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Development of an Independent Monitor Unit Verification Program for Photon Beams in 3-Dimensional Conformal Treatment Planning System

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ABSTRACT

This study focuses on the development of an independent monitor unit verification program for photon beams in 3-dimensional conformal radiotherapy as patient specific QA for isocentric treatment. An in-house MS-Excel spreadsheet program was developed to validate monitor units generated by the treatment planning system, with sole intention of ensuring an accurate dose calculation. A total of 3339 treatment fields generated from over 667 patient data for different treatment sites treated with either 6MV or 15MV or both energies were analyzed. The treatment plans were generated with Oncentra Masterplan V4.3 running on collapsed cone algorithm with heterogeneity correction. The planning system's generated monitor units for each field was based on prescribed dose per fractionation. The independent monitor unit verification program however was built with appropriate beam data obtained from ion chamber measurements. The planning system's dose at isocentre were juxtaposed with, and tested for accuracy with that calculated by the independent verification program. Variations between the two dose sets as well as dose at Dmax for a given monitor unit were analyzed. For homogenous medium, there was a good agreement between the treatment planning system's dose at isocentre and the Excel-developed program; with variations in dose at isocentre ranging between -0.15% and -1.73% (against a ±7% set-tolerance). Disparities in Dmax dose ranged between -0.34% and -1.4%. However, in analyzing heterogeneous patient media, disparity in dose at isocentre and Dmax were estimated as -2.09% and -2.12% respectively.

Keywords: Monitor Unit, Quality Assurance, Algorithm, Treatment Planning, Collapsed Cone.

I. INTRODUCTION

The success of radiation therapy crucially hinges on the accuracy with which a prescribed dose is delivered precisely to the tumour volume. Usually, a series of procedures are designed to realize this goal. One of such procedures in external beam therapy is a dedicated quality assurance (QA) protocol that fortifies uniformity between medical prescription and the safe delivery of such prescription; to achieve optimum prescribed dose to the target volume, and minimal dose to both healthy tissue and exposure of personnel. These steps are all geared towards an expected clinical upshot [1]. Patient specific QA procedures such as in-vivo dosimetry, patient positioning reproducibility techniques, and monitor unit (MU) verification, feature prominently in any successful radiation therapy procedure.

Independent verification of MUs or treatment-time to deliver a prescribed dose is mandatory in any radiation oncology QA procedure [2]. This has previously been executed by hand calculations using look-up tables, with verification done by second personnel repeating the entire procedure independently [2]. Latest recommendations of the AAPM's TG 40 and TG 114 again highlight the use of an independent MU calculation system as a mandatory tool for QA in a radiotherapy treatment planning system (TPS) [2], [3]; [4], [5].

According to the generally accepted recommendations of the International Commission on Radiation Units and Measurements (ICRU), the dose delivered shall not differ by more than ±5% of the prescribed dose [2], [3], [4]. Some studies propose that the standard deviation of the uncertainty in the delivered dose should not be greater than 3.5% [4], [5]. As part of this overall uncertainty arising from the process of dose calculations in treatment planning, the tolerances for the accuracy of TPS have to be appropriately smaller. Dose errors arising at the treatment planning phase, could potentially derail the entire treatment regimen, and therefore, it is of prime concern. For computerized calculation of MUs, errors may potentially arise from input beam data, the calculation algorithm, and data transfer to the treatment sheet or field [6].

Published recommendations for QA in radiation therapy stipulate routine checking of MU calculations using means independent of the original algorithm [7], [8], [9], and [10]. Reports on independent checks of MU calculations also confirm the usefulness of QA procedures in promoting accurate delivery of prescribed dose [10], [11], [12], and [13]. Such dedicated practices unveil the limitations of conventional dose calculation algorithms employed in computerized treatment planning systems [11].

This study was undertaken in a radiation oncology centre in Ghana, where the clinical policy requires all MUs from treatment plans generated by the TPS to be verified by an independent MU program before treatment delivery. The program performs various test procedures to verify MUs and maximum dose at depth (Dmax) dose for individual fields using beam data. The independent MU program has been employed for the verification of MUs associated with over 667 computerized treatment plans. The need for this method of independent MU verification becomes apparent due to its relatively simple process compared to the laborious work involved in performing hand calculations using look-up tables. The focus of this study is to design an independent MU calculation program using Microsoft (MS) Excel. It prescribes guidelines needed to help the physicist to set clinically reasonable action levels for agreement between the TPS generated MUs (MU_{TPS}) and the independently calculated MUs (MU_{ID}).

