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Beam Characteristics at Low Dose Monitor Unit Settings for Vero4DRT

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Abstract

The stability of delivery of low monitor unit (MU) setting is important especially for step-and-shoot intensity-modulated radiotherapy (IMRT), because the nature of the technique is inherent to repeat beam on/off according to the number of the segments. This study evaluates the dose linearity and profile flatness/symmetry under low MU settings for Vero4DRT, a new linear-accelerator based irradiation system that currently implements step-and-shoot IMRT. To evaluate the dose linearity and flatness/symmetry, the point doses and beam profiles were measured as functions of MU and dose rates. The accuracy of dose delivery depended on the dose rate. Under all dose rates, the dose was linear within 1% above 5 MU and within 2% above 3 MU. The beam symmetry was degraded in-line compared with crossline, although both profiles were symmetric within 2% at all dose settings. The profile flatness was also within 2% above 5 MU at any dose rate and showed no significant variation among the low MU settings. To ensure stable beam delivery without increasing the treatment time of Vero4DRT, we recommend a delivery of 5 MU per segment at a dose rate of 500 MU/min.

Keywords

Vero4DRT, Step-and-Shoot IMRT, Low Monitor Unit, Beam Characteristic

1. Introduction

Several linear-accelerator-based irradiation techniques, such as intensity-modulated radiation therapy (IMRT), stereotactic radiotherapy and conformal arc radiotherapy, deliver a highly accurate dose to the target volume

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while sparing the surrounding healthy tissue [1] [2]. The latest development in this approach is volumetric modulated radiotherapy (VMAT), where in the gantry speed, dose rate, and multileaf collimator (MLC) leaf speed are varied during gantry rotation, reducing the treatment time per fraction [3] [4]. IMRT is typically categorized into dynamic MLC (DMLC) mode (referred to as sliding window) [1] and static MLC (SMLC) mode (referred to as step-and-shoot) [2].

Recently, our center installed the Vero4DRT system (MHI-TM2000; Mitsubishi Heavy Industries, Ltd., Tokyo, Japan, and Brainlab, Feldkichen, Germany) [5]-[8]. As DMLC and VMAT are unavailable in the current commercial version of Vero4DRT, the system should be operated in the step-and-shoot IMRT mode. In previous reports, when step-and-shoot IMRT was implemented with several low monitor units (MUs) per segment at high dose rates, the dosimetric errors were large [9]-[14]. Among researchers who investigated the beam characteristics at low MU settings, Das *et al.* reported a dosimetric error exceeding 20% [10], and Ravikumar *et al.* measured the deviation in dose delivery as 20% - 25% (using 6 and 18 MV photon beams at low MU setting) [11]. By determining the uncertainty in the actual dose at low MUs, we can deliver the target dose to within ±5% for better tumor control [15].

However, the dosimetric characteristics of beams with low MU settings have not been reported for Vero4DRT. Therefore, this study evaluates the dose linearity and profile flatness/symmetry of Vero4DRT at low MU settings.

2. Materials and Methods

Vero4DRT is equipped with a 6 MV X-ray beam that operates at dose rates up to 500 MU/min (**Figure 1**). The characteristics of Vero4DRT are described elsewhere [5]-[8]. Briefly, Vero4DRT has a high precision isocenter at the mechanical center of the gantry, which is shaped like an O-ring. The X-ray head with the gimbals can be rotated on the O-ring and moved to pan and tilt directions for dynamic tumor tracking (DTT) [8]. Meanwhile, the O-ring can be skewed around its vertical axis, removing the need to shift the treatment couch (except during the IGRT procedure). Therefore, the Vero4DRT system delivers a stress-free, non-coplanar three-dimensional conformal beam radiotherapy to the patient.

