Iranian Journal of Medical Physics

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Monitor Unit Verification for Radiotherapy Irregular Fields Based On the Clarkson Method Combined With In-House MLC Shaper Software

M Athiyaman[1*], A Hemalatha[1], Gokul Raj [1], Neeti Sharma [2], Kumar HS [2], Mary Joan [3], Arun Chougule [3]

1. Department of Radiological Physics, SP Medical College, Bikaner, Rajasthan, India
2. Department of Radiotherapy, SP Medical College, Bikaner, Rajasthan, India.
3. Department of Radiological Physics, SMS Medical College, Jaipur, Rajasthan, India

ARTICLE INFO

Article type:
Original Paper

Article history:
Received: Feb 09, 2023
Accepted: Apr 26, 2023

Keywords:
Radiation Therapy
Conformal Radiotherapy
Dosimetry Calculations
Computer assisted

ABSTRACT

Introduction: In the present scenario, high precision-radiotherapy is delivered through Linear accelerators in which the dose delivery is achieved by delivering the proper monitor unit (MU). Treatment planning for the patients is carried out through treatment planning systems (TPS) in which the precise computation of MU is crucial. This TPS - calculated MU has to be verified using manual calculations for accurate dose delivery. In this study, we incorporated our in-house developed multi leaf collimator(MLC) shaper software and the well-known Clarkson method to compare the calculated MUs to the TPS-generated MUs.

Material and Methods: Conformal treatment plans of various sites of 30 patients were randomly selected containing different MLC-shaped field sizes. All the fields were shaped using MLC (leaf width of 1cm, 40 pairs) in the TPS. MLC log files were exported and fed into the in-house shaper software to get crucial inputs for the Clarkson-based calculation. The Tissue Maximum Ratio(TMR) & Scatter Maximum ratio(SMR) were utilized in our investigation. The Clarkson MU calculation was compared with the TPS calculation method. Paired t-test was performed for the statistical significance.

Results: The Clarkson method-based calculated had significant differences for all the esophageal cancers ($p<0.05$); however no significant difference was found in the other sites.

Conclusion: The compared MUs were within the acceptable deviation with the TPS for Head & Neck, Prostrate and Cervical cancer. The estimated MUs had significant difference in non-homogenous medium. The shaper software can be further enhanced to receive MLC log files from the TPS.

►*Please cite this article as:*
Athiyaman M, Hemalatha A, Raj G, Sharma N, HS K, Joan M, Chougule A. Monitor Unit Verification for Radiotherapy Irregular Fields Based On the Clarkson Method Combined With In-House MLC Shaper Software. Iran J Med Phys 2024; 21: 121-129. 10.22038/IJMP.2023.63585.2086.

Introduction

In linear accelerators, the dose delivery is achieved by delivering the proper monitor unit (MU). The precision of the MU computation plays a vital role in the safe and accurate administration of radiation-absorbed doses to radiotherapy patients. Essential dosimetric parameters such as percentage depth dose (PDD), output factor (O.F), tissue maximum ratio (TMR) & off-axis ratio (OAR) are required for estimating the accurate MU to be delivered at any point in the irradiated tumor volume. The MU calculation is simpler if the beam area is regularly shaped square or rectangular. Field shapes that are different from squares and rectangles can be considered irregular fields [1]. Irregular fields are generated when there is a need to spare the organ at risk from the main beam [2]. MU calculation for irregular fields is often challenging because of the complexity of estimating the dosimetric parameters such as PDD and TMR [3, 4]. The findings of these dosimetric parameters can be done either by phantom measurements or by geometric approximation method [5, 6]. Clarkson, James, and Cunningham developed the method of separating scatter components from the primary beam, and the dosimetric parameters were estimated. It is well understood that multileaf collimators (MLC) shape the field geometry and are also a cost-effective tool in replacing the traditional shielding blocks [7, 8]. In this work, we attempted to implement the Clarkson method to estimate the dosimetric parameters for irregular fields utilizing in-house developed MLC shaper software, and we compared the results with TPS calculations.

