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Technical notes

In-house spread sheet based monitor unit verification program for volumetric modulated arc therapy

Prakash Jeevanandam*, Dhanabalan Rajasekaran, Prabakar Sukumar, Vivekanandan Nagarajan

Department of Medical Physics, Cancer Institute (WIA), Adyar, Chennai 600 020, India

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ABSTRACT

Independent monitor unit verification calculation (MUVC) has been recommended by several authors for intensity modulated radiotherapy (IMRT) as a patient specific quality assurance tool. Aim of the present work is to develop an in-house excel spread sheet based MUVC program for volumetric modulated arc therapy (VMAT) using Clarkson's integration technique. Total scatter factor ($S_{c,p}$) and tissue maximum ratio (TMR) for circular fields obtained from Treatment planning system (TPS) were used for the calculation. Multileaf collimator (MLC) interleaf leakage, MLC round edge transmission and tongue and groove effect were accounted. MUVC calculation was performed for 58 patients both for patient anatomy and for homogenous cylindrical phantom. Radiological path lengths were used as water equivalent depths (WED) for calculations using patient anatomy. Monitor unit (MU) discrepancies between −2.60% and 0.28% with mean deviation of −0.92% ± 0.75% were obtained for homogenous cylindrical phantom calculations. MUVC for patient anatomy resulted in large variations between −19.02% and 0.67% for 14 plans where isocenter was at a region below −350 HU. But For 44 plans where the isocenter was at a region above −350 HU, variations between −3.44% and 0.48% were obtained with mean deviation of −1.73% ± 1.12%. For VMAT patient specific quality assurance, the independent MUVC algorithm can be used as an easy and quick auxiliary to measurement based verification for plans with isocenter at a region above −350 HU.

Introduction

Dosimetry verification is an important step during IMRT or VMAT implementation. Patient specific verification is usually conducted with phantom dose measurements to check together the TPS calculation and the treatment machines delivery capability [1,2]. Patient specific dose measurements can be corroborated with independent monitor unit verification calculation (MUVC) to verify the TPS's dose calculation [1,3]. MUVC is a faster verification process and unlike conventional and conformal radiotherapy techniques, independent monitor unit (MU) calculation for IMRT and VMAT are complex due to many irregularly shaped field segments.

Descriptions of MUVC algorithms developed either in-house or commercially are reported in the literature for Conventional, IMRT and VMAT plans [4–8]. Mancosu et al. has investigated the influence of total monitor units on VMAT plans [9].

The aim of the present work is to develop a spread sheet program for monitor unit verification calculation for VMAT (RapidArc) plans. The program uses Clarkson's integration technique [10] to calculate MUs for irregular MLC field segments. Total scatter factor ($S_{c,p}$) and tissue maximum ratio (TMR) data obtained from TPS phantom calculation, after verifying with measured data was used. MUVC was performed both for homogenous cylindrical phantom and for patient anatomy using water equivalent depth (WED) for each arc segment. MLC round edge transmission, MLC interleaf leakage, tongue and groove effect and couch attenuation were accounted.

Materials and methods

MU verification was performed for 58 VMAT (RapidArc) plans. The plans were grouped into head and neck, thorax and pelvic plans consisting 30, 22 and 6 plans respectively. The plans were generated for Varian Clinac-2100C/D linear accelerator with Millennium 120 leaves MLC. In the treatment planning system (TPS), Dose calculation was performed using anisotropic

* Corresponding author. Tel.: +91 8056073157.
E-mail addresses: j.prakash.medphy@gmail.com, panja_prakash@yahoo.co.in (P. Jeevanandam).

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analytical algorithm-version11 (AAA) and Acuros-XB-version11 (AXB) algorithm for all the plans for inter-comparison among MUVC and the two TPS algorithms. AXB algorithm calculates dose by implementing solution to linear Boltzmann transport equations. Dose distributions calculated by AXB have been reported to be accurate and to be in good agreement with BEAMnrc/DOSXYZnrc Monte Carlo dose calculations [11]. Comparisons between AXB and AAA algorithms have been reported by Bush et al. [11] and Kroon et al. [12]. For MUVC water equivalent depth (WED), calculated using the isocenter CT image section and an in-house developed MATLAB program was used for each segment. Dose calculation was also performed using AXB algorithm for homogenous water equivalent cylindrical phantom (diameter = 30 cm and length = 40 cm) for MUVC using cylindrical water phantom.

MUVC algorithm

MUVC algorithm was programmed using Microsoft Excel 2010 (c) Microsoft Corporation. In the TPS, VMAT plan is defined using control points where the leaf positions, gantry angle and cumulative MU weight are defined. The plans under consideration had either 177 or 178 control points for each arc. The treatment plans were exported from TPS to excel spread sheet program and the information of (i) isocenter dose, (ii) TPS calculated Monitor Units (iii) jaw positions (iv) MLC positions for each control point and (v) MU weight for each control point were obtained.

In the present work the VMAT arc portions between adjacent control-points were considered as segments. Leaf positions for each segment were taken to be the average of leaf positions at adjacent control points. To calculate WED, gantry angle for each segment was taken to be at the middle of each segment. MU weight for each segment was taken as the difference between the cumulative MU weights of the control-points adjacent to the segment.