To evaluate the dose linearity and flatness/symmetry of low MU beams during step-and-shoot IMRT by Vero 4DRT, the point dose and beam profiles were measured as functions of MU. The ionization readings were measured over a 10 × 10 cm^2 field in a Farmer-type ionization chamber (Model N30013; PTW, Freiburg, Germany) using a RAMTEC Smart™ electrometer (Toyo Medic, Tokyo, Japan). The electrometer was mounted in a hole of the Tough Water phantom (Kyoto Kagaku Co., Ltd., Kyoto, Japan). The identical source-to-surface distance (SSD) was set to 90 cm at a depth of 10 cm. Beam profiles (in-line and cross line profiles) were measured by a Profiler2™ Model 1174 (Sun Nuclear Corporation, Melbourne, FL). The plane of the diodes was

Figure 1. Photograph of the Vero4DRT system. The basic structure is the O-ring with diameter of about 350 cm. The gantry which is located inside of the O-ring can be rotated ±180˚ around the isocenter, and the O-ring itself can be rotated ±60˚ around its vertical axis through the isocenter.

set 100 cm from the accelerator radiation source and the radiological depth of the diodes was 10 g/cm^2. The radiological depth was determined by placing a 9 cm of Tough water phantom (density 10 g/cm^2) on top of Profiler2 and recoding the buildup thickness as 1.04 cm. The dose rate was varied as 100, 200, 300, 400, and 500 MU/min, where the MU was set to 1, 2, 3, 4, 5, 10, and 100. The 100 MU setting was used as the reference in the dose rate comparisons. The delivered dose per MU was obtained by dividing the dose by the number of MUs delivered. To compare the MU settings, the beam profiles were normalized at the central axis (CAX). Results are presented as the average and standard deviation of at least five independent measurements.

The beam flatness was calculated over an area covered by 80% of the field width. First, we compute the symmetry measure as follows:

$$\text{Symmetry} = \frac{D_{sym} - D_j}{D_j} \times 100$$

where D_j and D_{sym} are the delivered dose values at position j and the position physically symmetric to j, respectively. The flatness is then computed as

$$\text{Flatness} = \left| \frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}} \right| \times 100$$

where D_{max} (D_{min}) denotes the maximum (minimum) values within the defined region.

3. Results

Figure 2 plots the delivered MU as a function of the relative delivered dose per MU. The dosimetric variation was higher under low than under high MU settings, and the linearity was poor under the lowest setting (1 MU). At 1 MU, dose rates of 100, 200, 300, 400 and 500 MU/min increased the beam output by 2.4% ± 0.4%, 2.8% ± 0.4%, 4.0% ± 0.3%, 4.1% ± 0.4%, and 4.0% ± 0.9%, respectively. The accuracy of the dose delivery also depends on the dose rate, but remains within 1% above 5 MU and within 2% above 3 MU at any dose rate.

Figure 3(a) and **Figure 3(b)** present in-line and crossline profiles under 500 MU/min at various MU settings. The 1MU profile is slightly noisier than the other profiles due to loss of photon statistics. The other curves are almost indistinguishable from the 100 MU setting.

Figures 4(a) and **Figures 4(b)** plot the calculated symmetries of the in-line and crossline profiles on the CAX, respectively. Although the beam symmetry was slightly worse in the in-line profile than in the crossline, all beam symmetries at any MU setting remained within 2%. The profile symmetries are independent of dose rate.