Materials and Methods

The Clarkson method was used to estimate the MU for irregular fields generated by the multileaf collimators (MLC) for various clinical sites (Table 1). A total of 30 cases classified as Head and Neck, Esophagus, Prostate, and Cervix malignancies were

*Corresponding Author: Tel: +9571193473; Email: athiyaman.bikaner@gmail.com

considered for this study. The treatment plans were generated for linear accelerator Make: Varian Medical Systems, Palo Alto, USA, Model: 2100 CD with 80 leaves MLC for the above-mentioned cases. The anisotropic analytical algorithm (AAA) in the Eclipse TPS version 13.8 calculated the dosage (Figure 1).

Table 1. MU & dosimetric parameters (SMR, TMR, S_{cp}) estimated by the Clarkson method

Sr. No	Region	Estimated average radius(cm)	SMR value at calculation point	Total TMR value at calculation Point	S_{cp} for equivalent square field size	MU calculated by Clarkson method	MU calculated by TPS for 100cGy
1.	Head and Neck cancer	5.28	0.026	0.924	0.994	108.78	111
2.		5.42	0.026	0.926	0.997	108.54	105.5
3.		4.46	0.024	0.922	0.98	110.5	112
4.		6.03	0.03	0.93	1.006	106.5	107
5.		6.26	0.03	0.928	0.994	107	108
6.	Upper esophageal cancer	6.11	0.03	0.928	1.007	106.95	104.5
7.		5.09	0.026	0.924	0.991	109.11	104
8.		6.69	0.031	0.929	1.015	105.98	102.5
9.		6.07	0.029	0.927	1.006	107.1	103.5
10.		3.95	0.022	0.92	0.971	111.88	109.5
11.	Middle esophageal cancer	7.92	0.037	0.935	1.028	103.85	101.5
12.		7.45	0.035	0.933	1.024	104.58	102.5
13.		5.6	0.028	0.926	0.999	108	105
14.		5.78	0.03	0.926	1.002	107.7	103.5
15.		6.25	0.032	0.93	1.009	106.6	106
16.	Lower esophageal cancer	6.23	0.032	0.93	1.008	106.5	104
17.		6.02	0.03	0.928	1.006	107	104
18.		6.6	0.032	0.93	1.014	106	104
19.		6.63	0.03	0.928	1.014	106	102.5
20.		7.18	0.036	0.934	1.021	104.5	101
21.	Prostate cancer	5.18	0.025	0.923	0.993	109.1	109
22.		4.22	0.022	0.92	0.976	111.27	112
23.		4.27	0.021	0.919	0.977	111.28	112
24.		8.06	0.037	0.935	1.03	103.775	104
25.		8.48	0.038	0.936	1.033	103.335	99.5
26.	Cervical cancer	8.016	0.037	0.898	1.03	103.5	105
27.		6.605	0.032	0.93	1.014	105.5	104
28.		9.133	0.039	0.937	1.081	102.5	103
29.		6.677	0.032	0.93	1.015	105.5	106
30.		6.311	0.03	0.928	1.01	106.5	107