II. METHODS AND MATERIAL

A significant feature in the quality control (QC) protocol of the radiation oncology centre where the study was carried out requires all computerized treatment plans to be checked independently by a medical physicist. The approach in checking MU_{TPS} calculations is based on the standard system of dosimetric calculations [1], [14] using output factor, tissue phantom ratio (TPR) or tissue maximum ratio (TMR) tables, wedges factors and calibration factors. These factors were acquired independent of the data used by the Oncentra MasterPlan (OMP) TPS in use at the centre. Their applicability and precision has been previously validated through series of analysis in a dedicated routine QA on the treatment unit and has indicated no significant change in radiation beam characteristics throughout the years.

Some simplifications have however been applied to the planning system. These include the use of motorized wedges, isocenteric TPS dose measurements and corrections for field sizes greater than 4cmx4cm. The reference (normalization) point on which the MU calculations were defined and checked is based on recommendations of the ICRU 50 [15]. In a greater majority of these cases, the normalization point was placed at the isocentre. In calculating monitor units, the TPS requires a specific dose prescription and a percentage isodose level applicable to the entire planning target volume (PTV) or clinical target volume (CTV), based on clinical protocol. The TPS then computes the MUs for each beam (field); taking into account beam modifiers such as multi-leaf collimators (MLCs), and wedge angle definitions. The calculated monitor units are then entered into the patient's beam information for all fields.

The MU-check method employs an MS-Excel spreadsheet for the calculations. Density corrections based on radiological depths and TPR ratios were applied only for lung and major bone-tissue inhomogeneities (e.g., pelvis, thorax). Dose calculations for the treatment sites were based on CT data. With the TPS deriving electron densities from CT numbers through an appropriate calibration, a standard value of 0.3 was assigned as the relative electron density within contours representing the lung. Applicable dosimetric

factors based on interpolation from actual field sizes, and readouts from commissioning data were incorporated into the spreadsheet. These quantities return an estimated MU value after computation. Any other parameter was manually entered into the spreadsheet. Thus, the general formula used in calculating the monitor units from a field with dose prescription, D_{cal} is given in equ.1 [16], as

$$MU = \frac{D_{cal}}{Cal.F \times K_{iso} \times OF \times TMR} \quad (1)$$

Where

D_{cal} = calculated dose by OMP TPS
K_{iso} = inverse square correction
$Cal.F$ = calibration factor
MU = monitor units
OF = output factor
TMR = tissue maximum ratio

The verification process is in two (2) steps: (i) Excel MU calculation worksheet with beam calibration data and tables and (ii) Excel MU calculation worksheet with MU from OMP TPS.

The Elekta synergy 11 Platform Linac in use at the radiation oncology centre has two photon energies (6MV and 15MV). The Commissioning data (*TMR, OF, Cal F*), for the (6 MV and 15 MV) photon energies were entered into the MS-Excel MU worksheet database. These commissioning data had earlier been selected and input in the OMP algorithm settings at the clinic. For verification between the tables (data), and input data in the Excel MU worksheet (software), TMR and OF for all square fields at varying depths were computed in the MU worksheet. The TMR and OF values were expected to be the same, hence no possibility of errors in the transfer of information from beam data to the MU worksheet. Statistics describing the ratios of beam data for both open and wedged beams were generated and analysed.

For purposes of comparison of MUs between the OMP and the Excel worksheet, different square fields with wedge (IN or OUT) were simulated in a homogeneous environment (water phantom in a 30cm×30cm×30cm matrix) in OMP. Complex fields with MLCs covering almost 25% the field size were also simulated for both energies. Each field simulated on OMP was normalized at 100MUs, and its consequent dose and Dmax values were calculated explicitly using the *collapsed cone algorithm.*

At the MS-Excel worksheet, doses were calculated from the MU values (open or wedged fields), depths and field sizes (FX and FY) from the treatment plan printout. The Dmax dose calculated in the OMP TPS printouts were also entered into the Excel worksheet. Doses obtained from the OMP and MS-Excel worksheet calculations were analysed.

In a non-homogeneous medium, 3339 fields generated from 667 patient treatment plans, calculated on patient CT scans were used. The different treatment sites such as breast and Chestwall, head and neck, brain, prostate, rectum, cervix and others were treated with either 6 MV or 15 MV or both energies on the Linac system. Monitor units (open or wedged fields) recorded for each treatment printout was analysed for all treatment plans, representing different levels of complexity. Statistics describing the distribution of dose calculation deviations were also generated and analysed. Tissue heterogeneity corrections were applied during the OMP dose calculations. Consequently, corrections were also done for isocentric depth to radiological equivalent depth for lung, bone, fat and dense bone (skull) in the Excel worksheet.
Figure 1 is a schematic representation of tissue heterogeneity corrections for isocentric depth to radiological equivalent depths [6].

