A COMPREHENSIVE STUDY OF THE FACTORS THAT INFLUENCE THE GAMMA PASSING RATES IN IMRT PLAN SPECIFIC QUALITY ASSURANCE

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Abstract— **This study aims to evaluate various parameters which affect the gamma passing rate (GPR) in IMRT Quality Assurance. A correlation between the modulation factor in the treatment planning, various treatment sites in planning, gamma analysis criteria such as low dose threshold value (LDT) and various normalization methods were analyzed against gamma passing rate. The study included 108 patients who were treated in Elekta Versa HD. The treatment plan was exported to imatrixx phantom and the fluence was calculated. The calculated fluence was compared against delivered fluence and Gamma analysis was performed. There is a negative correlation found between delivered MU and GPR. The Brain, Head and Neck have relatively lower passing rate than Pelvis and Thorax. When the low dose threshold value is increased from 5 to 10%, the global normalization method shows a decrease in gamma passing, whereas the local normalization method shows the contrary results. The Monitor Unit has to be controlled in treatment planning as this will improve Gamma Passing Rate. The Brain and Head and Neck are having lowest passing rate since these sites have OAR closer to the PTV. The Global Normalization method has better passing rate than local as it hides the error in low dose area. Irrespective of LDT value applied, the Gamma passing rate is above 95 % in Global Normalization method whereas Selection of LDT is crucial in Local Normalization method as the passing rate goes as low as 90% when the LDT is 5%.**

Keywords— **Intensity Modulated Radiation Therapy, Gamma Passing Rate, Normalization method, Low Dose Threshold.**

I. INTRODUCTION

Intensity modulated radiation therapy (IMRT) can deliver highly conformal prescription doses to target volumes while minimizing doses to organs at risk (OAR) in proximity to the target volumes, which enables high local control as well as reduction of complications related to radiotherapy [1]. In IMRT the modulated beams are produced using complex motion of Multi Leaf Collimator. As the dose gradient in IMRT is sharp and also the Monitor Unit delivered is very high than conventional treatment like 3DCRT, the discordance between the planned and delivered dose could cause critical clinical malpractices. Therefore, pre-treatment plan-specific quality assurance (QA) for IMRT and Volumetric Modulated Arc Therapy (VMAT) plans are highly recommended in the clinic as a verification procedure of the treatment plan before patient treatment [1]**.** 2D gamma evaluation is generally performed in the clinic which compares the planned and delivered dose distribution. A composite analysis developed by Harms et al [2] called gamma index which combines both the dose difference and distance to agreement in low dose and high dose gradient respectively. This gamma index can be affected by both the precision of the TPS calculation and the precision of treatment delivery [3]. In TPS calculation the plan complexity is measured in terms of MU and there are various parameters used in the analysis of Gamma index which affects Gamma passing rate. Task group (TG) generated by the American Association of Physicist in Medicine recommends global normalization with acceptance criteria of 3% of dose difference, 3mm distance to agreement (DTA). In addition to this low dose threshold is applied to remove the background noise (possible measurements due to the effects of radiation scattering). AAPM TG-119 instructs facilities to use a 10 % of Low Dose Threshold value or Region of Interest determined by jaw setting [4]. According to a survey [5], 70 % of clinics use a low dose threshold of 0-10 %. But there is no clinical data to quantitatively demonstrate the impact of Low Dose Threshold. This study aims to study various parameters which are used in the analysis that affects the Gamma Pass Rate (GPR) and thus be able to apply it by establishing norms and criteria for evaluating the gamma index for the future. In addition to this, a correlation between GPR and the treatment site was also studied.

II. METHODOLOGY

This study included 108 cases from the Brain, Head, Neck, Thorax, and Pelvic regions. These patients were planned dynamic IMRT in Monaco TPS (v. 5.11.03) and were generated using 6MV beam. The Equivalent Uniform Dose (EUD) based optimization was used in the Planning system. The calculation algorithm used in TPS was Monte Carlo. The calculation grid size was 0.3 cm, and statistical uncertainty was 1% set in the calculation parameters. Plans were evaluated using Quantitative Analyses of Normal Tissue Effects in the Clinic (QUANTEC) criteria.

Treatment plans were transferred and calculated on 2-D array system (IBA Dosimetry, Germany). This array has 1020 vented parallel ion chamber which can measure an active area of 24.4 × 24.4 cm^2 and the detector spacing of the array is 7.62 mm. This array was scanned with 5 cm build-up and 5 cm back scatter material (Fig-1). The build-up phantom material is PMMA and of density 1.16 g/cc. The density of phantom was forced in TPS, and the plan

was calculated for QA on phantom. The output calibration was routinely performed every quarter to account for the output deviation of the machine. There are studies which prove there is no statistically significant difference in the gamma analysis between zero and non-zero treatment angles [6]. Hence the various gantry angles of IMRT plan were collapsed to zero angle during QA calculation. The coronal plane dose distribution exported to my QA software (v. 2017-002(2.9.23.0)) for measured and calculated dose comparison (Fig-2) The plans were delivered in Elekta Versa HD (Stockholm, Sweden) LINAC.