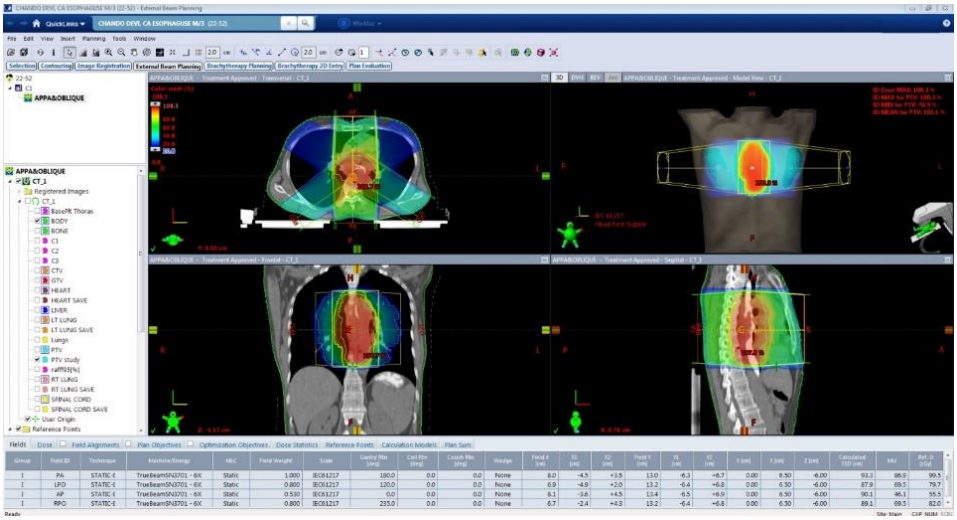

Figure 1. MLC shaped conformal treatment planning performed in TPS

Theory of Clarkson method calculation

The dose deposited in a medium that reaches a specific point consists of two parts: the main dose according to the hypothetical concept of zero field size (1) and the scattered dose (2). The primary photon fluence, which for a point source varies with distance in accordance with the inverse square law and exponential absorption, produces the primary dose. The field dimension expansion leads to an increase in the collimator and phantom scatter that adds an additional dose to the primary beam. The SMR, a scattering feature of TMR, can be utilized to compute scattered dosage in an uneven field using Clarkson's method [1].

The ratio of the scattered dosage at a specific point in the phantom to the dose in free space at that same point can be used to define SMR. Similar to the TMR, the SMR is not reliant on the SSD; rather, it is determined by the beam energy, depth, and field size. The corresponding TMR curves were extrapolated to provide tissue maximum ratio (TMR) values for zero field size. SAR is determined mathematically by the difference between the TMR for the given field and the TMR for the 0 × 0 field because the dispersed dose at a point in the phantom is equal to the total dose minus the primary dose at the point in question. The relationship illustrated by formula (1) can be used to predict the SMR at depth d for field radius r.

$$SMR\ (d, r_d) = TMR\ (d, r_d) - TMR\ (d, 0) \quad (1)$$

* TMR (d,0) denotes the principal component of the beam.
* SMR (d, r_d) – scatter maximum ratio for depth d and for the circular field having radius r_d
* TMR (d, r_d) – tissue maximum ratio for depth d and for the circular field having radius r_d
* TMR (d, 0) - tissue maximum ratio for depth d and for the field size 0 x 0 cm^2

Since the TMR data were available in-house it was able to construct a look-up table for SMRs. As initial steps, the TMR curves for all the depths were extrapolated to find the zero fields TMR. By deducing the total dose contribution from a primary beam component all the SMR values were estimated for the circular areas. Using the formula s/d = 0.891, equivalent circles for square field sizes were calculated. where d is the field contour's diameter and s is the equivalent square's side [9]. The average radii were estimated from the shaper software. The framed SMR lookup tables were independent of the source-to-surface distance and can be used for different SSDs for circular field sizes up to the depths of 25cm. The look-up table was used to determine the aggregate SMR scores at the computation point. The total TMR values were estimated by summing the total SMR value and the zero-field size TMR value at the calculation depth and SMR values of the same depth.

In-house developed MLC shaper software (Figure 2) was designed to estimate the field shape parameters especially the average radius of the calculation points which was essential for the Clarkson method calculation. The TPS exported MLC log files were transferred to the shaper software manually through an external hard disk. The filed shapes were reproduced in the shaper software. The shaper software was enhanced with additional features like measuring the area of the shaped files, selecting points within the shaped fields, estimating the distances of the field edge from the calculation point, etc.TPS calculated reference point location is reproduced in the shaper software. The shaper software divides the field geometry into a section of 10 degrees. The radius of their sectors was estimated and the average radius was given output by the shaper software.

The MLC log files of these plans were exported from the TPS that contains the position details of each leaf from the isocenter. The exported MLC log files were transferred to the shaper software manually; the enhanced shaper software was used to estimate parameters like the perimeter of the field shapes, the total area of the field geometry, and the radius of the sectors from the calculation point to the field boundary. These parameters were essential for the estimation of the average scatter maximum ratio from which the total tissue maximum ratio will be estimated by summing the zero field tissue maximum ratio values at any depth.

Figure 2. In-house developed shaper software

Method of MU calculation

The conventional method of MU calculation was modified to adopt the Clarkson method. The MU can be determined by the below formula in routine clinical practice. As described earlier TPS dose calculation was performed in the water equivalent homogeneous phantom created (CT & HU value of the phantom). The $S_{c,p}$ values were estimated for the equivalent square values obtained from the relationship of circular field and square field. The TMR values for these average radius estimated from equation (2).

$$TMR(d, r_d) = SMR(d, r_d) + TMR(d, r_o) \quad (2)$$

where

- TMR (d, r_d) is the average tissue maximum ratio of the calculation depth d,
- SMR (d, r_d) is the average scatter maximum ratio of depth d for the average radius r calculated from the center of calculation point to the field edges.

