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Verification of Monitor Unit Calculations for Eclipse Treatment Planning System by in-House Developed Spreadsheet

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ABSTRACT

Introduction: Computerized treatment planning is a rapidly evolving modality that depends on hardware and software efficiency. Despite ICRU recommendations suggesting 5% deviation in dose delivery the overall uncertainty shall be less than 3.5% as suggested by B.J. Minjnheer. J. In house spreadsheets are developed by the medical physicists to cross-verify the dose calculated by the Treatment Planning System (TPS).
Materials and Methods: The monitor unit verification calculation (MUVC) verification was tested for pre-approved and executed treatment plans taken from the TPS. A total of 108 square fields and 120 multileaf-collimators (MLC) shaped fields for Head & Neck cancers, cervical and esophageal cancers were taken for evaluation. In house developed spreadsheet based on Microsoft Excel was developed. The dose calculation parameters such as Output Factor (O.F), Percentage Depth Dose (PDD) and off axis ratio (OAR) data were taken from the TPS.
Results: The overall MU ratio fell within the range of 0.999 to 1.02 for square field geometries showing deviation of 1% between the TPS calculation and the spread sheet calculation. The MU ratios were 0.995 for Head & Neck plans & 1.012 for cervix plans with the standard deviation of 0.024 & 0.029 respectively. However we observed the mean MU ratio for Esophagus plan was 1.026 with the standard deviation of 0.040.
Conclusion: The spreadsheet was tested for most of the routine treatment sites and geometries. It has good agreement with the Eclipse TPS version 13.8 for homogenous treatment sites such as head &and neck and carcinoma cervix.

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Introduction

Radiotherapy is a form of treatment in which ionizing radiations are directed towards the tumor that eradicating the cancer cells. At least 50% of the patients with malignancies require radiotherapy treatment in their course of treatment either exclusively or combined with other modalities [1]. Curative radiotherapy is aimed at providing best local control and preserves the function of normal surrounding structures. The accuracy of the delivered dose must be less than ±5% of the prescribed dose [2, 3, 4].Treatment delivery is associated with daily patient setup, dose calculation & dose delivery. All these parameters are monitored and kept in tight tolerance to achieve overall accuracy. Calculating dose per monitor unit at the calculation point is essential to ensure accurate dose delivery.

In-hand monitor unit calculations can be performed for simple geometry fields. Computer-based calculation is required for advanced techniques such as 3D conformal radiotherapy, and intensity modulated radiotherapy etc. This is accomplished by delivering the suitable radiation dose accurately to the tumor with meticulous computerized planning in the Treatment Planning system (TPS).Computerized treatment planning is a rapidly evolving modality that depends on hardware and software efficiency [5]. Despite various ICRU recommendations suggest 5% deviation in dose delivery the overall uncertainty shall be less than 3.5% as suggested by Minjnheer.[6-8] .

TPS is commercially available are available which functions with different techniques to determine dose [9-11]. To ensure accurate dose delivery to the patients independent or secondary verification of monitor units (MU) check is preferred [11-14]. The TPS calculation being a part of overall uncertainty, measures should be taken to reduce the errors in calculation. TPS dose calculation is validated either by hand calculations or by homegrown software [15-17]. Although modern TPS performs sophisticated

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calculations improper use and software faults can result in radiation accidents [18].In house spreadsheets are developed by the clinical medical physicists to cross verify the dose calculated by the TPS. The Task Group 40 &and 114 recommends that the calculation results of any TPS should be independently verified [19-20].The presence and aid of computers will surely reduce the time consumed for manual checks.

The aim of this present work was to develop a spreadsheet program (MS-Excel based) for MU verification calculations (MUVC) for square fields, rectangular fields, as well as complex and irregular shaped photon beams used in 3D conformal radiotherapy. The quantities necessary for dose calculation such as total scatter factor (Sc,p), tissue maximum ratio (TMR)are taken from the measured beam data. We aimed to estimate the accuracy of in-house developed spread-sheet for MU calculations performed for the conventional and 3D conformal radiotherapy techniques compared with eclipse TPS.

Materials and Methods

The MUVC was tested for pre-approved and executed treatment plans taken from our TPS database (Make: Varian Medical System, Model, Eclipse version 13.7). The treatment plans were made for Linear Accelerator (Make: Varian Medical Systems, Clinac 2100CD, Palo Alto, CA) with [integrated 80 leaf Multileaf collimator] for 6MV X-ray beams. The commissioned beam data are present in the TPS for dose calculation. The performance of the TPS was ensured at the time of commissioning by TPS QA test recommended by TRS 430.

In- house developed spreadsheet based on MS-Excel was used in this study. The necessary dose calculation parameters such as Output Factor (O.F), Percentage depth Dose (PDD) and off axis ratio (OAR) data were taken from the TPS. The OF & PDD values were taken for the field sizes of 4x4, 6x6,8x8,10x10,12x12,15x15,20x20,25x25,30x30,35x35, and 40x40 cm^2 square field sizes. The OAR values were taken for the same mentioned field sizes at the depths of d_{max}, 5cm, 10cm, 15cm, 20cm and 30cm. These parameters were fed in MS- Excel software and calculation spreadsheet was generated by developing a look- up table.

Calculation Formalism

The calculation formula for MU checks were programmed in the MS-Excel software. A look-up table was framed for PDD values against all the field sizes. The output factors for square fields were fed in the spreadsheet and missing values were obtained through Lagrange interpolation. The parameters mentioned in table 1 were used for calculating MUs.

Calculation Method

SSD Technique

Monitor unit calculations require PDD data as a prime input for determining the MU for SSD beam delivery. The MU required to deliver dose (D) at depth (d) for the field size (A_s) is determined as below in Figure 1.

$$MU = \frac{D\ x100}{D0xScpxPDD(d,A,SSD)xWFxOAR} \tag{1}$$

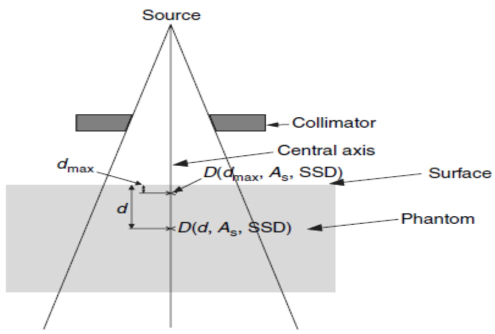


Figure 1. Dosimetric setup for SSD-based calculation

Table1. Essential input parameters required for in-house dose calculation

Sr. No	Symbol of input parameter	Nomenclature	Definition
1	D	Prescribed tumor dose	Dose prescribed per fraction for tumor eradication
2	D_0	Reference dose rate	Dose rate per MU under normal reference conditions
3	S_{cp}	Total scatter factor	Ratio of dose per MU in phantom for a given field size to that of reference field size
4	A_d	Field size	Field size defined at the depth d
5	As	Field size	Field size defined at the surface
6	PDD	Percentage-depth- dose	ratio of dose rate at depth d, to that of dose rate at d_{max} in water phantom for a given field size defined at source to surface distance
7	TMR	Tissue Maximum Ratio	ratio of dose rate at depth d, to that of dose rate at d_{max} in water phantom for field size defined at SAD
8	WF	Wedge Factor	Wedge factor is the ratio of dose rate at the point of calculation for a wedged field to that for a same field without wedge modifier
9	OAR	Off Axis Ratio	The ratio of the open field dose rate at an off-axis point to that for the same field shifted such that the point of calculation lies on the central axis

