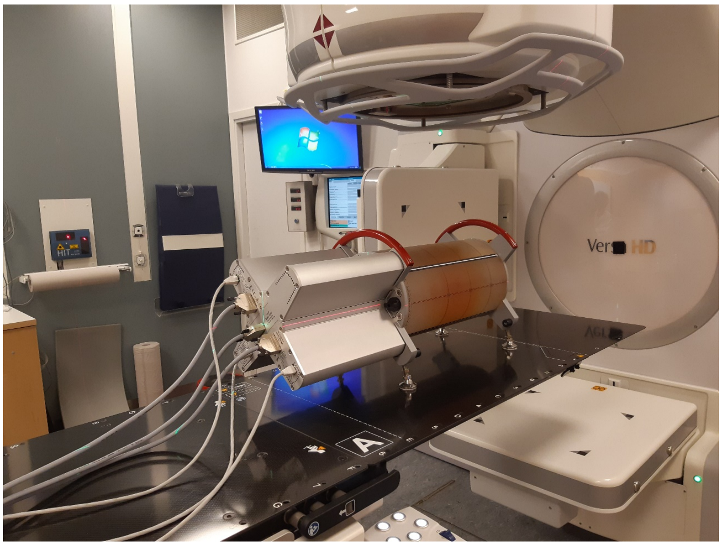

Figure 1. A setup of the Delta4 phantom on the Elekta linear accelerator.

3. Results

The results are shown in **Table 1** and **Figures 2-4** below.

The mean total gamma pass rate for the 6 MV plans was 99.9% and a standard deviation of 0.1 and that of the FFF plans had a gamma pass rate of 98.4% and a standard deviation of 2.2. (See **Table 1**).

The red points lying above the blue line (see **Figure 3**) mean that all FFF plans had higher monitor units than the 6 MV plans.

4. Discussion

The mean monitor units for the 6 MV plans was 506.3 MU and a standard deviation of 48.6 while that of the FFF plans had a mean MU of 701.5 with a standard deviation of 87.6. The total monitor units (MUs) for the FFF plans were significantly greater than the 6 MV plans ($p = 6.1 \times 10^{-5}$). This is in agreement with Kumar *et al.* [14] where it was concluded that FFF plans require more numbers of monitor units in comparison to conventional filtered beams. Ahamed *et al.* [15] reported that there was an increase of 20.5% and 43.7% in MUs for FFF of 6 and 10 MV respectively in comparison to flattened beams of 6 and 10 MV. Increased monitor units for FFF compared to conventional flattened beams were also reported by Rout *et al.* [16]. Also, increased number of MUs was observed for the use of FFF beams compared with conventional flattened beams [17].

One reason for this could be due to the fact that FFF beams are inhomogeneous and therefore requires more modulation thus increasing the MU. Intensity of FFF beam decreases sharply with off-axis distance for field sizes larger than and equal to $10 \times 10\ cm^2$ hence, requires the off-axis distance-dependence modulation of FFF photon beam. This requires large number of MUs to deliver radiation dose to the tumour [18]. Due to the shape of the dose profile for flattening filter free beams, the dose is lower beyond the central axis for the FFF beams and the additional MU allows the dose to be delivered away from the beam axis.

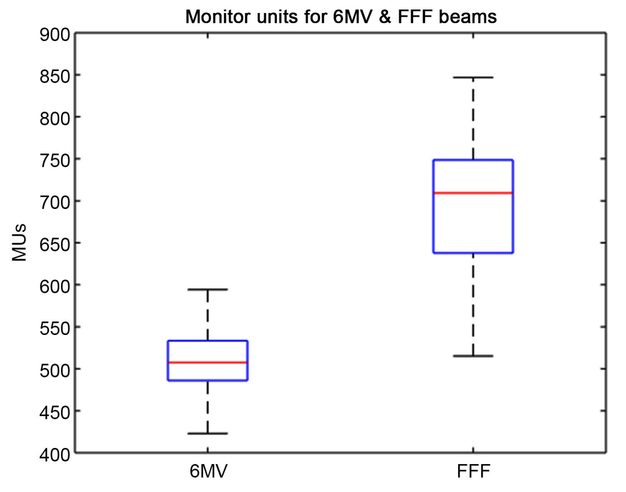

Figure 2. Boxplot of monitor units for 6 MV and FFF plans.