MUs were estimated for the irregular fields from the below-mentioned modified formula (3).

$$MU = D / D_0 * S_{c,p} * \sum_{i=1}^{36} TMR * f_w \quad (3)$$

where D- Dose prescribed at the depth, D_0 – reference dose (cGy/MU), The total scatter factor is denoted by $S_{c,p}$, $\sum_{i=1}^{36} TMR$ = average TMR for sectors projected from the field border to calculation point & f_w- is the field weighting factor for the field (here in most of the plans considered as unity).

MU Comparison

Treatment plans containing irregular MLC shapes were exported to the Linac console through the record & verify (RV) system and the MLC shapes were reproduced in the console (Figure 3 & 4). The calculated MU with the assistance of shaper software through the Clarkson method was compared with the MU calculated by TPS in the Imatrix phantom (Figure 5, Make: Scanditronix wellhofer, IBA, Germany) that consist 1020 vented ion chamber detectors arranged in a 32cm x 32cm grid. Each chamber volume is 0.08 cm^3 with the height of 5 mm and diameter of 4.5 mm [10-11]. The Imatrix phantom was calibrated for 6MV X-Ray beams as per the manufacturer recommendations.

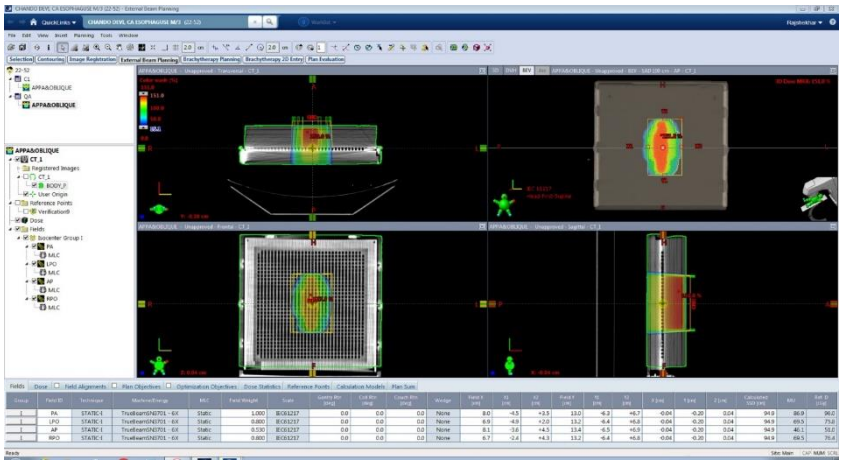

Figure 3. Treatment plan prepared for verification

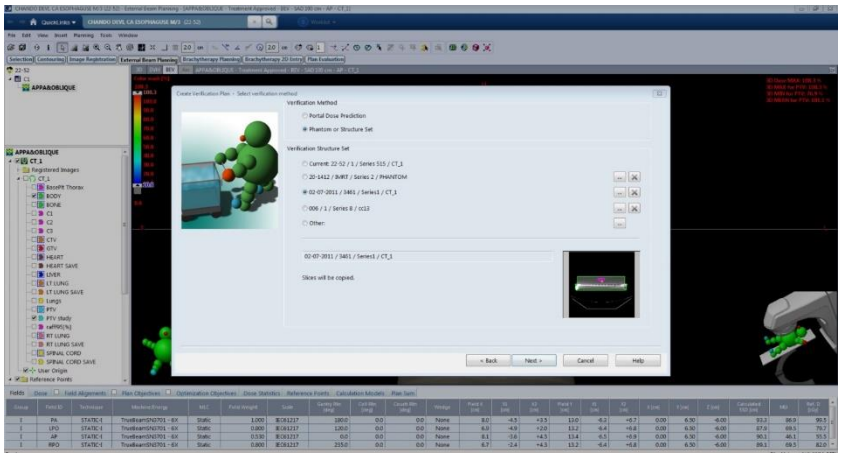

Figure 4. Plans transferred to Imatrixx phantom for verification

Figure 5. Imatrixx phantom

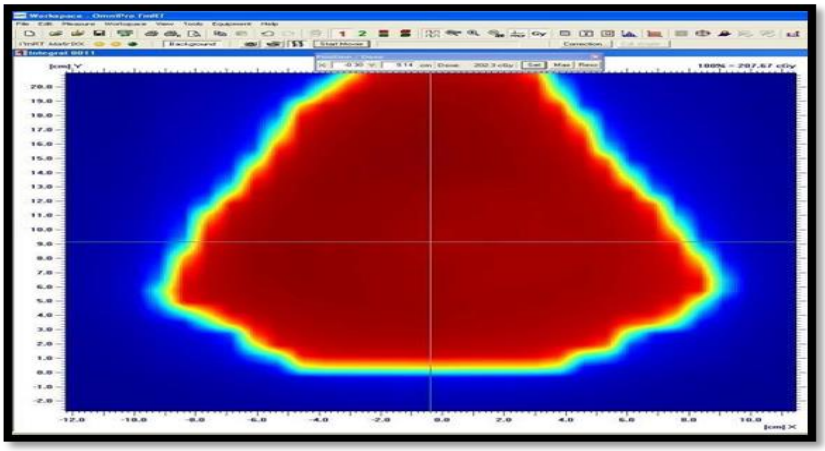

Figure 6. Estimation of dose for various sites in Imatrix phantom

The calculated MU by the Clarkson method was delivered in the Imatrix phantom at the depth determined in the TPS (Figure 6). The transmission of MLC of 1.5% is also accounted for in the MU estimation. The 100cGy prescribed dosage in the TPS was compared to the dose received in the Imatrix phantom. The percentage of deviation was estimated between the measured doses due to the Clarkson method calculated MU and the TPS calculated dose.

Results

Comparison of MU between Clarkson method and TPS

The MU calculated by the Clarkson method and MU calculated by the TPS were tabulated for sites taken for evaluation (Table 1). During the dose computation, the dosimetric parameters total scatter factor ($S_{c,p}$), tissue maximum ratio, and scatter maximum ratio were additionally identified. These were listed in table 1.

