

Complexity metric as a complement to measurement based IMRT/VMAT patient-specific QA

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Abstract. IMRT/VMAT treatment plans contain treatment fields with MLC openings of various size and shape. Clinical dose calculation algorithms show limitations in calculating the correct dose in small and irregular parts of a MLC opening which leads to differences between the planned and delivered dose distributions. The patient-specific IMRT QA is often designed to compare planned and measured dose distributions and is therefore heavily dependent on the measurement equipment and the evaluation method. The purpose of this study is to develop a complexity metric based on shape and size of MLC openings that correlates to the dose differences between planned and delivered 3D dose distributions. Different MLC openings are measured and evaluated and used to determine a penalty function to steer the complexity metric and make the complexity scores correlate to dose difference pass rates. Results of this initial study show that a correlation was found between complexity scores and dose difference pass rates for static fields with varied complexity. Preliminary results also show that the complexity metric can distinguish clinical IMRT fields with higher complexity.

1. Introduction

Measurement based pre-treatment patient-specific quality assurance (QA) is a common approach to ensure the accuracy of the delivered absorbed 3D dose distribution of advanced radiotherapy treatments such as intensity modulated radiotherapy and volumetric modulated arc therapy treatments (IMRT/VMAT). Treatments with intensity modulated techniques are increasing in popularity due to the capability to create treatment plans of high conformity and to increase the target dose but still retain the dose level to the organs at risk [1]. The intensity modulation is mainly accomplished by varying the shape of the multi-leaf collimator (MLC) opening but also by varying the dose rate and sometimes the speed of the gantry rotation. Advanced dose optimization algorithms within the treatment planning systems (TPS) generate treatment plans that fulfill the user-selected constraints and objectives and contain treatment fields with MLC openings of various size and shape. Irregularly shaped MLC openings with smaller sub-field components are challenging from a dosimetric point of view [2]. Unfortunately, advanced clinical dose calculation algorithms have difficulties to estimate a correct dose distribution when it comes to small and irregular beam apertures where there is lack of charged particle equilibrium (CPE) [2]. This leads to a calculated dose distribution associated with increased uncertainties for treatment plans that consist of small and irregular MLC openings which in turn leads to dose differences between planned and delivered dose distributions for those plans.



Commonly used measurement based QA methods are designed to compare the calculated 3D dose distribution with a dose distribution measured using a semi-3D dosimetry system (e.g. Delta^{4PT}, ArcCHECK®, OCTAVIUS® etc.), which makes the method heavily dependent on the accuracy of the measurement equipment and the choice of evaluation method. Clinically relevant dose differences between planned and measured dose distributions in evaluated dose volume metrics of interest are in some cases not detected in common QA procedures [3,4]. The intention with the QA differs between departments and some departments might focus their QA on finding only the large errors that corresponds to something going wrong in the preparation procedure or the delivery. The purpose of this study, however, is to develop a complexity metric based on shape and size of MLC openings to identify all treatment plans with clinically relevant deviations between planned and delivered dose due to, for example inaccuracies in the absorbed dose calculation procedure. This initial study focuses on the limitations within the TPS to calculate a correct dose for small and irregular MLC openings. Delivery of treatment plans with similar dose distributions may differ very much in complexity due to different shapes of the MLC openings [5] and the use of a complexity metric to score different treatment plans will simplify the choice of plan to be used in order to deliver a robust treatment to the patient. This method will also make the patient-specific QA more effective by avoiding unnecessary time consuming phantom measurements that might limit the number of patients treated with advanced intensity modulated treatment techniques. The main idea is to develop a method that can be used to effectively distinguish treatment plans that need to be reconsidered or need extra attention during the quality assurance.

2. Material and method

An in-house developed MatLab® program (Mathworks, Natick, MA) is used to derive field specific complexity parameters. The MLC openings for each control point for both IMRT and VMAT plans are quantified as measured distances both parallel and opposed to the direction of the MLC leaves every 0.5 cm to cover the entire MLC opening (figure 1). Shorter distances are related to the complexity of irregularities and smallness of MLC openings and larger distances are related to non-complex large openings.

