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FLUENCE COMPLEXITY FOR IMRT FIELD AND SIMPLIFICATION OF IMRT VERIFICATION

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Abstract – **Intensity Modulated Radiation Therapy (IMRT) requires dosimetric verification of each patient's plan, which is time consuming. This work deals with the idea of minimizing the number of fields for control, or even replacing plan verification by machine quality assurance (QA). We propose methods for estimation of fluence complexity in an IMRT field based on dose gradients and investigate the relation between results of gamma analysis and this quantity. If there is a relation, it might be possible to only verify the most complex field of a plan. We determine the average fluence complexity in clinical fields and design a test fluence corresponding to this amount of complexity which might be used in daily QA and potentially replace patient-related verification. Its applicability is assessed in clinical practice. The relation between fluence complexity and results of gamma analysis has been confirmed for plans but not for single fields. There is an agreement between the suggested test fluence and clinical fields in the average gamma parameter. A critical value of average gamma has been specified for the test fluence as a criterion for distinguishing between poorly and well deliverable plans. It will not be possible to only verify the most complex field of a plan but verification of individual plans could be replaced by a morning check of the suggested test fluence, together with a well-established set of QA tests.**

Keywords – **IMRT verification, gamma analysis, fluence complexity, plan deliverability**

1. INTRODUCTION

The radiotherapeutic technique IMRT (Intensity Modulated Radiation Therapy) allows to increase dose to tumor and decrease radiation damage to organs at risk (OARs). Thus, it allows better tumor control. However, due to the increased dose, there is a higher risk of damage to OARs in case of wrong dose delivery and the whole process requires precise verification. This is time-consuming and often an argument against the use of IMRT at busy clinics. The question is whether it is possible to simplify the verification process without increasing the risk for patient.

There might be a possibility to reduce the time needed for patient-related verification. Let us suppose that the results of verification of a particular field correspond to the fluence complexity of the field. Then it would be enough to verify only one field of the patient's plan – the one with the most complex fluences. If this field met the tolerance criteria, we could say that other fields meet them automatically. There is yet another solution: to determine the average fluence complexity of a clinical IMRT field and create a test fluence that would be close to this amount of complexity and that would be verified during the morning checks of the linear accelerator. This test, together with extended quality assurance (QA) of the multileaf collimator (MLC), could potentially replace patient-related verification.

Several means of fluence complexity definition have been published, among them the Modulation Index (MI) or the Modulation Complexity Score (MCS). However, different research groups publish different, conflicting results - because their IMRT verification process differs. Thus, it is difficult to find a universal definition of fluence complexity which would be suitable to evaluate dose delivery at all clinics.

This work defines fluence complexity in a new way. We look for a correlation between thus defined quantity and results of gamma analysis of IMRT fields. We try to confirm the hypothesis that the more complex the fluences are, the worse results of gamma

analysis we get. Based on a set of clinical plans, we calculate the average fluence complexity in an IMRT field and we design a test fluence with similar complexity which can be used for morning checks of the linear accelerator. Suitability of this fluence is tested in clinical practice.

2. MATERIALS AND METHODS

Works that have been published so far calculate fluence complexity in an IMRT field using plan parameters such as the optimal fluence estimated by the treatment planning system (TPS) or the number of monitor units (MU). The most frequently used parameters are probably the *Modulation Index* [1, 2] and the *Modulation Complexity Score* [3]. Recently, another promising solution has been proposed by Nauta et al. [4] using fractal analysis. Here we define fluence complexity using the number and the amplitude of dose gradients in matrices of dose distribution calculated by the Portal Dose Image Prediction algorithm (PDIP) [5] in the plane of the Electronic Portal Imaging Device (EPID) when creating a verification plan [6]. Mathematically, the quantity can be defined as

$$P_q = \sum_{i=1}^{m}\sum_{j=1}^{8n} k_{ij}, \qquad k_{ij} = \begin{cases} 1 & c_{ij} > q \\ 0 & c_{ij} \le q \end{cases}$$

$$V_q = \sum_{i=1}^{m}\sum_{j=1}^{8n} k_{ij}, \qquad k_{ij} = \begin{cases} c_{ij} & c_{ij} > q \\ 0 & c_{ij} \le q \end{cases}, \qquad (1)$$

where P_q is the number of dose gradients in the matrix mentioned above which are greater than a certain limit q, m and n are the matrix dimensions[1] and c_{ij} is the amplitude of the dose gradient on the position [i, j]. The latter is calculated as the difference between values in adjacent pixels divided by the real distance between measuring points of the detector (Fig. 1). Thus, for each measuring point we obtain 8 values of dose gradient (one in each of the 8 directions). The value of q was chosen to be 0, 200, 300 and 400 arbitrary units.[2] (We suppose that small gradients are present everywhere and equally distributed, so they do not affect fluence complexity in a significant way.)