The TPS-calculated MU was compared with the MUs for the assigned examples, which were determined using the Clarkson approach. The MU estimated based on the Clarkson method and MU estimated from the TPS is tabulated in Table 2 and a comparison was made for all the sites (Figure 7-12). The percentage of deviation was estimated between the Clarkson method and TPS and the same were mentioned in table 2. The MUs calculated by the Clarkson method were investigated for their accuracy by delivering the respective calculated MU for Head and Neck, Upper, lower & Middle Esophageal cancer, Prostate, and Cervical cancers in the Imatrix phantom.

The mean percentage of deviation were 1.58 ± 1.22, 2.48 ± 0.93, 2.43 ± 0.64, 2.79 ± 0.53, 2.43 ± 0.67, 2.18 ± 0.81 for Head and Neck, Upper, lower & Middle Esophageal cancer, Prostate, and Cervical cancers respectively (Table 3) and a comparison graph was made (Figure 13).

The Paired t-test was used to examine the statistical significance of the TPS MU and the Clarkson method MU (Table 3). It was observed that the p-value was significant $p < 0.05$ for all the Esophageal cancers. However, no significant difference was found for Head & Neck, Prostate, and Cervical cancers.

Table 2. MU comparison between the Clarkson method and TPS

Sr. No	Region	MU calculated by Clarkson method	MU calculated by TPS	Dose calculated by TPS(100cGy)	Measured Dose in Imatrix for Clarkson method	Percentage of deviation between TPS dose and Measured dose
1.	Head and Neck cancer	108.78	111	100	101.2	1.186
2.		108.54	105.5	100	102.3	2.248
3.		110.5	112	100	100.5	0.498
4.		106.5	107	100	100.6	0.596
5.		107	108	100	103.5	3.382
6.	Upper esophageal cancer	106.95	104.5	100	101.8	1.768
7.		109.11	104	100	103.4	3.288
8.		105.98	102.5	100	102.8	2.724
9.		107.1	103.5	100	101.3	1.283
10.		111.88	109.5	100	103.5	3.382
11.	Middle Oesophageal cancer	103.85	101.5	100	102.4	2.344
12.		104.58	102.5	100	101.6	1.575
13.		108	105	100	102.6	2.534
14.		107.7	103.5	100	103.5	3.382
15.		106.6	106	100	102.4	2.344
16.	Lower Oesophageal cancer	106.5	104	100	103.1	3.007
17.		107	104	100	102.1	2.057
18.		106	104	100	103.5	3.382
19.		106	102.5	100	102.5	2.439
20.		104.5	101	100	103.2	3.101
21.	Prostate cancer	109.1	109	100	102.5	2.439
22.		111.27	112	100	101.5	1.478
23.		111.28	112	100	102.5	2.439
24.		103.775	104	100	103.5	3.382
25.		103.335	99.5	100	102.5	2.439
26.	Cervical cancer	103.5	105	100	102.5	2.439
27.		105.5	104	100	103.4	3.288
28.		102.5	103	100	101.3	1.283
29.		105.5	106	100	102.5	2.439
30.		106.5	107	100	101.5	1.478