Source to axis distance isocentric technique: The SAD calculations require TMR as the input data and MU calculation is performed as shown in Figure 2.

$$MU = \frac{D}{D0\ x\ Scp\ x\ TMR(d,Ad,)\ x\ WFxOAR} \quad (2)$$

Isocentric 3D CRT Plans

Verification was performed for sites namely brain, head & neck, esophagus, abdomen, pelvis, prostate and rectum as shown in table 2 . The treatment plans were mainly isocentre based performed by 6MV X-rays. Additionally the MUVC checks are performed for open beam square, rectangular fields along central axis and off axis points for both SSD and SAD techniques.

The majority of the plans were planned on isocentre based; the calculation formula for isocentric method was used for calculating MU for the conformal radiotherapy plans as well. The inputs required for MUVC were effective area (cm^2), water equivalent depth (cm), total dose (cGy), and dose per field (cGy), and beam weightings (%) were taken from the TPS. Various planning tools available in the eclipse TPS were used for obtaining the inputs for MUVC verification. The effective area was calculated by creating a field aperture contour in plan parameters workspace (Figure 3).

The obtained effective area was square rooted and side of Equivalent Square was obtained. The water equivalent depth (d_{eff}) is calculated from the Water Equivalent Depth (WED) tool in the TPS (Figure 4); d_{eff} =d x ρ is the radiological depth that accounts the mass density (ρ) and distance (d) of the calculation point.

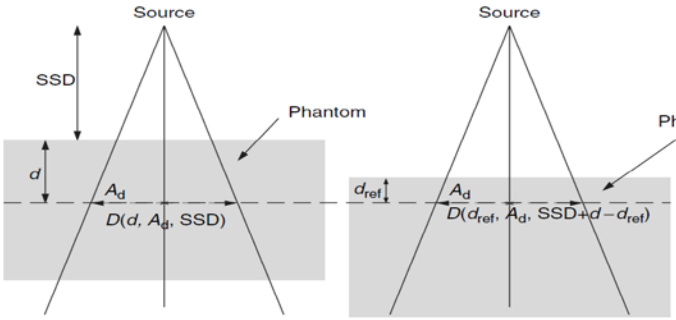


Figure 2. Dosimetric setup for SAD isocentre based calculation

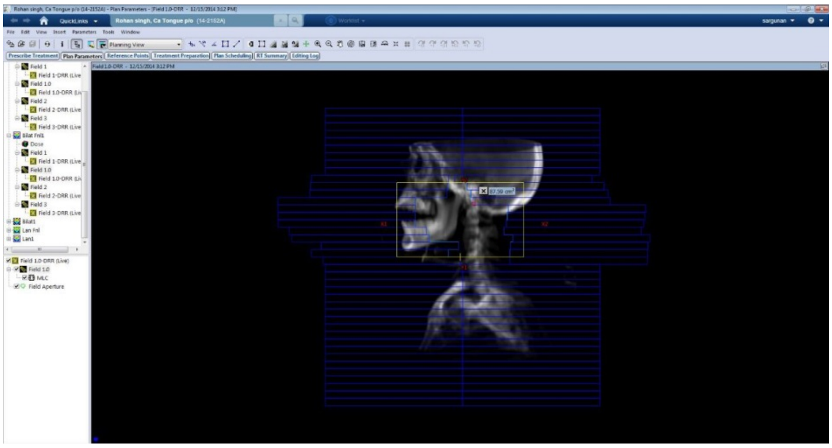


Figure 3. Measurement of effective area from the plan parameter workspace

Table 2. Treatment sites taken for monitor unit verification calculation

Sr. No	Site	Treatment technique	Setup(SAD/SSD)	No of fields taken for MUVC
1	Head and neck	MLC - based 3D Conformal Technique	SAD	40
2	Esophagus	MLC- based 3D Conformal Technique	SAD	40
3	Cervix	MLC- based 3D Conformal Technique	SAD	40

