

# Complexity metric based on fraction of penumbra dose - initial study

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**Abstract.** Volumetric modulated arc therapy improve radiotherapy outcome for many patients compared to conventional three dimensional conformal radiotherapy but require a more extensive, most often measurement based, quality assurance. Multi leaf collimator (MLC) aperture-based complexity metrics have been suggested to be used to distinguish complex treatment plans unsuitable for treatment without time consuming measurements. This study introduce a spatially resolved complexity score that correlate to the fraction of penumbra dose and will give information on the spatial distribution and the clinical relevance of the calculated complexity. The complexity metric is described and an initial study on the correlation between the complexity score and the difference between measured and calculated dose for 30 MLC openings is presented. The result of an analysis of the complexity scores were found to correlate to differences between measurements and calculations with a Pearson's r-value of 0.97.

## 1. Introduction

Modulated radiation therapy treatment techniques, such as volumetric modulated arc therapy (VMAT) has the potential to increase the dose to the tumor and at the same time decrease the dose to healthy tissue as compared to conventional three dimensional conformal radiotherapy (3DCRT). The fields of VMAT treatment plans are divided in control points with multileaf collimator (MLC) openings of various size and shape. Irregularly shaped MLC openings with small sub-opening components are challenging from a dosimetric point of view in consideration of both calculation, delivery and measurement [1, 2]. For example, small MLC openings increase the sensitivity of small MLC positioning errors during delivery [3] and increase the challenge of measuring as well as calculating dose because of volumes lacking charged particle equilibrium (CPE) [4]. Treatment plans with fields composed of small MLC sub-opening components might therefore cause clinically relevant discrepancies between calculated (planned) and delivered dose distributions, and can be considered as complex.

Metrics to quantify this complexity have been suggested as a complement to measurement-based quality assurance (QA) of VMAT treatment plans and/or to be used within the optimization procedure in the treatment planning system (TPS) to reduce the plan complexity (e.g. [5, 6]). In a previous study, aperture-based complexity metrics were evaluated for static MLC openings [5]. The static MLC openings represented control points in a theoretical VMAT treatment plan and the correlation of the metric scores and the difference between the calculated and measured dose of the MLC openings were investigated. Such metrics have the ability to distinguish complex treatment plans that are unsuitable for



patient treatments and need to be reconsidered or need extra attention during the quality assurance. However, they cannot give any information on where in the patient the delivered dose will be different from the calculated dose or the clinical relevance of the differences.

The regions lacking CPE and causing dose calculation errors and regions sensitive to MLC positioning errors during delivery are located in the penumbra of the MLC opening. It is likely that an increased amount of dose in a voxel that originates from a penumbra region will correlate to the probability of increased difference between calculated and delivered dose in that voxel. For example, for VMAT treatments, the center of the target volume will probably have a low fraction of penumbra dose while organs at risk most probably will have a higher fraction originating from the penumbra and thereby a higher probability for differences between calculated and delivered dose. A voxel-based complexity score that correlate to the fraction of penumbra dose have the possibility to also reveal information on the clinical relevance of the difference between calculated and delivered dose.

This study is the initial step in a project with the overall objective to develop a complexity metric that correlates to the fraction of penumbra dose in a three dimensional (3D) volume for VMAT treatments. The hypothesis is that such a complexity metric presented as a distribution in a 3D volume of the patient will correlate to the difference between calculated and delivered dose in the volume. In this initial study, a method to calculate the complexity score for static MLC openings in a 2D plane perpendicular to the beam direction is developed to verify that the fraction of penumbra dose correlate to differences between calculated and delivered dose. The next step will be to study the 2D distribution of complexity scores to establish suitable parameters for the calculation of the complexity scores before moving on to 3D calculations.

## 2. Materials and methods

### 2.1. MLC-openings

30 MLC openings, created and described by Götstedt *et al* [5] simulating individual VMAT control points in a treatment field were used in this study (figure 1). They were designed in six series (A-F) including five openings in each series with gradually increasing complexity in their shape and size. The MLC openings were created in Eclipse treatment planning system (TPS) (Eclipse™ version 11, Varian Medical Systems) using a 6 MV photon beam of a Clinac iX (Varian Medical Systems) linear accelerator with the Millennium™ 120 MLC with leaves of 5 mm width in the central 20 cm of the field and 10 mm width further out from the central axis.

### 2.2. Calculation of complexity scores

A C# software with dynamically linked MatLab® (Mathworks, Natick, MA) libraries was developed to calculate the complexity scores. The input to the software is the DICOM-file of the treatment plan from where the MLC and collimator positions are collected. The MLC and collimator positions define the appearance of the field opening in the beams eye view (BEV) 2D plane. The calculation of complexity scores are performed in the following steps:

1. The pixels of the BEV plane (pixel size in this study was 0.25 mm) is structured binary in open beam (1) or blocked beam (0) according to the MLC and collimator positions.
2. The binary BEV from step 1 is convolved with a Gaussian function normalized to 1. This will increase the complexity score of the penumbra dose higher in regions with higher dose and lower in the low dose region of the penumbra. It will mimic the clinical relevance of the penumbra dose since a dose deviation in the low dose region is of less clinical importance than a deviation of a higher dose. The resulting 2D distribution of this convolution can roughly be interpreted as the relative dose distribution of the field opening. In this study the calculations were done with a sigma for the Gaussian function of 0.5, 2 and 5 mm.
3. The pixels of the BEV plane is structured binary in field edge (1) or no edge (0).