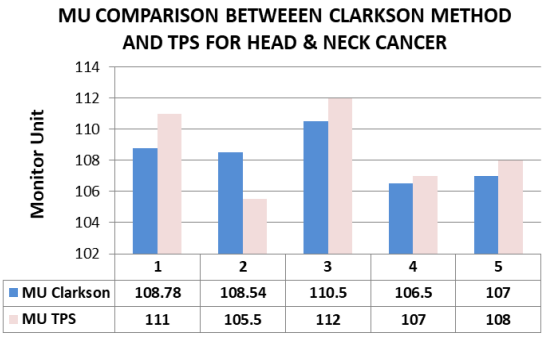

Figure 7. Comparison of MU between the Clarkson method and TPS for Head and neck cancers

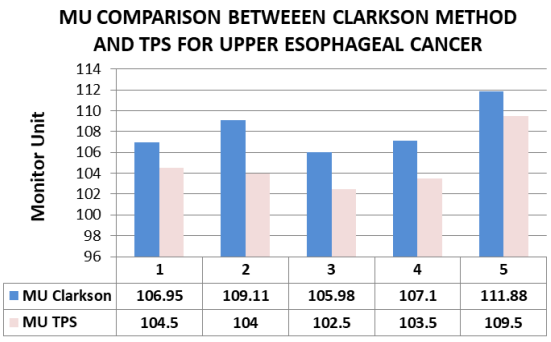

Figure 8. Comparison of MU between the Clarkson method and TPS for upper esophageal cancer

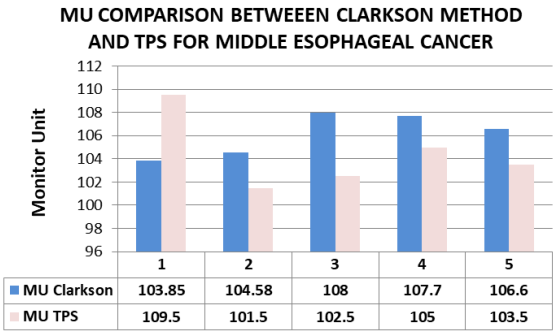

Figure 9. Comparison of MU between the Clarkson method and TPS for middle esophageal cancers

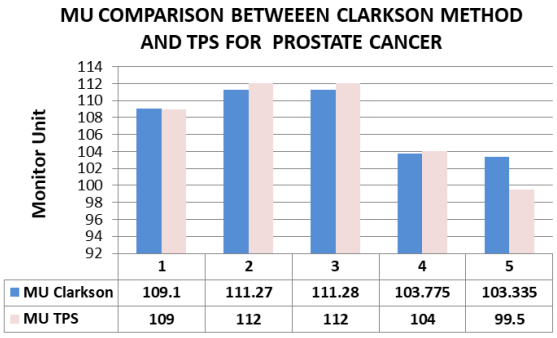

Figure 11. Comparison of MU between the Clarkson method and TPS for prostate cancer

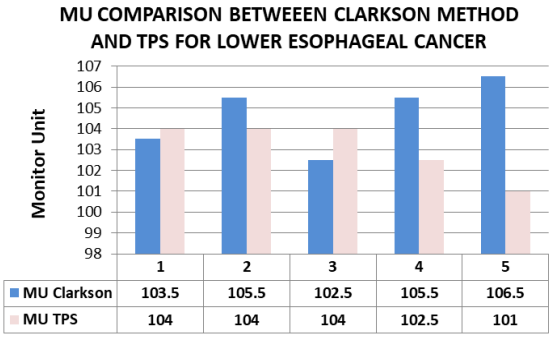

Figure 10. Comparison of MU between the Clarkson method and TPS for lower esophageal cancer