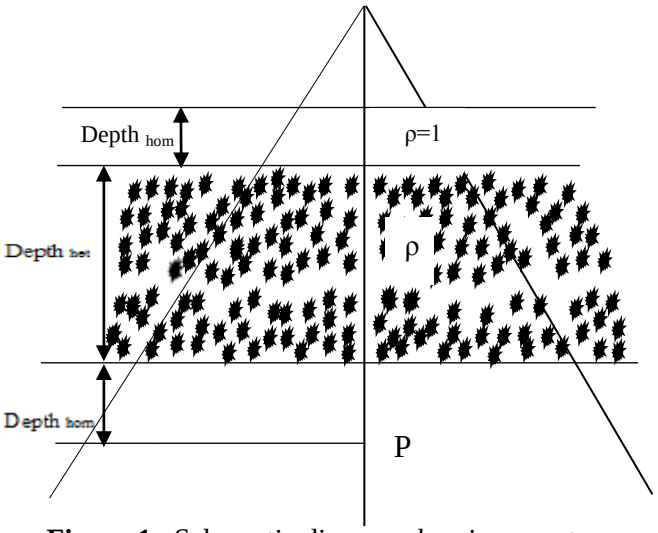

Figure 1. Schematic diagram showing a water equivalent phantom (ρ=1) containing an inhomogeneity of electron density (ρ) relative to water. P is the point of dose calculation.

From Figure 1,

$$depth_{(total)} = depth_{(\hom)} + depth_{(inhom)} \quad (2)$$

$$depth_{(eqv)} = depth_{(\hom)} + depth_{(inhom)} \times \rho_{rel} \quad (3)$$

From equation (2),

$$depth_{\hom} = depth_{(total)} - depth_{(inhom)} \quad (4)$$

Substituting equation (4) into equation (3)

$$depth_{(eqv)} = depth_{(total)} - depth_{(inhom)} + depth_{(inhom)} \times \rho_{rel} \quad (5)$$

$$depth_{(eqv)} = depth_{(total)} - depth_{(inhom)}(1 - \rho_{rel}) \quad (6)$$

Table 1 present the relative densities of some common media to water

Table.1 Relative densities of various medium to water

Medium	Relative density (ρ)
Lung	0.30
Fat	0.90
Bone	1.15
Dense bone	1.50

Making substitution of the relative densities for the medium through which the beam traverses, the equivalent depth correction for that specific medium is obtained with equation (6).

III. RESULTS

A. MU calculation worksheet with beam data tables

The MU calculations worksheet was used to verify the table data, and the ratio of the table data to the MU (open and wedged beams) was generated for each commissioning data:

$$ratio = \frac{X_{Data}}{X_{Excel}} \quad (7)$$

Where X represents a commissioning parameter (i.e. *OF* or *TMR*)

From table 2 and 3 below, OF for both energies had a ratio of 1.000 for open and wedged (60°) beams. A comparison of the TMR from the commissioning data gives the same values for both open and wedged beams calculated by the MS-Excel worksheet, hence a ratio of 1.000. Sample of the MS-Excel MU calculation with OMP treatment plans in homogeneous medium is presented in table 4 with deviations below tolerance values.

B. MU calculation worksheet with OMP

The MS-Excel MU worksheet was used in verifying the OMP TPS calculations for both homogeneous and heterogeneous media. The deviations of the TPS calculations and the Excel MU spreadsheet were generated for each treatment field using equation 8

$$Deviation(\%) = \frac{MU_{OMP} - MU_{EXL}}{MU_{EXL}} \quad (8)$$

Where;

MU_{OMP} ; is the MU from OMP TPS calculation

MU_{EXL} ; is the MU from the Excel worksheet calculation

For homogeneous medium, a 10cm × 10cm symmetric field size was simulated, and dose was estimated at depth of 1.5cm and 2.5cm respectively for the 6MV and 15MV energies. Each of the energies had an open field, wedged field and a field blocked with MLCs covering about 25% of the field size

IV. DISCUSSIONS

The calculations were in three phases: (i) comparing the commissioning data (tables) with the Excel MU worksheet, (ii) comparing the phantom created in OMP (homogeneity) with the Excel MU worksheet and (iii) comparing patients' plans (inhomogeneity) with the Excel MU worksheet.

In verifying the commissioning tables (TMR and OF) and that in the Excel MU, there is almost a minimal possibility for errors in the transfer of data from beam tables to the Excel worksheet. For verification of MU in phantom and that of the MS-Excel, a treatment plan was designed from a homogeneous phantom (water equivalent) created in OMP. Table 4 gives the dose and Dmax deviations for various beam descriptions (6MV and 15MV open and wedged beams, 6MV and 15MV with MLCs covering 25% of the field). The dose deviations and Dmax values for all the plans were below a set tolerance value of ±7%, with a maximum deviation of -1.73% (0.04Gy).