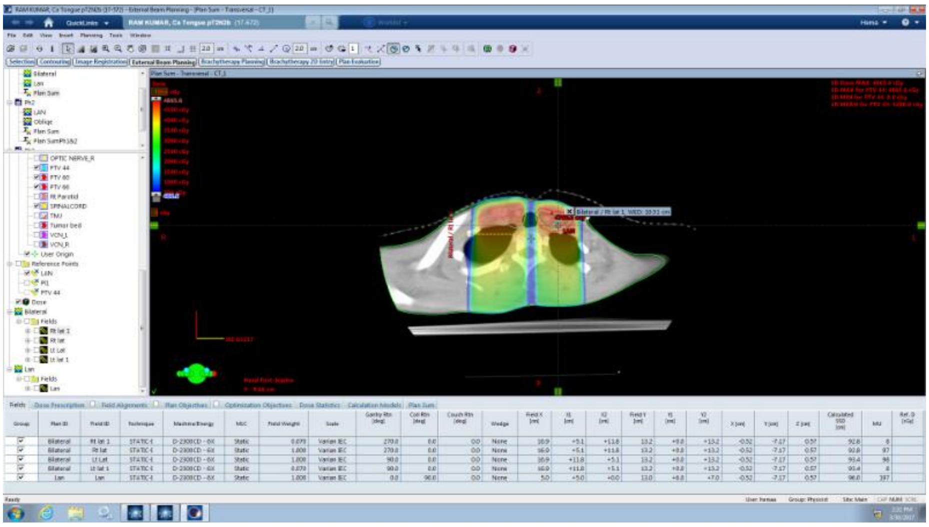


Figure 4. Calculation of water equivalent depth

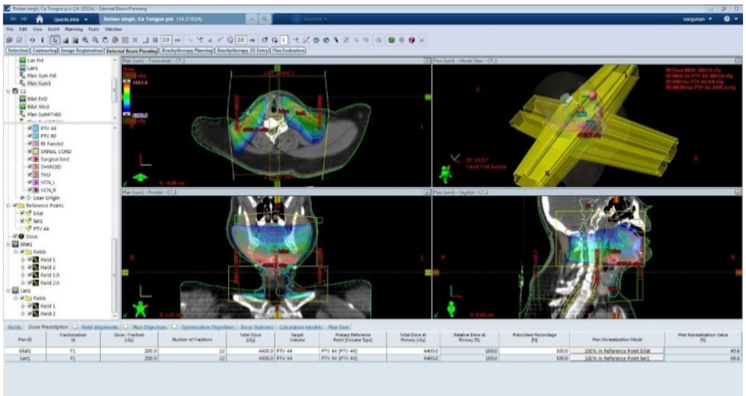


Figure 5. Bilateral and lower anterior neck field placement for Head and Neck

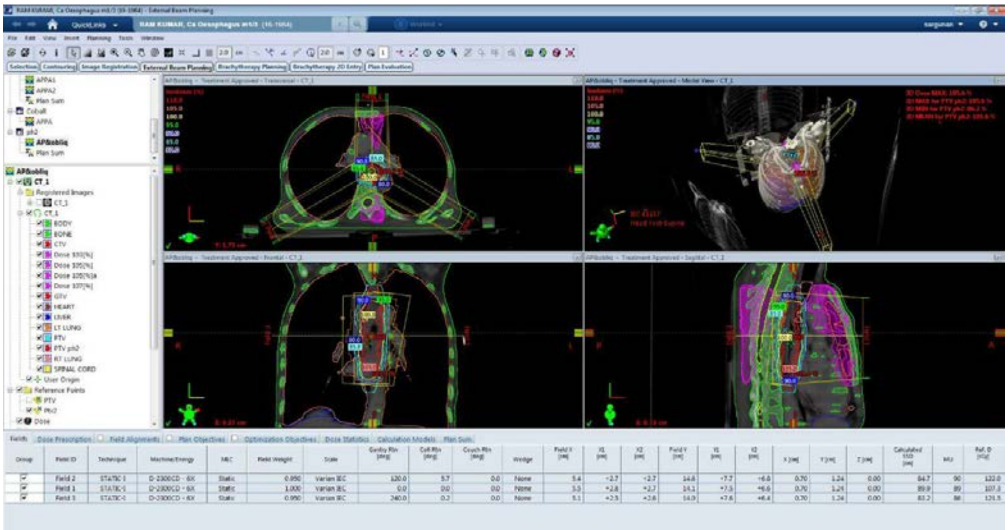


Figure 6. Treatment plan for esophageal cancer

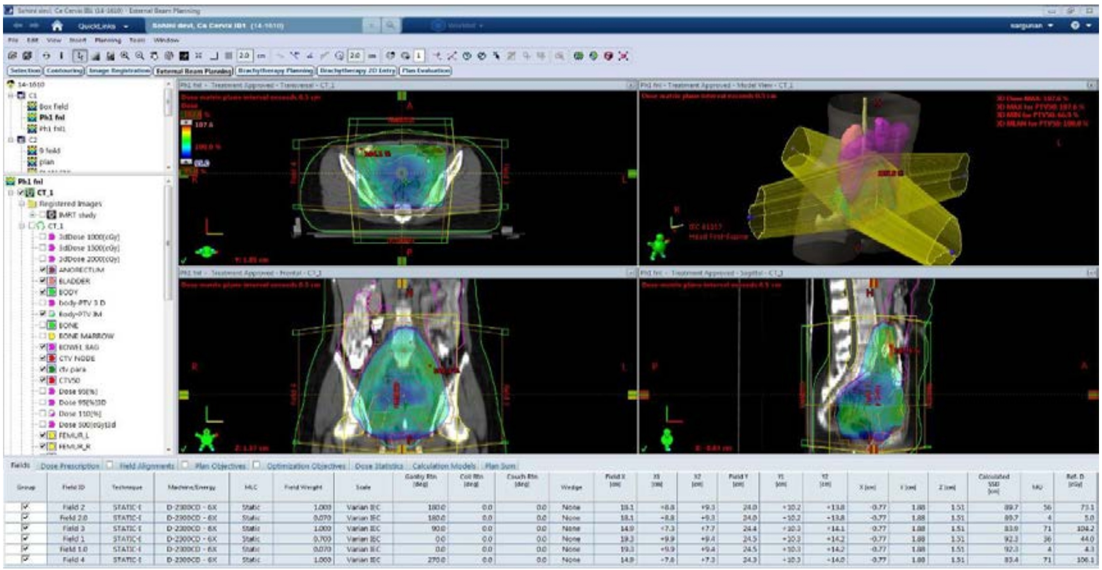


Figure 7. Treatment plan for cervical cancer

The effective area and WED were given as input in the spreadsheet; VLOOKUP and HLOOKUP operations from the excel spreadsheet gave values for PDD and TMR. The O.F values were obtained for the square rooted side of equivalent square. The dose per fraction and its respective beam weightings inputs were provided finally for estimating the MU values. The MU values were calculated as per Equation 2.

The concept of MU ratio was estimated between the TPS calculation MU and hand calculation of MU.

$$MUratio = \frac{TPScalculatedMU}{SpreadsheetcalculatedMU} \quad (3)$$

Head and neck: The plans usually consisted of bilateral and lower anterior neck (LAN) fields. We have mainly selected tongue cancer and carcinoma of buccal mucosa with the level IV nodal involvements that required lower neck irradiation. Single isocentre was maintained as both the bilateral and LAN fields were of half beam blocked fields to avoid generating hotspots [figure 5].

Treatment plans are normalized by creating a reference point to achieve acceptable planning target volume coverage. Effective area and WED details were obtained from the TPS as described above

Esophagus: The esophagus cases were planned using the traditional approach of delivering adequate dose through oblique fields up to the tolerance of lungs [Figure 6.]

MLCs were used for shielding the organs at risk such as lung. Further additional dose were delivered through AP-PA method. Majority of the treatment plans were normalized on the reference point that gave adequate coverage.

Cervix: Four field box techniques were used for the treatment plans for cervical cancer cases. The plans were normalized either at isocentre or at a reference point (Figure7). MLC leaves were utilized for shielding the organs at risk such as the bladder and rectum.

Results

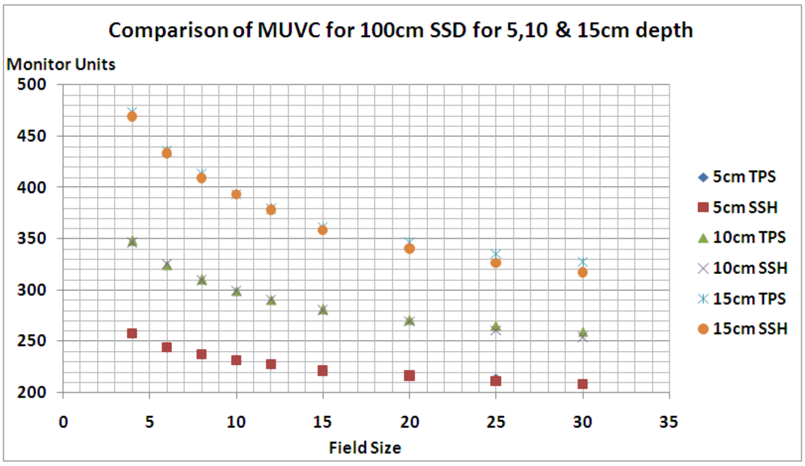
a) Verification of Open Beam Square Fields(SSD and Isocentric Technique):

The MU required for delivering 200cGy was estimated for mainly three depths of 5cm, 10cm, and 15cm for square fields and fixed SSD of 100cm. The calculated MUs by the spreadsheet and by the TPS are shown in Table 3. The MU ratio values for each field size at all the depths are presented in the table. The mean MU ratios for 5cm, 10cm and 15cm depths were 1.002 ± 0.004, 1.006±0.007, & 1.012 ± 0.011 respectively. The comparison of MU for all the above depths is presented in Figure 8.