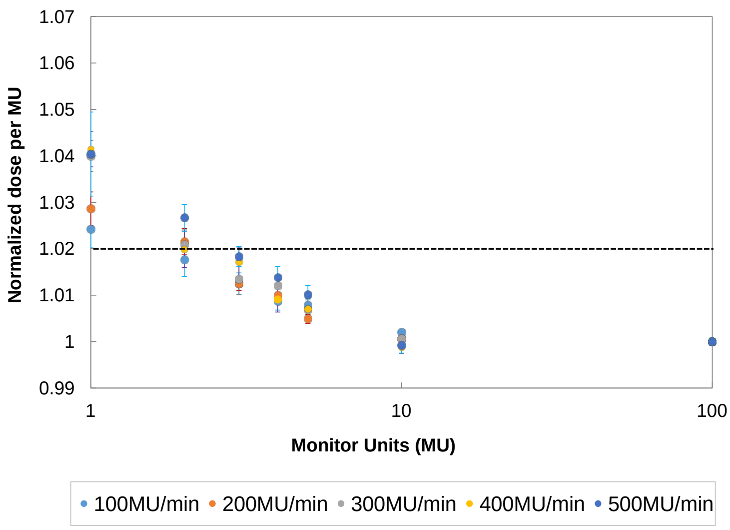
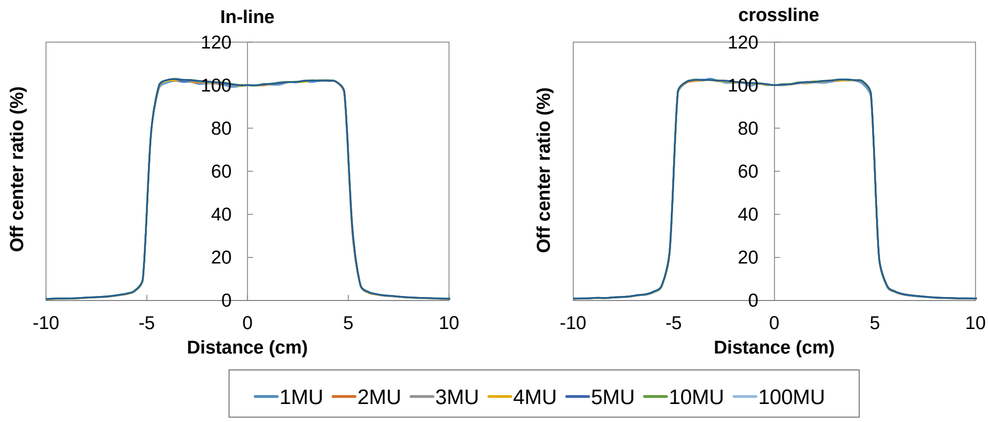
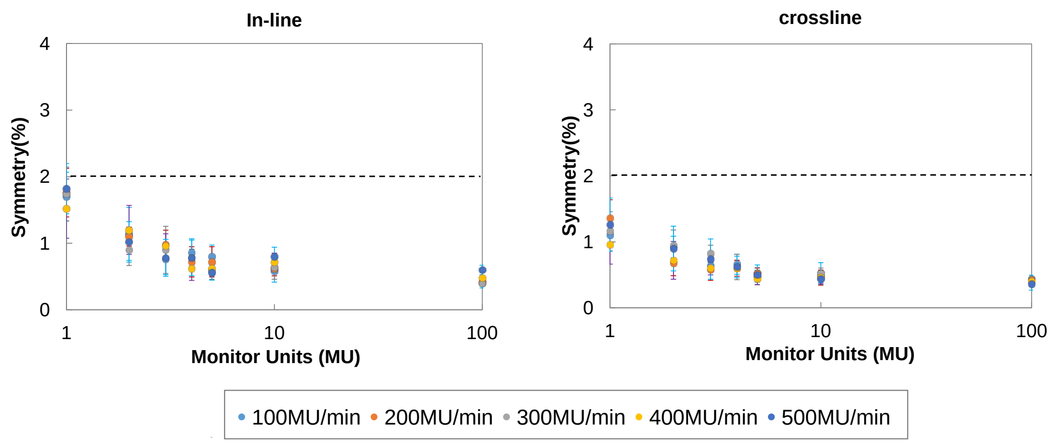


Figure 2. Relative delivered dose per MU in a (10 × 10) cm^2 field versus the MU setting. Results are plotted for several dose rates. The error bars represent 1 standard deviation based on five measurements. Dashed lines represent the 2% dose variation.



(a) (b)

Figure 3. Dose profiles of the (a) in-line and (b) crossline at various MU settings under a dose rate of 500 MU/min. Beam profiles were normalized at the central axis (CAX).



(a) (b)

Figure 4. Calculated symmetries of the (a) in-line and (b) crossline profiles in a (10 × 10) cm^2 field versus the MU setting. Results are plotted for several dose rates. The error bars represent 1 standard deviation based on five measurements. Dashed lines represent the 2% symmetry variation.

The flatness values of the in-line and crossline profiles on the CAX are presented in **Figure 5(a)** and **Figure 5(b)**, respectively. At MUs above 5, the profiles are flat to within 2%, regardless of dose rate. The profile flatness shows no significant variations among the low MU settings.