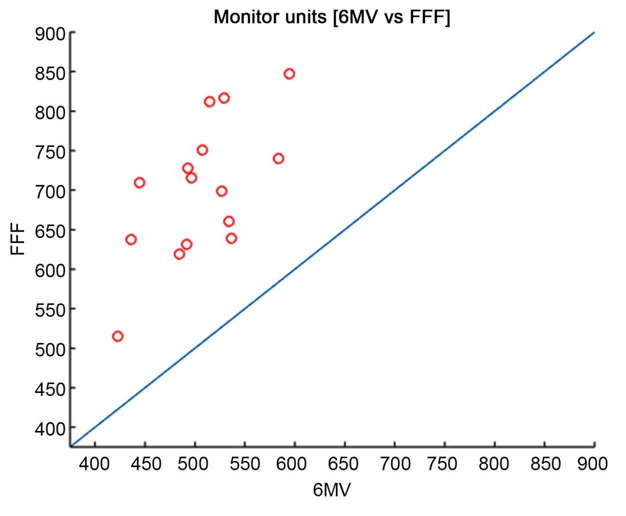

Figure 3. Scatter plot of MUs of 6 MV vs FFF plans. The blue line represents a unity line (x = y).

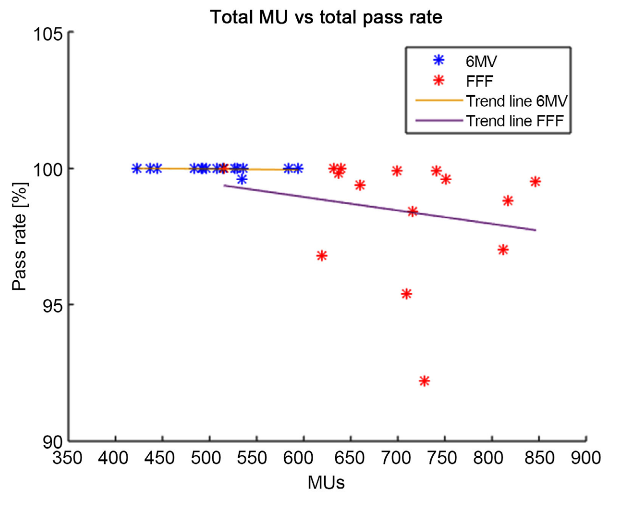

Figure 4. Scatter plot of the total monitor unit vs the total gamma pass rates for 6 MV and FFF plans.

Table 1. Gamma pass rates for 6 MV and FFF plans. Arc 1 [%] and arc 2 [%] are the individual gamma pass rates for the 6 MV whereas arc 3 [%] and 4 [%] are the pass rates for the FFF plans.

Patient	6 MV			FFF		
	arc 1 [%]	arc 2 [%]	Total [%]	arc 3 [%]	arc 4 [%]	Total [%]
PT1	100.0	100.0	100.0	99.7	97.8	97.0
PT2	99.8	100.0	100.0	100.0	99.8	100.0
PT3	100.0	99.8	100.0	99.8	99.8	99.8
PT4	99.8	100.0	100.0	100.0	100.0	98.4
PT5	100.0	100.0	100.0	100.0	100.0	99.9
PT6	100.0	99.7	100.0	100.0	99.8	99.5
PT7	99.9	100.0	100.0	99.8	99.8	99.9
PT8	100.0	100.0	100.0	99.4	99.5	100.0
PT9	100.0	100.0	100.0	100.0	100.0	99.4
PT10	100.0	100.0	99.6	97.8	98.3	96.8
PT11	100.0	99.4	100.0	100.0	100.0	99.6
PT12	100.0	100.0	100.0	99.1	99.3	95.4
PT13	100.0	100.0	100.0	92.9	98.4	92.2
PT14	100.0	100.0	100.0	100.0	100.0	100.0
PT15	100.0	100.0	100.0	98.5	99.5	98.8

From Table 1, the gamma pass rates for the 6 MV and the FFF plans are shown to differ statistically significantly ($p < 0.05$). This suggests that the linear accelerator can deliver the 6 MV plans more precisely than the FFF plans. This agrees with Kumar *et al.* [5], who came to the conclusion that filtered beams were superior to FFF beams for cervix radiation because they had a greater gamma pass rate. This is because flattening filter free beams generate inferior homogenous dose distributions compared to conventional 6 MV flattened beams.

As MU increased for 6 MV plans (see Figure 4), it was observed that the pass rate was relatively constant (100% pass rate). This means that increasing the monitor unit for 6 MV plans has little or no effect on the gamma pass rate. The situation was however different for the FFF plans where increasing MU was found to decrease the gamma pass rate for FFF plans (see Figure 4). This could be due to the fact that rapid modulation of the multileaf collimator (MLC) is needed when using flattening filter free beam. Dose rate increases in FFF mode and therefore, it would require a longer MU to deliver the radiation dose. The pass rate for the FFF becomes scattered as MU increases.

5. Conclusion

Flattening filter free (FFF) plans require more numbers of monitor units in comparison to conventional 6 MV filtered beams for external radiation of cervical cancer with pelvic lymph nodes involvement. For irradiation of large fields such as gynaecological radiotherapy, it is recommended to use beams with a flattening filter, for the same energy of the radiation beams.

Declarations

Availability of Data and Material

Data for this article is readily available upon request.

Ethical Approval

This article does not contain any studies with human or animal participants performed by any of the authors.

Departmental Approval

Approval was obtained from the department before conducting the study.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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