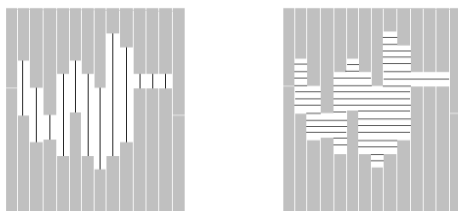


Figure 1. Measured distances both parallel and opposed to the direction of the MLC leaves.

The complexity metric is designed in two parts, $P = \overline{f(d_i)} \cdot f(a_{Eq})$, one part concerning the measured distances within the MLC opening and one part concerning the total field area. The distances d_i measured within the MLC opening and the equivalent field size a_{Eq} are penalized according to a penalty function f that is experimentally determined based on evaluated differences between planned and measured dose distributions. A control point can consist of more than one connected MLC opening and each MLC opening is treated separately in the complexity metric. The final complexity score for a control point is the mean value of all the individual MLC opening penalty values P . Static MLC openings of various complexities, each simulating one control point, are created in the Eclipse treatment planning system (Eclipse version 11, Varian Medical Systems) and grouped in seven series. The various shapes and sizes are determined based on the assumption that the TPS has difficulties to calculate a correct dose distribution for MLC openings smaller than 4x4 cm² [2]. Each series consists of MLC openings of similar shape, but modified to gradually become more complex regarding both the shape and size (figure 2). Series 4 and 5 have a constant area and series 3, 6 and 7 have a constant circumference.

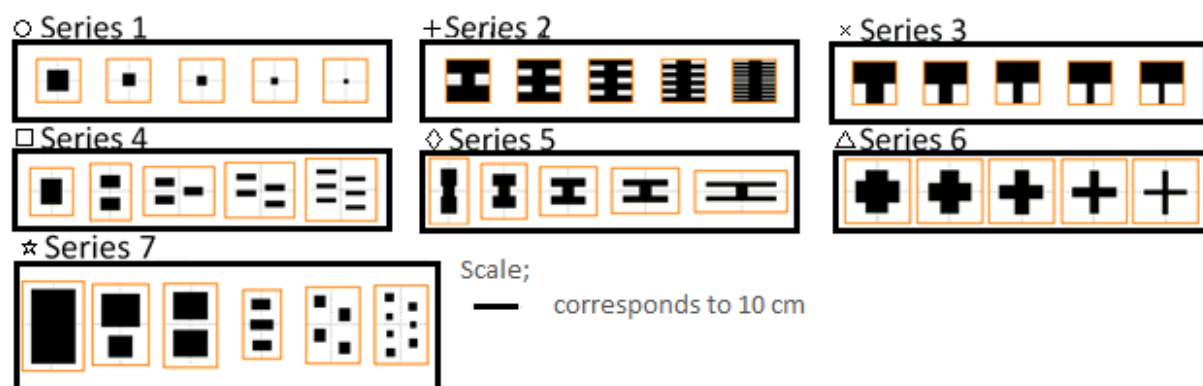


Figure 2. Static MLC openings simulating control points of various complexities.

All the 36 fields were delivered with a Clinac iX (Varian Medical Systems) linear accelerator and measured with an amorphous silicon electronic portal imaging device (EPID aSi 1000, Varian Medical Systems) in integrated image mode. The measurement session was started by calibrating the EPID for a 10 x 10 cm field shaped with the collimators. This field was repeatedly measured during the session to ensure that the measurements matched the calculated dose within 0.3 %. All measurements were carried out with the gantry at 0 degrees and a SSD of 100 cm. The number of MUs was adjusted to deliver 2 Gy centrally in the most open part of the field at a depth of 10 cm in a solid water phantom when calculated with the AAA algorithm in Eclipse. The measurements were analyzed within the Portal Dosimetry module in ARIA (Varian Medical Systems). The feature of auto align was used for 10 cm x 10 cm fields shaped with the MLC that also were repeatedly measured during the session, and the suggested correction was used to align all the static fields. The planned and measured doses were compared with different global dose difference criteria from 3-10% for each MLC opening. Pixels that received less than 10 % of the maximum dose were not considered in the evaluation. The relative number of pixels within the dose difference criterion was used as a measure of agreement between the planned and measured dose distributions. Dose difference pass rates of the static fields are used to derive the penalty function f in the complexity metric. The criteria of the penalty function was to give a penalty value between 0-1 and that a distance of 4-5 cm will be considered as non-complex and will be given the penalty value close to 1. The correlation between the calculated complexity score and the dose difference pass rate was evaluated with the Pearson's r-value. An initial test of the complexity metric was done for four clinical patient cases, two head and neck and two prostate IMRT treatment plans, both based on dynamic MLC with sliding window. All plans have been approved and used for treatment at Sahlgrenska University Hospital. These plans were measured field by field with EPID and evaluated in absolute dose mode using a 10 % dose cut off and the fields were auto aligned. The calculated complexity score for each field are compared to the global gamma (3%/2mm) pass rates, which is a commonly used evaluation method for patient specific QA.