Similarly, the isocentre-based open beam MUs were estimated by the spreadsheet displayed in Table 4. The mean MU ratio for 5cm,10cm and 15cm depths were 0.999 ± 0.01 , 0.999 ± 0.01 and 1.02 ± 0.01. MU comparison is exhibited in Figure 9.

Table 3. Comparison of Monitor Units between treatment planning system and spreadsheet for square field size at 100cm SSD

		Square field size(cm²)								
Depth		4	6	8	10	12	15	20	25	30
5cm	TPS Calculated MU	257	244	237	231	227	221	216	214	209
	Spread sheet Calculated MU	257	244	237	231	227	221	216	211	208
	MU Ratio	1.002	0.999	1.00	1.00	1.00	1.00	1.00	1.013	1.004
		4	6	8	10	12	15	20	25	30
10cm	TPS Calculated MU	348	324	310	299	290	281	271	265	259
	Spread sheet Calculated MU	346	325	309	299	290	280	269	260	254
	MU Ratio	1.005	0.998	1.004	1.002	1.000	1.003	1.009	1.019	1.018
		4	6	8	10	12	15	20	25	30
15cm	TPS Calculated MU	473	435	413	393	379	361	346	335	327
	Spread sheet Calculated MU	469	433	409	393	378	358	340	326	317
	MU Ratio	1.009	1.004	1.010	1.000	1.003	1.007	1.018	1.027	1.032



MU: monitor unit
TPS: Treatment planning system

Figure 8. Comparison of monitor unit verification calculation at 100cm SSD for 5, 10 and 15 cm depths for isocentric technique

Table 4. Comparison of monitor units between treatment planning system and spreadsheet for isocentric technique

			Square Field Size(Cm²)								
Depth	SSD		4	6	8	10	12	15	20	25	30
5cm	95cm	TPS Calculated MU	234	222	215	210	206	201	197	194	190
		Spread sheet Calculated MU	234	221	216	211	207	202	198	195	193
		MU Ratio	1.005	0.995	0.995	0.973	0.995	0.995	0.995	0.995	0.982
			4	6	8	10	12	15	20	25	30
10cm	90cm	TPS Calculated MU	290	271	258	249	242	234	225	219	215
		Spread sheet Calculated MU	290	276	262	252	245	237	227	220	214
		MU Ratio	1.00	0.982	0.986	0.989	0.987	0.989	0.992	0.994	1.004
			4	6	8	10	12	15	20	25	30
15cm	85cm	TPS Calculated MU	363	331	317	303	291	279	265	256	249
		Spread sheet Calculated MU	363	331	315	301	289	276	264	252	247
		MU Ratio	1.00	1.011	1.011	1.014	1.006	1.010	1.022	1.027	1.036

MU: monitor unit
TPS: Treatment planning system

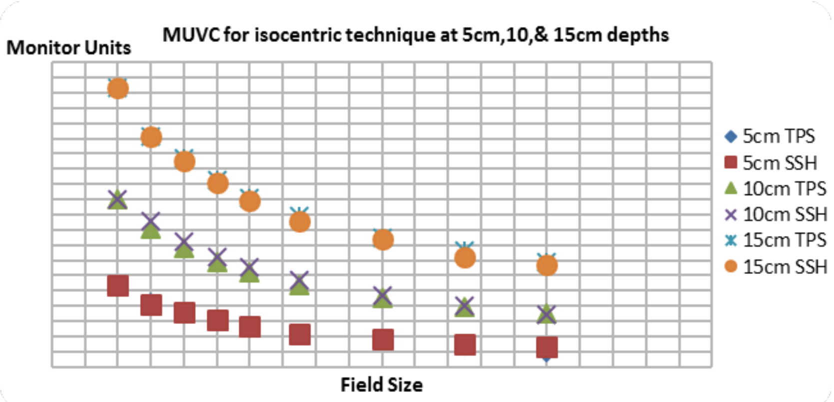


Figure 9. Comparison of monitor unit verification calculation at 100cm SSD for 5, 10, and 15 cm depths for isocentric techniques

Table 5. Comparison of Monitor Units for 15 degree wedge between treatment planning system and spreadsheet for isocentric technique in 5,10,and 15cm depths

			Square Field Size(cm²)					
Depth	SSD		4	6	8	10	12	15
5cm	100cm	TPS calculated MU	338	322	310	304	298	292
		Spread sheet Calculated MU	332.82	317.05	307.50	300.50	294.35	287.79
		MU Ratio	1.016	1.016	1.008	1.012	1.012	1.015
			4	6	8	10	12	15
10cm	90cm	TPS Calculated MU	445	423	404	391	380	369
		Spread sheet Calculated MU	449.63	421.58	400.68	387.52	376.62	363.59
		MU Ratio	1.012	1.003	1.008	1.009	1.010	1.015
			4	6	8	10	12	15
15cm	85cm	TPS Calculated MU	618	566	532	512	493	473
		Spread sheet Calculated MU	608.61	562.40	531.02	510.09	490.40	465.21
		MU Ratio	1.015	1.006	1.002	1.004	1.005	1.017

MU: monitor unit
TPS: Treatment planning system

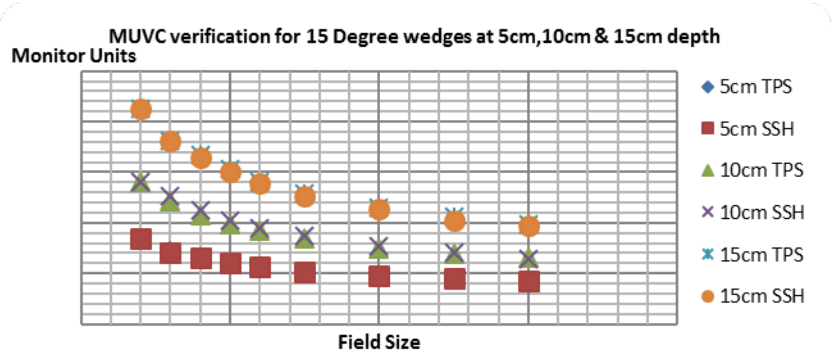


Figure 10. Comparison of monitor unit verification calculation at 100cm SSD for 5, 10 and 15 cm depths and 15 degree wedge