Gamma Passing Rate was analyzed for 3% dose difference and 3mmDistance to agreement criteria. This is the evaluation criteria originally recommended by Low et al [2]. The plans were analyzed using global normalization and low dose threshold set was 5%. The plans which had 90% pass percentage were accepted.

The relationship between various treatment site, MU, Modulation Factor which are decided in the TPS are analyzed against the GPR. The relationship between analyzing parameters such as Normalization method and Low dose threshold which are used in Gamma analysis are also analyzed against the GPR.

The average gamma passing rate found for all the patients was 97.11±2.36. There were 7 plans which did not pass with the 3%, 3mm criteria. The detector array setup was reverified and analyzed using different passing criteria. But these were excluded from the study. The Fig-3 given below shows distribution of Gamma Passing Rate of all 108 plans.

Figure 1: IMRT QA setup

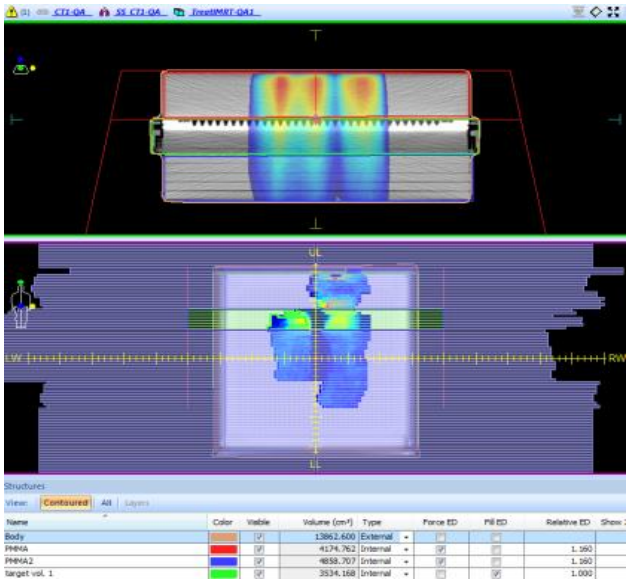

Figure 2: Dose delivery on imatrixx phantom in TPS

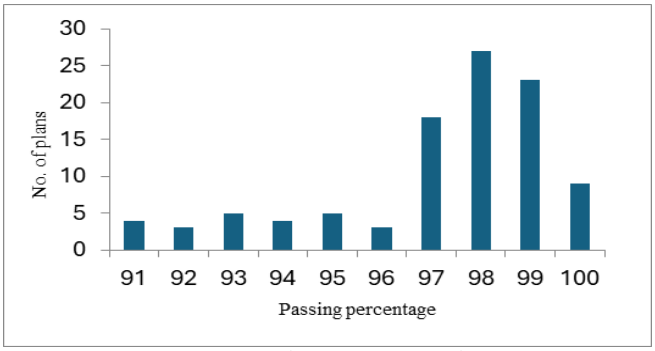

Figure 3: Distribution of gamma pass rate of 108 patients

III. RESULTS

Relationship between total MU, Treatment Site and Gamma Passing Rate:

A total of 20 brain, 24 pelvis, 25 thorax and 39 head and neck cases were included in the study. The bar graph below shows the Gamma passing rate of various treatment sites (Fig-4)

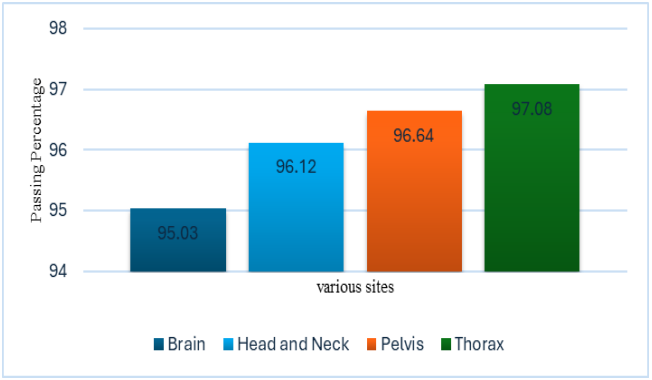

Figure 4: GPR of various Sites

In the modulated treatment like IMRT there are various parameters such as MU, Complex shaped segments, small apertures and a large number of segments affect the matching between planned and delivered dose distribution to the patient [7]. Among them Monitor Units delivered alone is taken to evaluate the plan complexity of IMRT plans. SPSS software was used to find the correlation between total MU and Gamma Passing Rate. A weak negative correlation was found between MU and Gamma Passing Rate. Spearsman correlation coefficient found to be -0.05172. Fig 5 shows the correlation found between MU and GPR.