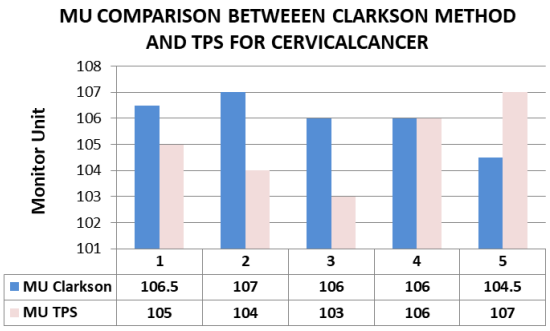

Figure 12. Comparison of MU between the Clarkson method and TPS for cervical cancer

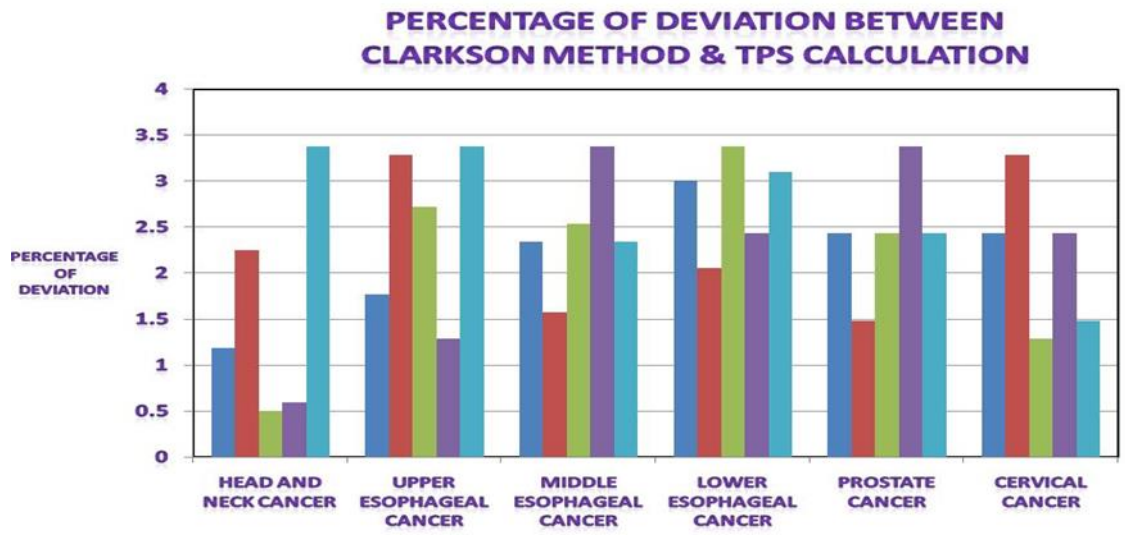

Figure 13. Comparison of percentage of deviation of dose between the Clarkson method and TPS

Table 3. Mean percentage of deviation and statistical significance between the Clarkson method calculated MU with TPS calculated MU

Sr. No	Name of the site	Mean Percentage of Deviation	Statistical significance
1	Head and neck cancer	1.58 ± 1.22	0.65
2	Upper esophageal cancer	2.48 ± 0.93	0.002
3	Middle esophageal cancer	2.43 ± 0.64	0.014
4	Lower esophageal cancer	2.79 ± 0.53	0.005
5	Prostate cancer	2.43 ± 0.67	0.62
6	Cervical cancer	2.18 ± 0.81	0.57

Discussion

Through this study, we attempted to estimate the MU for irregular fields by improvising shaper software which can shape the MLC and also that can estimate the area of the field shape and the radius of selected points in the field area. Clarkson J.R (1941) stated that the shape of the fields is not even approximately circular or squares used in radiotherapy treatments [12]. The variation of dose ΔD is stated as the function of radius r of the circle. A beam of any cross-sectional form may always be expressed as a sum of sectors of circular beams [13]. The MLC's coordinates were retrieved from the MLC log files and manually entered into the shaper program.