The field outline was plotted for each segment using the leaf position values of the segments. MLC round edge transmission was accounted by applying a radiation field edge offset of 1.15 mm (difference between light field edge and radiation field edge due to transmission through rounded leaf ends of MLC) along leaf travel direction for each MLC leaf projection at isocenter [4,5,13]. Tongue-and-groove under-dosage effect was incorporated by adding 0.3 mm width to each of the projections of central four leafs (30th and 31st leaf pairs) at isocenter plane, to their sides parallel to leaf motion direction and nearer to the isocenter [14]. Interleaf transmission of 3% was accounted for the segments where the central axis was blocked by MLC leaves.

The field outline plot of each segment was divided into 1° sectors around the isocenter. Rays emanating from the isocenter and moving along the middle of each sector were plotted. These rays represent the sectors. Each ray as it starts from the isocenter can intersect the field border one or more times where it moves from open to closed portion of the field or vice versa. The radii (r_n) of these points were determined. For each ray the points were separated into two groups A and B. Points where the ray moves from open portions to blocked portions of the field were contained in group-A and points where it moves from blocked portions to open portions of the field were contained in group-B. $S_{c,p}$ and TMR values were determined for these radii. $S_{c,p} \times$ TMR for individual sectors '$(S_{c,p} \times \text{TMR})_l$' and $S_{c,p} \times$ TMR for individual segments '$(\text{SCP} \times \text{TMR})_s$' were calculated,

$$(S_{c,p} \times \text{TMR})_l = \sum_{n \in A} S_{c,p_{r_n}} \times \text{TMR}_{r_n} - \sum_{n \in B} S_{c,p_{r_n}} \times \text{TMR}_{r_n}$$

$$(S_{c,p} \times \text{TMR})_s = \frac{1}{360} \sum_{l=1}^{360} (S_{c,p} \times \text{TMR})_l$$

MU for a VMAT field was calculated as;

$$\text{MU} = \frac{\text{isocenter dose}}{\text{reference dose per MU}} \cdot \sum_{s=1}^{n} \frac{1}{(S_{c,p} \times \text{TMR})_s \times \text{wt}_s}$$

wt_s is the MU weight of each segment. Reference dose per MU is the dose per MU for 10 × 10 cm^2 field in water phantom to isocenter point at reference depth of 1.5 cm. This was determined from dose measurement using IAEA TRS-398 protocol for 100 cm SSD and 10 cm depth. We have applied PDD correction to determine dose per MU at d_{max} and we have applied inverse-square-law correction to determine the dose per MU at d_{max} for 98.5 cm SSD [4,6].

$S_{c,p}$ and TMR data

For MUVC, total scatter factor ($S_{c,p}$) and tissue maximum ratio (TMR) for circular fields were obtained from TPS water phantom calculations for square and rectangular fields using AXB algorithm after verification with phantom measurements [7]. Since $S_{c,p}$ depends on MLC defined field size and on the jaw positions, $S_{c,p}$ data were obtained for various jaw settings for each MLC field size. During Clarkson's integration, the $S_{c,p}$ values were chosen based on the jaw positions for the given VMAT field. Equivalent square side 's' was obtained from rectangular field of width 'a' and length 'b' using formula '$s = 2 \cdot a \cdot b/(a + b)$'. Square side to equivalent circle radius conversion factor of 1.122 was used to determine circular field TMR and $S_{c,p}$ data.

$S_{c,p}$ data obtained from TPS were verified with water phantom measurements using 'PTW Pinpoint' ionization chamber (Model No. 31014) for various MLC defined field sizes between 3 × 3 cm^2 and 28 × 28 cm^2 with various jaw settings for each MLC defined field size. To verify TMR obtained from TPS, PDD curves were measured for jaw defined square field sizes in range of 3 × 3 cm^2 to 30 × 30 cm^2 using 'PTW' Radiation Field Analyzer and 'PTW Markus' ionization chamber (Model No. TM23343). PDD table was converted to TMR table using conversion formula.

MUVC validation

Dose was calculated using MUVC algorithm for 100 MU at a depth of 1.5 cm and 98.5 cm SSD for static MLC fields from 3 × 3 cm^2 to 28 × 28 cm^2 with various jaw setting for each MLC field size and compared with dose determined using ion chamber measurements. Ion chamber measurements were done using 'PTW Pinpoint' ionization chamber (Model No. 31014) at 10 cm depth in water phantom. PDD correction was applied to determine dose at depth of 1.5 cm.

MUVC calculated MUs were compared with TPS AXB algorithm for small square and rectangular MLC defined static fields from 0.1 × 1 cm^2 up to 3 × 3 cm^2 with 10 × 10 cm^2 jaw setting to deliver 100 cGy at various depths from 1.5 cm to 20 cm.

MUVC calculated MUs were compared with TPS AXB algorithm for square MLC field sizes from 3 × 3 cm^2 to 25 × 25 cm^2 for various jaw settings for each MLC field size to deliver 100 cGy at various depths from 1.5 cm to 20 cm.

Phantom dose measurement

For the plans under consideration, phantom dose measurements were performed as part of patient specific quality assurance