3. Results and discussion

A penalty function f that showed a good correlation between calculated complexity scores and the dose differences pass rates for the static fields was an inverse exponential function, $f(x) = 1 - e^{-x}$. The correlation between the calculated complexity scores and the dose difference pass rates for the static fields are shown as a scatter plot in figure 3a.

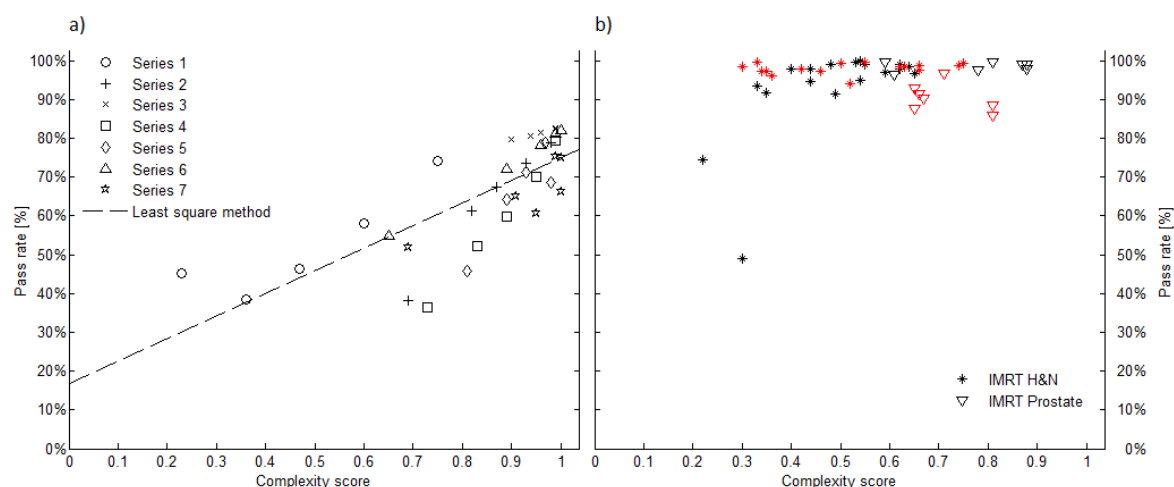


Figure 3. Scatter plots of the correlation between the calculated complexity scores and (a) the 5 % dose difference pass rates for the static fields and (b) the global gamma pass rates (3%/2mm) for the IMRT treatment plans.

The Pearson's r-value, which is a measure of the linear correlation, is 0.77 for the correlation of the static fields. Plans have been made to further develop the complexity metric in the near future.

The global gamma pass rates and the complexity score for the clinical IMRT treatment plans are shown in figure 3b. The complexity scores are generally lower for the H&N cases compared to the prostate cases as expected due to the more complex shape of the MLC openings in H&N treatment plans. Most of the fields of the clinical IMRT treatment plans that have been accepted and used for treatment have high gamma pass rates as expected. The two fields which have the lowest complexity scores are also the ones with the lowest pass rate and makes this initial test on clinical treatment plans promising. However, the complexity metric needs to be further validated to ensure that unacceptable treatment plans will be distinguished.

4. Conclusion

A complexity metric that is based on shape and size of MLC openings is developed. Initial results show that the extent of dose differences between planned and measured dose distributions correlates to calculated complexity scores. The design of the complexity metric needs further developments for better agreement between complexity scores and dose differences and further validation for clinical treatment plans.

5. References

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