Table 1. Gamma analysis tolerance limits

Dose difference	DTA	Maximum gamma	Average gamma	Area gamma
3 [%]	3 mm	≤ 3.5	≤ 0.3	3%

[1] The expression *8n* occurs in the formula due to the way the calculation algorithm is implemented in MATLAB.

[2] Values in the predicted matrix of dose distribution which is then exported in DICOM format from the TPS Eclipse are relatively proportional to dose. However, no physical quantity can be assigned to them.

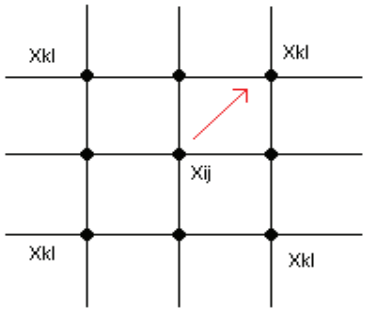

Fig. 1 - Distribution of the EPID detector measuring points

Matrices of dose distribution predicted in the plane of the detector EPID were exported in DICOM format from the TPS Eclipse version 8.6 (Varian Medical Systems, Palo Alto, USA). MATLAB was used to calculate fluence complexity. The experiment was carried out with the EPID aS500 and the Varian CLINAC 600C/D 6X (Varian Medical Systems, Palo Alto, USA).

First the correlation between fluence complexity in an IMRT field and results of gamma analysis [7, 8, 9] was observed. A statistical set of 100 IMRT plans for head-and-neck patients, that is 1310 fields, was used. Tolerance levels for gamma analysis at our institution are listed in Table 1, the dose difference criterion being the percentage of near-maximum planned dose [6]. The Spearman rank correlation coefficient was calculated to observe whether the rank of fields in a plan according to their fluence complexity is the same as the rank of the fields according to the gamma parameters. The percentage of plans where the correlation was significant was determined.

The average fluence complexity of a clinical IMRT field was estimated from the same statistical set of plans. It was determined by the total number of dose gradients in a field and by the average amplitude of one gradient in a field. Two test fluences that correspond to this average value of complexity were designed using the software Shaper (Varian Medical Systems, Palo Alto, USA). By a test fluence we mean a field of the size 10 x 10 cm which has a simple geometrical shape. These test fluences were verified in clinical practice over a one month period. With each patient plan verification, these fluences were delivered as well and the correlation between the gamma parameters of clinical plans and these test fluences was determined, again using the rank correlation coefficient.

3. RESULTS

For each of the 100 clinical IMRT plans the rank correlation coefficient was determined. The percentage of plans for which the correlation between the gamma parameters and fluence complexity in a field was significant was estimated. Table 2 and Table 3 show the results of correlation analysis for the case $q = 0$ and for the significance level $\alpha = 0.05$

and α = 0.01, respectively. The strongest correlation (at the significance level 95 %) was observed between the parameter average gamma and the number of gradients in a matrix of dose distribution, although only for 37 % of plans.

Table 2. Results of correlation analysis for IMRT fields

$q = 0$, $\alpha = 0.05$	
Type of correlation:	**Percentage of correlated data [%]**
γ_{max}/ Gradient amplitude	2
γ_{max} / Number of gradients	3
γ_{ave} / Gradient amplitude	25
γ_{ave} / Number of gradients	37
γ_{area} / Gradient amplitude	16
γ_{area} / Number of gradients	12

Table 3. Results of correlation analysis for IMRT fields

$q = 0$, $\alpha = 0.01$	
Type of correlation:	**Percentage of correlated data [%]**
γ_{max}/ Gradient amplitude	1
γ_{max} / Number of gradients	2
γ_{ave} / Gradient amplitude	18
γ_{ave} / Number of gradients	17
γ_{area} / Gradient amplitude	9
γ_{area} / Number of gradients	5

In the next step, the average fluence complexity in clinical IMRT fields was estimated by the average value of one dose gradient and the average number of gradients in a field (Table 4).