4. The binary BEV from step 3 is convolved with a box function (1 inside box, 0 outside). This will define a region, with the width of the box and symmetrically around the field edge, as the region of interest, i.e. the penumbra region, where the complexity metric will have a score  $\neq 0$ . In this study the width of the box was varied between 3, 5, 7 and 9 mm.
5. Finally the convolution from step 2 is multiplied with the convolution from step 4. This gives a 2D distribution of complexity scores. The complexity score will mimic a dose distribution from the field truncated so that only the dose from the penumbra region remains.

The calculated complexity scores of the 30 MLC openings were compared to differences between measured and calculated dose of the same openings. In this very first analysis of the complexity score this was accomplished by collapsing the 2D distribution of complexity scores into one score for each MLC opening by calculating the *mean complexity score* of each MLC opening relative to the *estimated mean dose* for that MLC opening. In this case the mean dose is estimated by the mean value of the 2D distribution from the convolution in step 2.

### 2.3. Dose measurements, dose calculations and evaluations

The fields with the different MLC openings were delivered with gantry angle  $0^\circ$  and measured with Gafchromic<sup>TM</sup> EBT3 film (Ashland) for a source to surface distance of 90 cm at 10 cm depth in a water equivalent plastic slab phantom of  $30 \times 30 \times 30$  cm<sup>3</sup> (Gammex and PTW). The number of MU for each MLC opening was adjusted to deliver 2 Gy, within  $\pm 2\%$ , centrally in the most open part of the MLC opening at a depth of 10 cm in water based on calculations with the analytical anisotropic algorithm (AAA) in Eclipse<sup>TM</sup> version 10 (Varian Medical Systems). The film was calibrated pixel by pixel based on a foregoing exposure to a known dose using a double exposure method. The calibration and film measurement procedure have been described earlier [5].

The 2D dose distribution of the film measurements were compared to the corresponding 2D dose distribution calculated with AAA using a calculation grid size of 2.5 mm x 2.5 mm. A MatLab software was developed to facilitate alignment using mutual information (RegularStepGradientDescent). The comparison was done pixel by pixel and the 2D distribution of dose differences between measured and calculated dose in absolute numbers for each MLC opening was registered. The region analyzed was limited by a cutoff value of 0.2 Gy calculated dose. The *mean dose deviation* of each MLC opening relative to the AAA *calculated mean dose* for that opening was registered.

## 3. Results and discussion

The correlation between *mean complexity score relative to estimated mean dose* and *mean dose deviation between measurement and calculation relative to calculated mean dose* for a sigma of the Gaussian function of 5 mm and a width of the box of 5 mm is shown in figure 2. The correlation expressed as Pearson's r-value is 0.97.

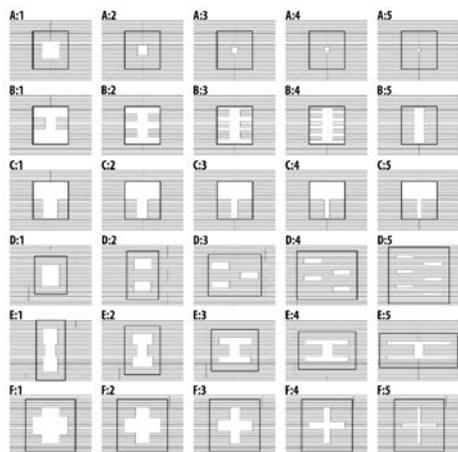
The mean complexity score and the mean absolute deviation between measurement and calculation are not expected to yield the same numbers with a 1 to 1 relationship since the complexity score is not in the same units as the absolute dose deviation which is expressed in Gy. However, the correlation seen in figure 2 is promising for the further development of the complexity score.

In this analysis of mean complexity scores, the sigma of the Gaussian function had minor influence on the complexity score for the 30 MLC openings investigated. An increasing width of the box used in the convolution described in step 4 increased the complexity score by a factor that was constant for all MLC openings meaning that it did not influence the correlation shown in figure 2. The influence of those parameters on an analysis of the uncollapsed 2D distribution is ongoing to find optimal values to be used in the future for analyses of complexity scores in a 3D volume.

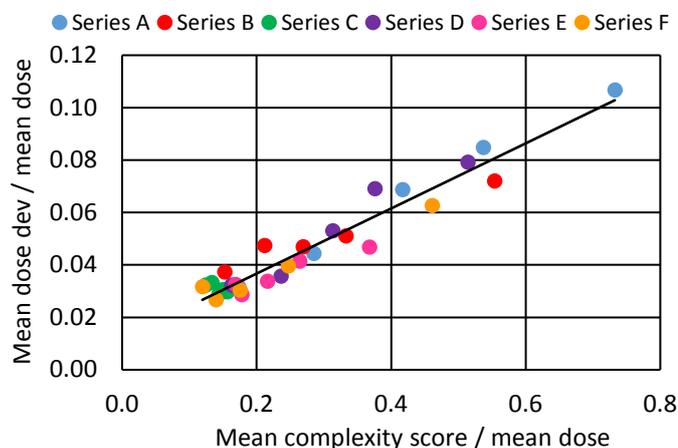
## 4. Conclusion

A new method for calculation of complexity scores based on the amount of penumbra dose was described for calculations of static MLC openings in a 2D plane. The result of an analysis of the

complexity scores were found to correlate to differences between measurements and calculations of 30 MLC openings that could represent control points in a VMAT treatment plan. The results are promising for further development of the calculation of complexity scores in a 3D volume.



**Figure 1.** The 30 MLC openings from [5], used in the study. The MLC openings are grouped in Series A-F numbered from 1-5 with increasing number for more complex MLC openings.



**Figure 2.** A scatter plot illustrating the correlation between the mean complexity score relative to estimated mean dose and mean dose deviation between measurement and calculation relative to calculated mean dose for the MLC openings (figure 1). Sigma of the Gauss function was 5 mm and the width of the box was 5 mm.

## 5. Acknowledgements

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