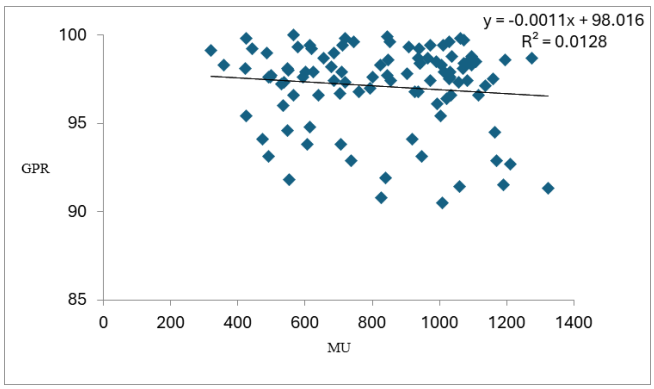

Figure 5: MU vs GPR

Confidence Limit:

There are always differences between measurement and calculation. This could be because of limited resolution of the QA device, limitation in the accuracy of dose calculation, limitation in the dose delivery system. TG-119 proposed a way to quantify the degree of agreement between measurement and calculation.

$$CL = (100 - \text{mean}) + 1.96\sigma \quad \text{.....(1)}$$

Where mean is the average of GPR and σ is the standard deviation.

Detectability Threshold:

$$DT = 100 - CL \quad \text{.....(2)}$$

As per TG-119 protocol the CL of overall 108 patients were analyzed and the CL found was 4.6 and Detectability Threshold (DT) calculated was 95.4.

Normalization method:

The data was analyzed using Global normalization method by changing the low dose threshold value from 5 % to 10 %. When the low dose threshold value increases from 5% to 10 % the gamma passing percentage decreases from 96.3 to 95.6% for the 3%, 3 mm. With stricter evaluation criteria like 2 %, 2 mm also the pattern observed remains same. The Gamma Passing Rate decreases from 93.5 to 92.5% (Figure 6).

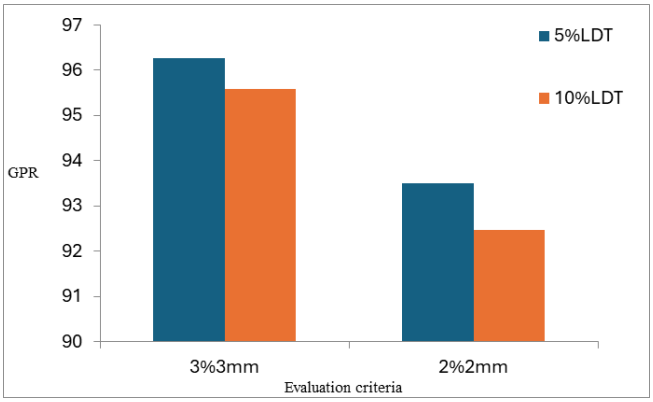

Figure 6: Global Gamma Index

Local Normalization: When Local Normalization was applied using 3%, 3mm passing criteria, GPR increased from 90.2 to 91.6% when Low Dose Threshold increased from 5 to 10 %. The pattern of increase in GPR remains same even with the stringent evaluation criteria such as 2%, 2mm. With the tighter evaluation criteria, the GPR increases from 87.5 to 88.6% (Figure 7).

Table 1: Comparison between Global and Local Normalization

Analysis Criteria	Low Dose Threshold	Local Gamma Index		Global Gamma Index	
		Mean	SD	Mean	SD
3%, 3mm	5%	90.19	5.89	96.26	4.19
	10%	91.61	6.29	95.59	4.87
2%, 2mm	5%	87.49	6.37	93.49	5.39
	10%	88.63	6.90	92.46	6.29

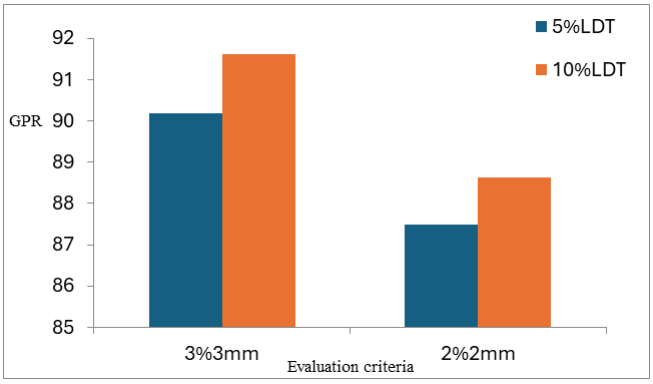

Figure 7: Local Gamma Index

Comparison Between the Global and Local Normalization for Various Threshold Values and Evaluation Criteria:

Similarly, 6.1% difference is seen between Global and Local gamma index for 3%, 3mm criteria at Low dose threshold of 5%. For 10% of Low dose threshold there is 4% of gamma index difference seen between Local and Global index.