Table 4. Average fluence complexity in a clinical IMRT field

q	**Average gradient amplitude [a.u./mm]**	**Variance [a.u.^{2}/mm^2]**	**Standard deviation [a.u./mm]**	**Relative standard deviation [%]**
0	29	18	4	15
200	304	394	20	7
300	409	673	26	6
400	509	1020	32	6
q	**Average number of gradients**	**Variance**	**Standard deviation**	**Relative standard deviation [%]**
0	74619	4 x 10^8	20449	27
200	2371	590528	768	32
300	889	136846	370	42
400	356	38878	197	55

Two test fluences were designed in the programme Shaper, so that they correspond to the average value of fluence complexity (Fig. 2). They were tested in clinical practice over a month. Table 5 summarizes the results of correlation analysis - they show the relation between the gamma parameters of the test fluences and of clinical IMRT fields. A significant correlation was observed for the parameter average gamma, even at the significance level 99 % (Fig. 3).

Table 5. Results of correlation analysis for the test fluences. Values of the Spearman correlation coefficient for the gamma parameters of clinical fields and the test fluences. Two measurements were performed for each test fluence every day. Significant correlation is highlighted

Spearman correlation coefficient				
	test fluence no. 1		**test fluence no. 2**	
maximum gamma	-0.1	-0.1679	-0.2036	0.025
average gamma	0.35	0.3536	0.7679	0.8107
area gamma	-0.0893	-0.075	-0.0571	-0.1286
Critical value	**α = 0,05**	0.5179	**α = 0,01**	0.6536

Even though a significant correlation was confirmed between the test fluences and clinical IMRT fields in the parameter average gamma, the tolerance threshold of this parameter used clinically was never exceeded by the test fluences (while clinical fields did sometimes exceed the threshold). Therefore, ROC

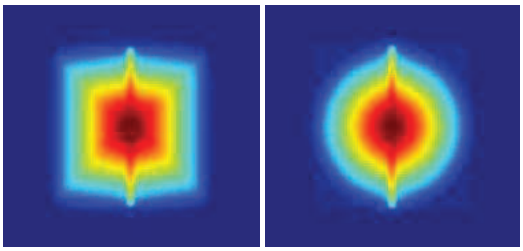

Fig. 2 - Test fluences (fluence no. 1 on the left, fluence no. 2 on the right)

analysis (Receiver Operating Characteristic) was performed in order to estimate a lower tolerance threshold for average gamma of the test fluences. If the test fluence exceeded this treshold during the morning check of the linear accelerator, it would mean that clinical plans would not meet the tolerance criteria on that particular day, either. The best value was found to be γ_{ave} = 0.210 (Table 6). This test

revealed non-deliverable plans[3] with 94% sensitivity but only 38% specificity[4].