In the verification of a patient's treatment plan (inhomogeneities) with that of the Excel worksheet,

fields from patient's treatment plans, calculated on patient CT data were used. MUs from treatment plan printouts were analysed with the Excel MU calculations over a 4 year period, and all the deviations were found to be below the set tolerance. The average dose deviation at isocentre and Dmax were -2.09% and -2.12% respectively. Hence, the Excel MU worksheet provides a credible alternative in crosschecking OMP TPS calculations.

Table.2: Ratio of beam data to MU of Output factor for 6MV

	Eq. Squared Area (cm^2)	16	25	36	49	64	100	144	225	400	625	900	1600
Output Factor (Open Field)	Data	0.9337	0.9470	0.9653	0.9718	0.9852	1.0000	1.0132	1.0299	1.0537	1.0695	1.0787	1.0834
	Excel	0.9337	0.9470	0.9653	0.9718	0.9852	1.0000	1.0132	1.0299	1.0537	1.0695	1.0787	1.0834
	Ratio	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Output Factor (60° W)	Data	0.2447	0.2499	0.2546	0.2571	0.2618	0.2690	0.2753	0.283	0.2974	0.3035	0.3095	
	Excel	0.2447	0.2499	0.2546	0.2571	0.2618	0.2690	0.2753	0.2830	0.2974	0.3035	0.3095	
	Ratio	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	

Table.3: Ratio of beam data to MU of Output factor for 15MV

	Eq. Squared Area (cm^2)	16	25	36	49	64	100	144	225	400	625	900	1600
Output Factor (Open Field)	Data	0.9149	0.9372	0.9551	0.9653	0.9804	1.0000	1.0183	1.0341	1.0593	1.0707	1.0811	1.0834
	Excel	0.9149	0.9372	0.9551	0.9653	0.9804	1.0000	1.0183	1.0341	1.0593	1.0707	1.0811	1.0834
	Ratio	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Output Factor (60° W)	Data	0.2504	0.2573	0.263	0.2661	0.2723	0.2798	0.2886	0.2974	0.3132	0.3206	0.3258	
	Excel	0.2504	0.2573	0.263	0.2661	0.2723	0.2798	0.2886	0.2974	0.3132	0.3206	0.3258	
	Ratio	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	

Table.4: Deviations of OMP and MU Excel calculations in homogeneous medium

Beam description		OMP TPS Printout			Excel MU Calculation		Deviation		
		MU	Iso Dose (Gy)	D_{max}	Iso Dose (Gy)	D_{max}	Dose (Gy)	Dose (%)	D_{max} (%)
6 MV Energy	Open	1003.70	6.74	13.77	6.75	13.817	-0.01	-0.15	-0.34
	Wedged	1000.00	1.89	3.73	1.91	3.703	-0.02	-1.05	0.73
	MLC	1000.00	6.53	13.54	6.55	13.618	-0.02	-0.30	-0.57
15 MV Energy	Open	1000.00	7.87	13.68	7.89	13.753	-0.02	-0.25	-0.53
	Wedged	1000.00	2.27	4.23	2.31	4.290	-0.04	-1.73	-1.40
	MLC	1010.34	7.78	13.61	7.80	13.698	-0.02	-0.26	-0.64

Table.5: Deviations of OMP and MU Excel calculations in inhomogeneous patient media

Deviation	Dose at iso (%)	Dose at iso (Gy)	Dmax(Gy)	Dmax (%)
Max	4.8%	0.25	11.10	5.1%
Min	-5.2%	-0.32	0.05	-6.4%
Average	-1.76%	-0.02	1.24	-1.96%

When deviations are found to be above the threshold, then a number of actions or checks are required to be undertaken. These include repositioning or measuring the Dmax point correctly, estimating correctly the percentage of the treatment field covered with MLCs and changing the isocentric depth to radiological equivalent depth for inhomogeneous medium. An appropriate wedge factor may also be required to be estimated and included in the input parameters for plans in which wedges were used.

A higher deviation value can also be attributable to an accumulation of differences introduced by multiple factors in the monitor unit calculation.

V. CONCLUSION

This study has presented a detailed analysis of differences between the MU calculations of the OMP treatment planning system and a simple MS-Excel calculation for various plans in different media.

Analyses of these data have been useful in establishing action thresholds for the investigation of individual patient's treatment plan when MS-Excel calculations differ from those of the planning system. The action thresholds will depend on the treatment site (inhomogeneity) and the complexity of the planning geometry. The MS-Excel MU worksheet named after the oncology center has the version 2013-07-04 and is used predominantly in verifying the OMP treatment plans.

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