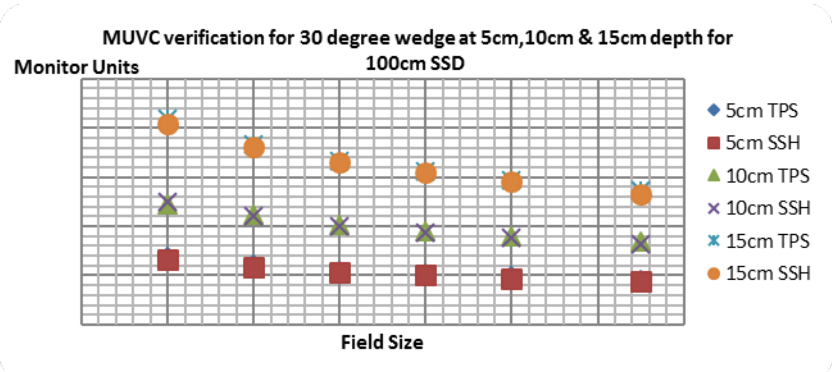


Figure 11. Comparison of monitor unit verification calculation in 5, 10 and 15 cm depths for 30 degree wedge and100 cm SSD

Table 6. Comparison of Monitor Units for 30-degree wedge between treatment planning system and spreadsheet for isocentric technique in 5, 10 and 15 cm depths

			Square Field Size(cm²)					
Depth	SSD		4	6	8	10	12	15
5cm	100cm	TPS calculated MU	338	322	310	304	298	292
		Spread sheet calculated MU	332.82	317.05	307.50	300.50	294.35	287.79
		MU ratio	1.016	1.016	1.008	1.012	1.012	1.015
			4	6	8	10	12	15
10cm	90cm	TPS calculated MU	445	423	404	391	380	369
		Spread sheet calculated MU	449.63	421.58	400.68	387.52	376.62	363.59
		MU ratio	1.012	1.003	1.008	1.009	1.010	1.015
			4	6	8	10	12	15
15cm	85cm	TPS calculated MU	618	566	532	512	493	473
		Spread sheet calculated MU	608.61	562.40	531.02	510.09	490.40	465.21
		MU ratio	1.015	1.006	1.002	1.004	1.005	1.017

MU: monitor unit
TPS: Treatment planning system

Table 7. Comparison of Monitor Units for 45-degree wedge between treatment planning system and spreadsheet for isocentric technique and 100 cm SSD

			Square field size(cm²)					
Depth	SSD		4	6	8	10	12	15
5cm	100cm	TPS calculated MU	529	504	490	475	469	458
		Spread sheet calculated MU	520	496	485	471	465	455
		MU ratio	1.018	1.018	1.010	1.008	1.009	1.019
			4	6	8	10	12	15
10cm	90cm	TPS calculated MU	702	659	632	611	596	575
		Spreadsheet calculated MU	702	658	626	605	590	571
		MU ratio	1.000	1.001	1.010	1.010	1.014	1.007
			4	6	8	10	12	15
15cm	85cm	TPS calculated MU	937	869	826	789	765	733
		Spreadsheet calculated MU	950	875	829	796	765	730
		MU ratio	0.986	0.993	0.996	0.991	0.999	1.009

MU: monitor unit
TPS: Treatment planning system

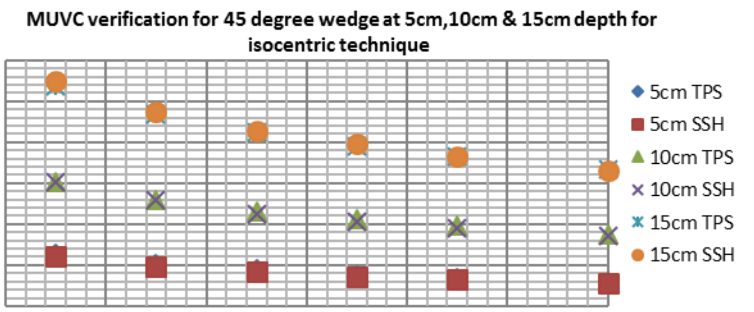


Figure12. Comparison of monitor unit verification calculation for 5, 10 and 15 cm depths for 45 degree wedge for 100 cm SSD

b) Verification of Physical Wedged Fields(Isocentric Technique):

Tables 5, 6, and 7 demonstrate the MU estimated from spreadsheet for 15°, 30°and 45° wedges and the MU estimated for the same setup by the TPS. The comparison of MU between TPS and spreadsheet is shown in figures 10, 11, and 12 for wedge angles 15, 30 and 45. The wedge factors were applied while calculating MU for the respective wedges. The average MU ratios for 15 degree wedges in 5cm, 10cm and 15cm depths were 0.992 ± 0.009, 0.991±0.006, and 1.015 ± 0.011, respectively.

For estimating MU for 30 degree wedge angle, wedge factors were applied in the spreadsheet. The calculated MU by spreadsheet increased as the wedge angle increased from 15 degree to 30 degree. The average MU ratios for 30 degree wedge angle in 5cm,10cm, and 15cm depths were 1.013 ± 0.003, 1.009 ± 0.004 and 1.008 ± 0.006, respectively.

A similar approach was adopted for estimating MU for 45 degree wedge angle; MU ratio was estimated for 5cm, 10cm, and 15cm depths; the average MU ratios were 1.0317± 0.005, 1.007 ± 0.005, and 0.995 ± 0.007, respectively .

c) Verification of 3DCRT Treatment Plans(Isocentre- Based Plans):

MUs for conformal radiotherapy plans were verified between TPS and spreadsheet for head and neck, esophageal and cervical cancers. Forty fields were taken for the evaluation of each case. All the fields were of open fields shaped by MLC. The comparison parameters were tabulated in tables 8, 9, and 10 for head and neck, esophageal and cervical cancers respectively. The comparison diagram for both methods of MU calculation is depicted in figures13, 14, and 15.

Mean MU ratio and average percentage deviation were calculated using the TPS and spreadsheet MU values. The average MU ratios for open fields for head and neck, cervical and esophageal cancers were 0.995 ± 0.024, 1.012 ± 0.029, and 1.026 ± 0.040 respectively. The observed average percent deviation for the above mentioned sites between TPS and spreadsheet calculations were 0.048, 1.16, and 2.45, respectively.

Table 8. Comparison of Monitor Units for head and neck cancers between treatment planning systems and spreadsheet