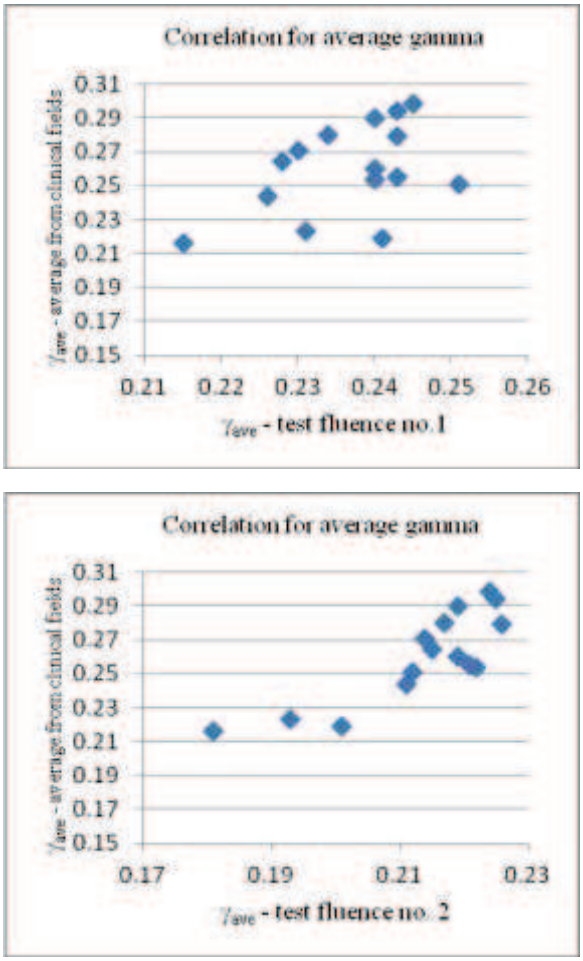

Fig. 3 - Correlation of average gamma for clinical fields and the test fluences

Table 6. Sensitivity and specificity for different threshold values of γ_{ave} for the test fluence no. 2. TP – true positive, FP – false positive, TN – true negative, FN – false negative

Treshold	TP	FP	TN	FN	Sensitivity	Specificity
$\gamma_{ave} \geq$ 0,235	0	0	16	18	0,00	1,00
$\gamma_{ave} \geq$ 0,215	15	4	12	3	0,83	0,75
$\gamma_{ave} \geq$ 0,210	17	10	6	1	0,94	0,38
$\gamma_{ave} \geq$ 0,200	17	13	3	1	0,94	0,19
$\gamma_{ave} \geq$ 0,180	18	16	0	0	1,00	0,00

[3] A non-deliverable plan is a plan where the parameter average gamma exceeds the tolerance level at least in one of the fields.

[4] The test correctly identified non-deliverable plans in 94 % of cases but it only correctly identified deliverable plans in 38 % of cases.

The ROC curve is shown in Figure 4. The AUC parameter (Area Under Curve) has the value of 0.84, which means a very good test.

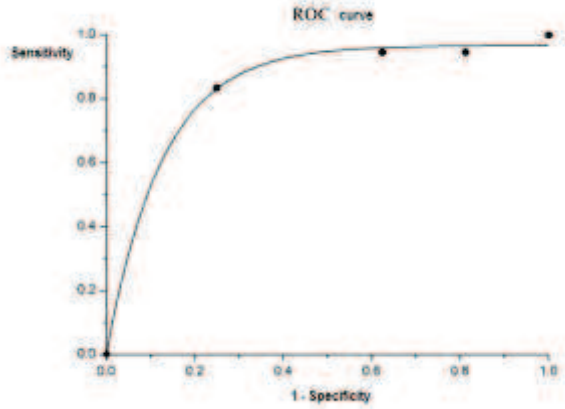

Fig. 4 - ROC curve for 5 threshold values from table 5

4. CONCLUSION

A new method for estimation of fluence complexity in an IMRT field has been proposed, which differs from those already published [1, 2, 3, 10]. It is based on matrices of dose distribution predicted for EPID in a verification plan. Fluence complexity is calculated as the amplitude and the number of dose gradients in an IMRT field.

In contrast to most papers, this publication uses a much larger set of data (100 plans, 1310 fields) and verifies the new method using clinical plans and clinically applied tolerance levels for gamma analysis. In a way, the method proposed here is similar to the MI parameter but it uses a different type of matrix.

A correlation between fluence complexity of IMRT fileds and results of gamma analysis has been confirmed for a certain percentage of plans. However, this percentage is not big enough to only verify the most complex field of a plan, as intended.

For that reason, the average fluence complexity of clinical fields has been assessed and a test fluence of which the complexity is equal to the average value has been created. The test fluence has been verified in clinical practice and has been found to correlate well with clinical IMRT plans in the parameter average gamma. A critical value of average gamma has been proposed and if the test fluence exceeds it, it will mean that clinical plans will not meet the tolerance criteria, either, due to malfunction of the MLC or the EPID. This method has a high sensitivity in determining poorly deliverable plans, although due to low specificity it recognizes some plans as false positives.

The aim of this work was to simplify the process of IMRT verification. This can be done by replacing patient-related verification with a set of QA tests of

the MLC and the EPID, one of which would be a morning check of the proposed test fluence.

In future experiments it would be desirable to include other tumor localities, e.g. prostate and brain. The test fluence should be verified in clinical practice over a longer period of time. If the methods proposed here were to be used at all institutions, it would be necessary to include other detectors, because the EPID detector is not available at all clinics.

5. REFERENCES

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