New method for estimation of fluence complexity in IMRT fields and correlation with gamma analysis

T Hanušová1,2, V Vondráček3, K Badraoui-Čuprová1,3, I Horáková4 and I Koniarová1,4
1Department of Dosimetry and Application of Ionizing Radiation, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Břehová 7, 115 19 Praha 1, Czech Republic
2Hospital Na Bulovce, Budínova 67/2, 180 81 Praha 8, Czech Republic
3Proton Therapy Center Czech, Budínova 2437/1a, 180 00 Praha 8, Czech Republic
4National Radiation Protection Institute, Bartoškova 28, 140 00 Praha 4, Czech Republic

E-mail: terezahanusova@centrum.cz

Abstract. A new method for estimation of fluence complexity in Intensity Modulated Radiation Therapy (IMRT) fields is proposed. Unlike other previously published works, it is based on portal images calculated by the Portal Dose Calculation algorithm in Eclipse (version 8.6, Varian Medical Systems) in the plane of the EPID aS500 detector (Varian Medical Systems). Fluence complexity is given by the number and the amplitudes of dose gradients in these matrices. Our method is validated using a set of clinical plans where fluence has been smoothed manually so that each plan has a different level of complexity. Fluence complexity calculated with our tool is in accordance with the different levels of smoothing as well as results of gamma analysis, when calculated and measured dose matrices are compared. Thus, it is possible to estimate plan complexity before carrying out the measurement. If appropriate thresholds are determined which would distinguish between acceptably and overly modulated plans, this might save time in the re-planning and re-measuring process.

1. Introduction

Intensity Modulated Radiation Therapy (IMRT) helps to avoid organs at risk in proximity of the tumor and thus allows to increase prescribed dose compared to 3D conformal radiotherapy. Because the technique is quite complex, clinics that are not confident with their implementation of IMRT still verify each patient’s plan prior to treatment. As IMRT is indicated in an increasing number of cases, this process might soon be inapplicable. The question is how to reduce time needed for verification without compromising patient safety. One solution is to avoid production of overly modulated fields by recognizing excess plan complexity on the planning stage, and thus avoid complete replanning and remeasurement of the plan. Here we propose a method for fluence complexity calculation that can help to distinguish between adequately and inadequately complex IMRT fields or plans. Moreover, our method might be suitable to calculate dose complexity in all three dimensions, unlike previously published works.
2. Fluence complexity calculation

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] and the Modulation Complexity Score [2, 3]. Other parameters are described in [4, 5, 6]. Recently, another promising solution has been proposed by Nauta et al. [7] 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 Calculation algorithm (PDC) in Eclipse (version 8.6, Varian Medical Systems, Palo Alto, USA) in the plane of the Electronic Portal Imaging Device (EPID) when creating a verification plan. Mathematically, the quantity can be defined as

\[
P_q = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{\phi=1}^{8} k_{ij\phi} \\
V_q = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{\phi=1}^{8} l_{ij\phi}
\]

where \( P_q \) is the number and \( V_q \) is the sum of amplitudes of dose gradients in the matrix mentioned above which are greater than a certain limit \( q \), \( m \) and \( n \) are the matrix dimensions and \( c_{ij\phi} \) is the amplitude of the dose gradient on the position \([i, j]\) in the direction \( \phi \). There are 8 directions for each point of the matrix\(^5\) as illustrated in figure 1. The amplitude \( c_{ij\phi} \) is calculated as the difference between values in adjacent pixels divided by the real distance between measuring points of the detector. The value of \( q \) was chosen to be 400 arbitrary units\(^6\), based on histograms showing the number of different dose gradient amplitudes in the IMRT fields considered. This is a way to exclude small dose gradients that are present outside the actual treatment field, because the PDC algorithm calculates dose distribution in the entire sensitive area of the EPID detector.

Even if dose distribution is used for calculation, we use the term fluence complexity, supposing that these two physical quantities are correlated. If fluence complexity in an IMRT field is changed at the planning stage, dose complexity in the distribution perpendicular to the beam central axis should change accordingly. However, when speaking of the third dimension, it would be more appropriate to use the term dose complexity.