Field	Field name	Dose(cGy)	Depth(cm)	Area(cm^2)	MU TPS	MU calc	MU ratio	% Deviation
1	Bilat	100	4.9	101.61	101	102	0.99	-0.99
2	Bilat	100	5.3	105.21	105	107	0.981	-1.905
3	LAN	200	3.3	108.23	204	202.3	1.008	0.833
4	Bilat	92.8	5.9	139.45	98	97	1.01	1.02
5	Bilat	7.2	5.9	107.13	8	8	1	0
6	Bilat	92.8	5	144.7	98	98.1	0.999	-0.102
7	LAN	7.2	5	102.77	8	8	1	0
8	Bilat	90.4	8	118.08	104	105	0.99	-0.962
9	LAN	153.8	2.4	103.7	155	154	1.006	0.645
10	LAN	46.2	14.5	103.7	55	57	0.965	-3.636
11	Bilat	100	5.5	112.79	103	106	0.972	-2.913
12	Bilat	100	4.9	117.04	101	102	0.99	-0.99
13	LAN	200	1	88.9	197	208	0.947	-5.584
14	Bilat	100	5.3	124.65	103	105	0.981	-1.942
15	Bilat	100	5.7	123.17	103	105	0.981	-1.942
16	LAN	200	2.3	84.63	196	200	0.98	-2.041
17	Bilat	95.6	6.8	136.88	101	102	0.99	-0.99
18	Bilat	5.4	6.8	80.19	6	6	1	0
19	Bilat	94.2	6.6	136.88	102	101.3	1.007	0.686
20	Bilat	4.8	6.6	78.65	5	5	1	0
21	LAN	200	1	124.88	200	204	0.98	-2
21	Bilat	100	5	102.53	106	107.78	0.983	-1.679
22	Bilat	100	4.5	103.21	104	103.56	1.004	0.423
23	LAN	200	3.5	109.21	202	201.48	1.003	0.257
24	Bilat	92.5	5.5	137	97	97.08	0.999	-0.082
25	Bilat	8.5	6.5	111	7	7.1	0.986	-1.429
26	Bilat	94	4.5	148	96	95.5	1.005	0.521
27	LAN	8	4.5	148	8	8.12	0.985	-1.5
28	Bilat	95	7.5	120	103	104.96	0.981	-1.903
29	LAN	158	2.5	106	153	155.86	0.982	-1.869
30	LAN	45	4.5	105	45	46.58	0.966	-3.511
31	Bilat	100	5	114	108	107.17	1.008	0.769
32	Bilat	100	4.5	118	104	102.87	1.011	1.087
33	LAN	200	2.5	92	197	198.8	0.991	-0.914
34	Bilat	100	5	124	105	106.64	0.985	-1.562
35	Bilat	100	5.7	122.17	106	105.29	1.007	0.67
36	LAN	200	2.5	84.63	200	199.15	1.004	0.425
37	Bilat	95.6	6.8	136.88	104	102.53	1.014	1.413
38	Bilat	6.5	6.7	82.12	8	7.2	1.111	10
39	Bilat	96	6	135.21	103	104.69	0.984	-1.641
40	Bilat	5.2	6.5	81.21	6	5.79	1.036	3.5

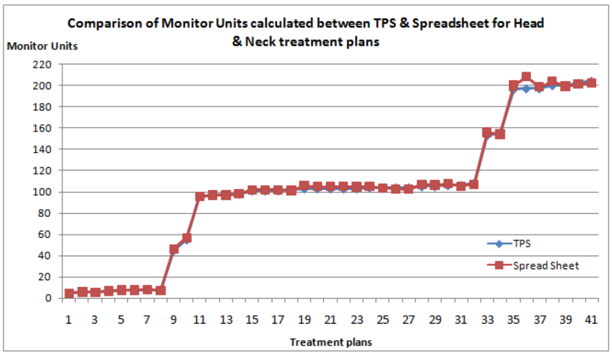


Figure 13a

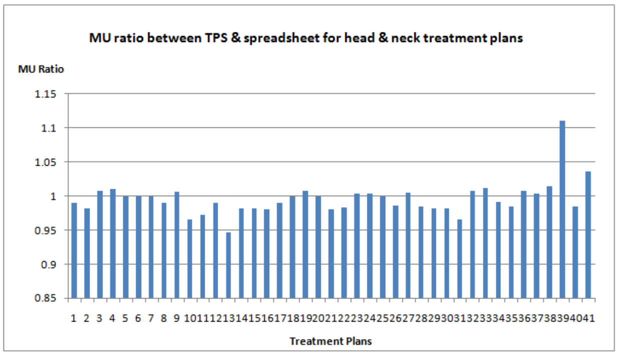


Figure 13b

Figure 13. Comparison of monitor unit (MU) for head and neck treatment: **13a:** MU comparison between treatment planning system(TPS)and spreadsheet calculations;**13b)** MU ratio calculated between TPS and spreadsheet

Table 9. Comparison of monitor units for cervical cancer between treatment planning system and spreadsheet

Field	Field name	Dose(cGy)	Depth(cm)	Area(cm²)	MU TPS	MU calc	MU ratio	% Deviation
1	Lt Lat	49.4	16.1	216.6	73	70.79	1.031	3.015
2	AP	42	11.4	299.51	51	49.51	1.03	2.91
3	Rt Lat	49.4	16.4	217.04	73	70.29	1.038	3.701
4	PA	59.2	8.5	285.59	65	64.59	1.006	0.625
5	AP	55	8.2	234.08	61	61.02	1	-0.039
6	Lt Lat	50	14.3	166.38	71	68.29	1.04	3.815
7	PA	45	9	241.78	50	51.52	0.97	-3.045
8	Rt Lat	50	14.2	168.04	69	68.42	1.008	0.84
9	Lt Lat	51.2	17.2	201.55	78	76.02	1.026	2.534
10	AP	30.8	10.8	299.34	37	35.19	1.051	4.865
11	Rt Lat	51.2	14.9	192.55	73	68.24	1.07	6.518
12	PA	66.6	10.4	264.61	79	77.27	1.022	2.178
13	AP	47.6	9.4	313.87	54	53.16	1.016	1.554
14	PA	57.2	9	291.49	65	64.72	1.004	0.43
15	Lt Lat	47.6	18	214.84	70	72.43	0.966	-3.476
16	Rt Lat	47.6	17.3	211.58	70	69.90	1.001	0.129
17	AP	40	11.8	288.28	49	46.98	1.043	4.117
18	PA	60	9.1	257.99	69	68.26	1.011	1.059
19	Lt Lat	50	17.1	199.29	78	74.44	1.048	4.556
20	Rt Lat	50	17.3	199.88	78	74.08	1.053	5.017
21	Lt Lat	46.8	18	190.62	75	72.56	1.034	3.246
22	Lt Lat	3.6	18	70.43	6	6.21	0.965	-3.586
23	AP	36.4	9.7	252.11	43	41.00	1.049	4.65
24	Rt Lat	46.8	16.4	187.16	72	67.75	1.063	5.893
25	Rt Lat	3.6	16.4	72.48	6	5.70	1.053	4.993
26	PA	62.6	10.2	242.88	75	73.55	1.02	1.928
27	Lt Lat	52.1	15	217	71	72.04	0.986	-1.465
28	AP	49	10.5	294	55	56.4	0.975	-2.545
29	Rt Lat	48	15.5	215	67	66.02	1.015	1.463
30	PA	58	9	287	68	65.79	1.034	3.25
31	AP	53	7.5	231	55	56.95	0.966	-3.545
32	Lt Lat	48	14	168.21	64	65.98	0.97	-3.094
33	PA	47	8	238.23	51	52.34	0.974	-2.627
34	Rt Lat	48.5	15.2	165.21	68	69.02	0.985	-1.5
35	Lt Lat	52.21	16.5	210.21	74	74.19	0.997	-0.257
36	AP	31.5	10	311.12	36	36.51	0.986	-1.417
37	Rt Lat	49.45	16	195.21	72	71.71	1.004	0.403
38	PA	63.21	10.21	267.21	75	73.63	1.019	1.827
39	AP	49.21	8.5	316.21	52	53.38	0.974	-2.654
40	PA	55.2	9.4	295.21	62	61.76	1.004	0.387