After comparing the MU determined by the TPS and the MU determined by the Clarkson technique, the percentage of variation was assessed. The dose calculation algorithm of TPS was an Anisotropic Analytical algorithm which always considers the inhomogeneous medium present in the beam path [14]. The MU estimated by the TPS through this algorithm has accounted for the differences in tissue mass density. The Clarkson method of calculation used the parameters of TMR and SMR. As a consequence of this, the Clarkson method-based calculation MU had differences in all the clinical sites from the TPS. This has led to deviation from the TPS calculation method as expressed in the table 2. The sites of esophageal cancers had the situation of encountering inhomogeneous medium and lung & muscle interfaces. This could also be the reason for the higher deviation between the Clarkson method and TPS-based calculation. It was also stated by J.R. Cunningham et al (1973) that dose calculations for irregularly shaped fields, such as mantle fields in Hodgkin's disease, were complex and challenging and typically required approximation techniques. and had constraints as well by the type of machine and measurement location [15].

The goal of constructing shaper software was to compute the shaped fields' average radius. Several researchers have previously examined this specific endeavor. To compare with the approximation approaches of Faiz M. Khan and Seymour et al., a computer program utilizing Clarkson's principle of distinguishing the primary and scattered components of dose at each point in the phantom based on Fortran CDC-3300 was developed. Using the coordinates of the field contour and the point of dose computation, the computer code subdivided the field into elementary sectors. Equations in mathematics were used in figuring out the sectors radii. Basic interpolation was used to assign SAR values to the sectors for the circular fields, and the average SAR values were the outcome. By combining the SAR with zero fields TAR, the computed average SAR values are transformed into TAR values. The inputs stored in the computers were SAR table published by Johns and Cunningham and off-axis ratio tables and corrected PDD values for the irregular fields were determined [16]. Tatcher et al analyzed the equivalent square concept applicability for arbitrary shaped fields and addressed the problem of encountering beams having a non-rectangular cross-section in radiotherapy treatment; expressed that the SAR values have to be found by deducting the zero field TAR from TAR of that particular depth [17]. Based on the empirical scatter radius function, Morris Tatcher, created the BJR equivalent table, and the equivalent squares determined by sector integration of experimental scatter data for various energies and depths. Further they suggested that the SAR tables used in the computers can be replaced by the empirical formula. A nine-parameter equation was framed and the estimated values of TAR were compared with the published values and measured values. The percentage of deviation was within 2%. The sector integration method was also attempted by several authors along with the compensator filter used in IMRT [18-20].

The relationship between square fields and circular fields was also evaluated in this study. The radius of the equivalent circles for square field sizes was estimated with the relationship s/d =0.891 and the same relationship has been utilized for estimating the output factor for the irregularly shaped fields. F.M. Khan et al(1973) expressed that Clarkson method is always tedious process when it is performed manually and also it is impractical do it without the help of computer programming in a busy clinic. In modern radiotherapy clinics the dose calculation shaped by MLC are done by highly sophisticated calculation algorithm in the TPS. Hence our work was to verify the accuracy of the dose calculation performed by the TPS algorithm through external independent method for which we have chosen the Clarkson method. However our verification had many limitations that all the sites have been considered as tissue equivalent whereas the TPS dose calculation algorithm would account for the in-homogeneities present in the beam direction as described by Kan MW(2011). The introduction of MLC shaper software which could give the average radius of the field was a significant improvisation in this study.

Conclusion

The Clarkson method was a standard and traditional method for performing dose calculation in irregular fields. Through this study we attempted to enhance this method of calculation by developing shaper software that estimated the average radius of the irregular fields. By extending the TMR curves field size values 0x0 cm^2, the scatter maximum ratio tables were created from the tissue maximum ratio table. To estimate the accuracy of the MUs calculated by both methods the respective MUs were delivered in the Imatrix phantom and the percentage of deviation was estimated.

In conclusion, all esophageal tumors had significant differences. However, no significant difference was found for Head & Neck, Prostate, and Cervical cancers. This could possibly be due to the shaper software's limitations or the necessity for a more advanced dosage-calculating technique.

The shaper software has to be improved further with the ability to directly import MLC plans from the TPS and account for comparable depth and effective density in order to improve the accuracy of MU computed using the Clarkson technique. The calculation spreadsheet may be improved by accounting for the equivalent depth, which can then be accounted for throughout the MU calculation process. By taking these factors into account, the Clarkson method's MU computation will be more accurate and comparable to the TPS.

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