4. Discussion

Although the low MU setting in the Vero4DRT system yielded poor dose output, the dosimetric characteristics revealed good symmetry and flatness of the in-line and (especially) crossline profiles. The dose output was accurate within 2% at MU settings of 3 or higher, whereas the symmetry and flatness were within 2% at all MUs and dose rates. The American Association of Physicists in Medicine Task Group 142 recommends an IMRT dose linearity within 5% for 2 - 4 MU and 2% for ≥5 MU [16]. Our results lie within the recommended levels. Several authors have reported the dosimetric characteristics of linear accelerator therapy systems at low MU settings [9]-[14]. Das *et al.* reported dose errors higher than 20% for the first few MUs, which stabilize within 5% at MUs exceeding 10 [10]. According to Li *et al.*, SMLC-IMRT affords accurate dose delivery in low MU segments of the recent Varian TrueBeam (Varian Medical Systems Inc., Palo Alto, CA). They reported an accuracy of ±0.2% for all combinations of low MU per segments (1 - 10) and high dose rates (200 - 600 MU/min) [13]. In our study, the Vero4DRT system achieved dose errors within 2% above 5 MU at all dose rates. Regarding

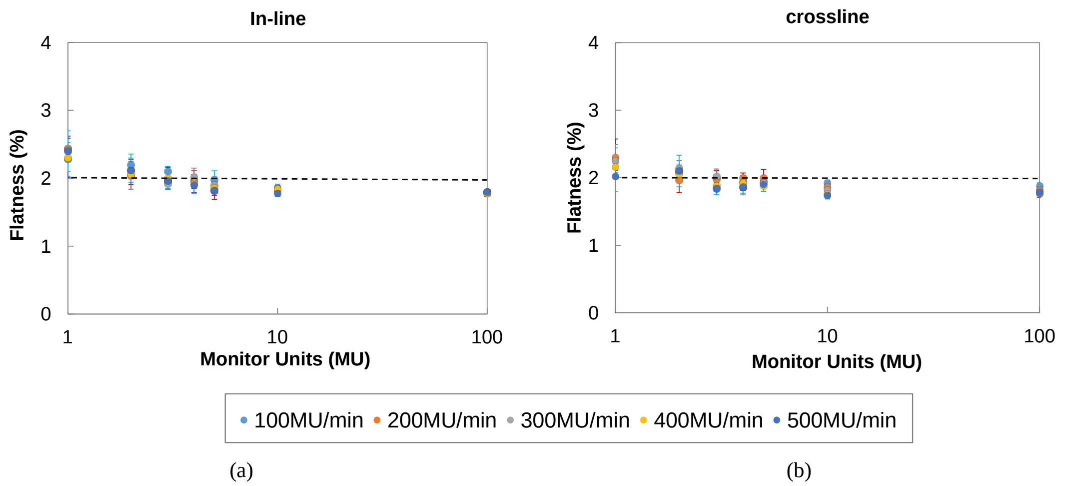


Figure 5. Flatness of the symmetry, calculated for (a) in-line and (b) crossline profiles in a (10 × 10) cm^2 field versus the MU setting. Results are plotted for several dose rates. The error bars represent 1 standard deviation based on five measurements. Dashed lines represent the 2% flatness variation.

symmetry and flatness, Kang *et al.* reported that both measures were uncorrelated with the dose rates in the Varian 21EX (Varian Medical Systems Inc., Palo Alto, CA) system [12]. In our study, the symmetry and flatness of the 6 MV beam in the Vero4DRT system behaved similarly at dose rates of 500 and 100 MU/min. That is, accurate dose delivery with low MU segments is machine specific. Note that the symmetry and flatness profiles can be evaluated by other methods, such as the International Electrotechnical Commission (IEC) protocol [17].

Large numbers of low MU segments and high dose rates in step-and-shoot IMRT might significantly degrade the accuracy of clinical dosimetry. Lower dose rates may stabilize the beam output [18], but at the expense of longer overall delivery time, which increases patient intrafraction motion. During treatment planning, the maximum dose rate should consider the MUs delivered per segment. Dosimetric error can be avoided by an appropriate treatment plan. Bhangle *et al.* recommended segments greater than 5 MU for avoiding dosimetric error [19]. Similarly, Takahashi *et al.* reported that segments exceeding 5 MU will ensure stable beam delivery and output [20].

5. Conclusion

We have measured and evaluated the dosimetric characteristics of Vero4DRT under low MU settings prior to step-and-shoot IMRT. Dose linearity depended on the dose rate up to 3 MU; at higher MUs, it was stabilized within 2% at any dose rate. The profiles were symmetric to within 2% at all dose settings, and their flatness values were unrelated to dose rate. Above 5 MU, the dose error was within 2% regardless of the dose rate. Therefore, to ensure stable beam delivery without increasing the treatment time of Vero4DRT, we have recommended 5 MU per segment at a dose rate of 500 MU/min.

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