MU: monitor unit TPS: Treatment planning system

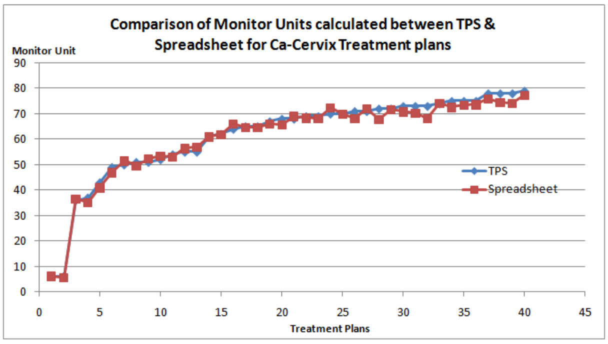


Figure 14a

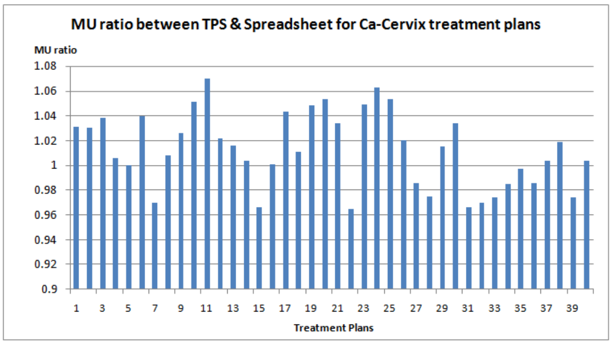


Figure 14b

Figure14.Comparison of monitor unit (MU) for cervical treatment plans; **14a)** MU comparison between TPS and spreadsheet. **14b)** MU ratio calculated between TPS and spreadsheet

Table 10. Comparison of Monitor Units for esophagus between treatment planning system and spreadsheet

Field	Field name	Dose(cGy)	Depth(cm)	Area(cm^2)	MU TPS	MU calc	MU ratio
1	Oblique	83.8	9.6	94	95.54	0.984	-1.64
2	PA	9.4	9.6	12	11.62	1.032	3.119
3	Oblique	93	8.5	104	103.31	1.007	0.66
4	Oblique	14	8.5	17	16.95	1.003	0.256
5	AP	100	9.3	112	113.67	0.985	-1.5
6	PA	100	9.5	118	114.53	1.03	2.941
7	AP	5	7.9	48	44.8	1.071	6.667
8	AP	89.6	7.9	8	7.9	1.013	1.25
9	Oblique	6	11.1	9	8	1.125	11.111
10	Oblique	99.6	11.1	128	128.57	0.996	-0.447
11	PA	94.4	9.3	111	115.09	0.964	-3.692
12	AP	94.4	6.3	107	104.31	1.026	2.509
13	AP	5.6	9.3	7	7.21	0.97	-3.123
14	AP	5.6	6.3	7	6.48	1.079	7.338
15	Oblique	57.2	12.9	76	75.86	1.002	0.174
16	PA	57.2	10.8	72	71.02	1.014	1.347
17	AP	57.2	10.9	69	70.98	0.972	-2.871
18	Oblique	28.6	10	38	36.14	1.051	4.886
19	AP	85.8	6.8	97	94.67	1.025	2.393
20	AP	85.8	5.5	41	40	1.025	2.439
21	PA	14.2	6.8	7	7.1	0.986	-1.429
22	AP	14.2	5.5	6	5.5	1.091	8.333
23	PA	97.4	8.7	108	109.59	0.985	-1.478
24	PA	7	8.7	8	8.20	0.975	-2.61
25	PA	88.4	9.4	105	102.95	1.02	1.947
26	PA	7	9.4	10	8.78	1.138	12.144
27	AP	87.2	10.6	107	104.56	1.023	2.278
28	AP	97.8	9	118	114.78	1.028	2.722
29	AP	5.8	10.6	8	7.46	1.071	6.63
30	PA	9.4	9	12	11.89	1.009	0.914
31	PA	66.6	6.8	77	74.40	1.035	3.366
32	AP	63.4	8.8	77	75.38	1.021	2.097
33	AP	26.6	5.2	31	29.37	1.055	5.256
34	AP	43.4	7.1	56	51.32	1.091	8.347
35	AP	93	6.8	106	101.00	1.049	4.712
36	PA	74.4	8.8	88	86.21	1.021	2.033
37	AP	9.4	6.8	11	10.92	1.007	0.718
38	PA	9.4	8.8	12	11.55	1.039	3.71
39	AP	120	5.4	125	122.08	1.024	2.332
40	PA	80	10.8	94	91.90	1.023	2.226

MU: monitor unit TPS: Treatment planning system

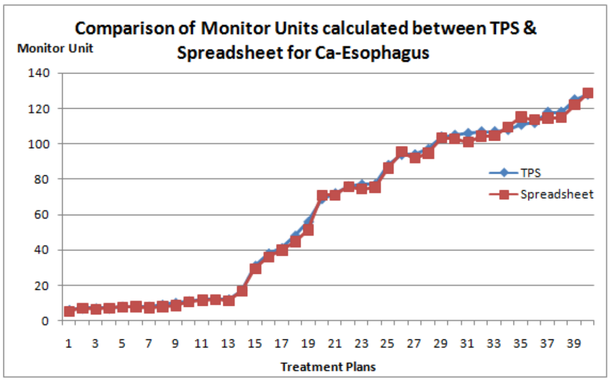


Figure 15a

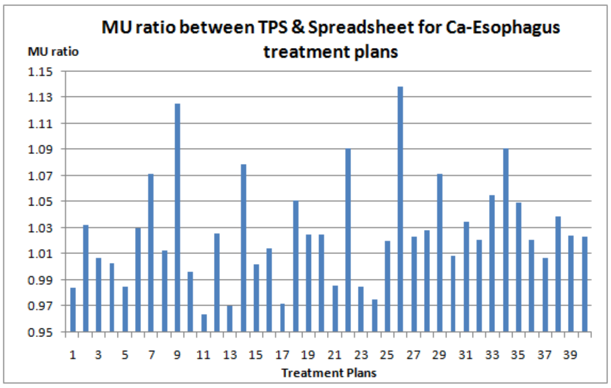


Figure 15b

Figure15. Comparison of monitor unit (MU) for esophageal cancer treatment plans; **15a)** MU comparison between treatment planning system (TPS) and spreadsheet. **15b)** MU ratio calculated between treatment planning system (TPS) and spreadsheet

d) Summary of MU Comparison Between TPS And Spreadsheet

The summary of MU ratio and percentage of deviation for SSD and isocentric methods are shown in table 11a. Similarly, the MU ratio details for physical wedges are presented in table 11b.