Using the 2%, 2mm criteria, the percentage difference observed was 6% between global and local gamma index

with 5% Low Dose Threshold. With 10 % threshold 4% difference was found between global and local normalization.

Irrespective of the dose evaluation criteria, the percentage of difference observed between global and local normalization remains same and local gamma index shows decrease in the GPR than Global gamma index for various Low dose threshold values.

Table-1 Shows the comparison between the Global and Local Normalization for various threshold values and evaluation criteria.

IV. DISCUSSION

Correlation Between Treatment Site and Gamma Passing Rate:

In this study lowest gamma passing rate was found in brain and Head and Neck cases of 95.03 and 96.12 % respectively. The reason could be that the highest modulation was done in these cases as these sites involve the major critical organs such as Optic structures, Brain Stem and Spinal Cord. These results are comparable to the results obtained by Shizhang Wu [7] where chest and abdomen have highest passing rate and head and neck have the least passing rate.

Correlation Between MU and Gamma Passing Rate:

The quantity of MU delivered is an indicator of treatment efficiency. The higher the total MU, lower the treatment efficiency. Hence, the total MU in treatment plans optimization to be controlled. The passing rate improves by this and also the treatment efficiency.

Confidence Limits:

When the large number of data points are to be evaluated, an additional quantity of Confidence Limit is introduced by Venselaar (2001) [8] which combines the systematic and random deviations. The confidence limit is based on the average difference between measurements and calculations for a number of data points in a comparable situation, and the standard deviation (SD) of the average of the differences. The confidence limit is then defined as the sum of the average deviation and 1.5 SD. The factor 1.5 was based on experience and a useful choice in clinical practice. A multiplicative factor of 1.96 instead of 1.5 proposed by Palta et al [4] for having 5% of the individual points exceeding the tolerance level.

As per TG-119 the CL was found and it was 4.6 and Detectability Threshold (DT) calculated (100-CL) was 95.4. These values show that the overall the IMRT QA results are stable and of statistical significance.

Various Normalization Methods:

Global normalization applied to the maximal value of the calculated dose distribution. In contrast the local normalization applied to the currently evaluated pixel. Both the local and global γ have advantages and disadvantages. The local tends to highlight failures in regions of high dose gradient, and in the global, these failures are less evident but show the errors within the high dose regions within the dose distributions.

Nelms et al [9] also mentioned as Global normalization focuses only on the maximum dose, it hides the error in the low dose region and leads to insensitivity in gamma analysis especially in the 3%, 3mm passing criteria. But irrespective of the low dose threshold value in global normalization with 3%,3mm criteria, the passing rate is above 95%. Hence, we conclude that the low dose threshold has less impact in global normalization method.

In contrast to the global normalization, in local normalization with increase in the low dose threshold the gamma passing rate increases. Among the low dose threshold studied 5 and 10 %, the 5% has gamma passing rate 90.19% for 3%, 3mm criteria.

Generally, a low dose value falls on the periphery of target or penumbra regions. However, if low dose falls on the Organ at Risk it could cause fatal consequence. Moreover, the low dose has the risk of causing secondary cancer especially in pediatric cases. Hence Low doses should be evaluated strictly and delivered. The impact of low dose threshold is high in local gamma analysis. Applying 5 % low dose threshold value in the gamma passing rate is as low as 90 %. Thus, applying various threshold values in local gamma analysis would be a helpful approach to evaluate the gamma passing rate.

V. CONCLUSION

We tried to evaluate various parameters of treatment planning and gamma evaluation which affects the Gamma Passing Rate. As far as Monitor Unit (MU) is concerned, a negative correlation is found between the MU and Gamma Passing Rate which shows the MU should be controlled in the planning system to have better Gamma Passing Rate. By this not only the passing rate increases but also the treatment efficiency improves which has clinical relevance.

We also tried to find the correlation between various treatment sites and gamma passing rate. The lowest passing rate was seen in Brain and Head and neck. This could be because the study selected were all close to the Organ at Risk like Brain Stem, Optic chiasma in brain and Spinal Cord in Head and Neck which are highly constrained.

We conclude that in Global normalization method, the gamma passing rate is above 95% irrespective of low dose threshold value using 3%,3mm criteria whereas in Local normalization method, the gamma passing rate is only 90% when the low dose threshold value is 5%. Hence it is recommended that adequate selection of low dose threshold value in local gamma analysis is required as it affects the gamma passing rate.

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