Matrices of dose distribution predicted in the plane of the detector EPID were exported in DICOM format from TPS Eclipse. MATLAB was used to calculate fluence complexity. The experiment was

\[\text{Figure 1. Distribution of the EPID detector measuring points.}\]

\(^5\) Implementation of the algorithm in MATLAB takes account of the matrix edges.
\(^6\) 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.
carried out with EPID aS500 and Varian CLINAC 600C/D as well as Varian CLINAC 2100C/D (Varian Medical Systems, Palo Alto, USA).

3. Evaluation of the method
The method was evaluated using clinical IMRT plans that were further modified. Six patients with different diagnoses (head and neck, pelvis, pancreas) and different photon energies (6 MV, 18 MV) were included. Plan 1 was the original plan with no smoothing performed after optimization. The optimization parameters X smooth and Y smooth were set to 40 and 30, respectively. Plan 2 was a modification of Plan 1 – manual smoothing of field fluences was applied, using the Smooth Transmission Factors tool in Eclipse Fluence Editor, with brush size equal to one third of the first field X dimension, as is normally done during the planning process at our institute. Fluences were further modified in Plan 3 and Plan 4 in the same way, reducing the brush size to one third of its previous size in each iteration, unless the brush size dropped below 1 cm. Finally, for each patient we obtained 4 plans with increasing level of smoothing and decreasing number of MU.

Verification plans to be measured with the EPID detector were then created for all plans and fluence complexity was calculated using our method. For each plan we estimated the average sum of dose gradient amplitudes in a field (average $V_q$) and the average number of dose gradients in a field (average $P_q$) averaging out all fields in each plan. These two parameters were used as the measure of plan complexity. The calculated plan complexity agreed with the manual level of smoothing in all cases. An example for one patient is shown in figure 2.

All verification plans were delivered on the respective linear accelerator and dose distributions were measured with the EPID aS500 detector. We looked for a correlation between our measure of plan complexity and results of gamma analysis using the criteria 3%/3 mm. Due to the small number of plans for each patient, the correlation could only be determined qualitatively. An example is shown in figure 3. Similar results were obtained for all the six patients studied, both for the average $V_q$ in a field and the average $P_q$ in a field (not shown).

![Figure 2](image1.png)

(a) Average number of dose gradients in a field (b) Average sum of dose gradient amplitudes in a field

**Figure 2.** Correlation between plan complexity as defined with our method (average number of dose gradients (a) and average sum of dose gradient amplitudes in a field (b), averaged over all fields in a plan) and the level of manual smoothing of field fluences. Plan 1 is not smoothed, Plan 4 is smoothed the most.
4. Conclusions
A new method for fluence complexity calculation in IMRT fields has been proposed. It differs in principle from other methods published so far. Evaluation of our tool with six IMRT cases showed agreement between the level of manual smoothing of field fluences, plan complexity calculation with our tool and plan verification with the EPID detector using gamma analysis. Estimation of fluence complexity prior to plan verification could help to recognize overly modulated fields or plans and save time avoiding reoptimization and remeasurement. However, fluence complexity is systematically different for different patients. This might be due to many factors, such as the site of treatment, shape of tumor, position of organs at risk etc. Therefore, further investigations need to be done to estimate appropriate thresholds in order to recognize overmodulation. Individual fields must be taken into account, rather than average value for a plan. Owing to the different design and relatively short computation time of our method, it might allow to determine plan complexity in all three dimensions, unlike previously published works. This has not been tested yet but will be done in the near future.

5. References
[1] Webb S 2003 Phys. Med. Biol. 48 2051-62
[2] Nicolini G et al 2007 Radiat. Oncol. 42 42-54
[3] McNiven A L et al 2010 Med. Phys. 37 505-15
[4] Mohan R et al 2000 Med. Phys. 27 1226-37
[5] Llacer J et al 2001 Phys. Med. Biol. 46 2637-63
[6] Coselmon M M et al 2005 Med. Phys. 32 1234-45
[7] Nauta M et al 2011 Med. Phys. 38 5385-93