The statistical significance between the TPS calculated MU and spreadsheet calculated MU was estimated through paired t -test and tabulated is tabulatedin11c. No significant difference was observed between the two methods of calculation.

Table 11a. Mean monitor unit ratio and percentage deviation for square fields for fixed SSD and isocentric method

	Mean MU ratio			Percentage deviation from TPS		
	5cm	10cm	15cm	5cm	10cm	15cm
Square fields @ 100cm SSD	1.002 ± 0.004	1.006±0.007	1.012 ± 0.011	0.208±0.474	1.205±1.06	0.611±0.800
Isocentric Square fields	0.999 ± 0.01	0.999 ± 0.01	1.02 ± 0.01	-.452±0.536	-0.889 ± 0.753	0.644 ±0.494

MU: monitor unit TPS: Treatment planning system

Table 11b. Mean monitor unit ratio and percentage deviation for physical wedges

Wedge angle	Mean MU ratio			Percentage deviation from TPS		
	5cm	10cm	15cm	5cm	10cm	15cm
15 degree	0.992 ± 0.009	0.991±0.006	1.015 ± 0.011	-0.452 ± 0.536	0.889 ± 0.753	-0.644 ± 0.494
30 degree	1.013 ± 0.003	1.009 ± 0.004	1.008 ± 0.006	1.109 ± 0.431	0.630 ± 0.446	-0.486 ± 0.643
45 degree	1.0317± 0.005	1.007 ± 0.005	0.995 ± 0.007	1.104 ± 0.421	0.741 ± 0.321	0.846±0.123

MU: monitor unit TPS: Treatment planning system

Table 11c. Mean monitor unit ratio and percentage of deviation for head and neck, cervical and esophageal cases

	Number of fields	Mean MU ratio	Percentage deviation from TPS	Statistical significance
Head and neck	40	0.995 ± 0.024	-0.483 ± 2.33	0.013
Cervix	40	1.012 ± 0.029	1.166 ± 2.915	0.006
Esophagus	40	1.026 ± 0.040	2.451 ± 3.70	0.001

MU: monitor unit TPS: Treatment planning system

Discussion

In this work, we sought to estimate the accuracy of in-house developed spreadsheet with TPS. The comparison was made for fixed SSD beams, Isocentric open square fields, and isocentric based 3D conformal treatment plans for head and neck, cervical cancers.

As per TG-40, the acceptable deviation for the secondary MU check is 2%. The average percentages of deviation for open square fields were 0.208, 1.205, and 0.611. Smaller deviations were expected due to the uniformity of square fields and the homogenous phantom medium taken for dose calculation. The MU values for isocentric beams gave the percentage of deviations of -0.452, -0.889, and 0.644 from the TPS values. In our designed spreadsheet, the TMR values were calculated from the measured PDD values; a similar method of calculation was incorporated in most of the commercial TPSs. The lesser deviation ensured that the spreadsheet can be used for both methods of, SSD and SAD-based treatment. Additionally it ensured that the traditional method of estimating the TMR values from the measured PDD values can still be continued.

The mean MU ratios for square fields for fixed SSD technique and isocentre beams were within the acceptable range for the taken depths of 5cm, 10cm,and 15cm. We observed a higher value of 1.02 ± 0.01 for 15cm depth. The overall MU ratio lies within the range of 0.999 to 1.02 for square field geometries, which shows a deviation of 1% between the TPS calculation and the spread sheet calculation. Chanetal [7] and Starkshallet al[10].presented similar results in their studies. These two authors showed their work on the Pinnacle planning system and they presumed that the deviation may be due to precision in determining the beam entry point while other factors are kept constant.

The percentage of deviation of MU for the three physical wedges of 15, 30, and 45 degree were estimated for three depths, namely 5cm, 10cm, and 15cm listed in table 11b. It is observed that the entire physical wedge MUs estimated by the spreadsheet were within the acceptable tolerance of 2%. Higher deviations of 1.109 and 1.104were observed for 30 and 45 degree wedges at 5cm depth; this deviation was also under the recommended tolerance of 2%.

The 15 degree wedges had the mean MU ratio of 0.992 for 5cm and 10cm depths and 1.015 for 15 cm depth. This ensured that the open beam geometries with wedge as the only beam modifying device had a good agreement with the TPS dose calculations. It was anticipated that the MU ratio should be near unity for these simple geometric fields in the absence of in heterogeneities, filed shape irregularities, and off axis corrections.

The MU ratios were estimated for head and neck, cervix and esophagus cases only. A total of 40 fields for each treatment site were taken for estimation. The MU ratio was 0.995 for Head and Neck plans and 1.012 for cervix plans with standard deviations of 0.024 and 0.029 respectively. However we observed that mean MU ratio for esophagus plans was 1.026 with the standard deviation of 0.040. This higher deviation from the TPS should be addressed. This deviation may be due to the heterogeneity, and lung tissue interface present in the beam path. This type of deviations can be well accounted by highly sophisticated algorithms. To overcome the deviations in the heterogeneity situations, the spreadsheet should be configured for accounting the situations. The limitation of the present spreadsheet was of lack of accounting for the difference in tissue densities. Konrad et al [11] also observed that the independent MU checks have limitations in heterogeneity situations and mentioned that the accuracy varies with treatment site.

The development of spreadsheets for MUVC is addressed by several authors. Independent MU checks are essential to ensure delivering the proper dose to the patients to achieve the ICRU recommendations. This study was performed for a limited number of fields for mostly treated sites in our institution. MUVC verifications gave the accuracy levels of our TPS system for the tested cases. The framing of spreadsheet needs inputs such as PDD, O.F and O.A.R. In our study we obtained the TMR values used for isocentric calculations from the traditional approach of obtaining TMR from PDD values. The resulted MU values also provided evidence that the PDD values can be used for estimating TMR values without the need for separate TMR measurement. Our spreadsheet design and approach is also similar method of TPS estimating TMR from the measured PDD values.

The necessity and advantages of the independent MU check system is recognized through this study. Our study indicated that the spreadsheet MU calculation can be corroborated to the TPS planning when the plans are normalized at the isocentre, or any reference point.

The limitations of the spreadsheet were also considered .The advancements in treatment techniques may comprise non-coplanar beams, and modulated fields increase the complexity in spreadsheet design. Our spreadsheet still needs to be improved to accommodate the various complex treatment techniques. Presently, the inputs for the spreadsheets were manually entered. There is need for designing a spreadsheet that has the capability to accept data through electronic transfer, so that the same spreadsheet configuration can be extended for various machines and beam qualities.

Conclusion

The independent spreadsheet was designed and tested for most of the routine treatment sites and geometries. The designed spreadsheet had good agreement with the Eclipse TPS, version 13.8, for homogenous treatment sites such as head and neck and cervix. The accuracy reduces in case of heterogeneous tissues such as the esophagus; however, the accuracy is still within tolerance. The inclusion of parameters to account for tissue homogeneity in the spreadsheet has to be considered.

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