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Original research article

Trajectory log file sensitivity: A critical analysis using DVH and EPID

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ABSTRACT

Aim: The aim of this study was to investigate the sensitivity of the trajectory log file based quality assurance to detect potential errors such as MLC positioning and gantry positioning by comparing it with EPID measurement using the most commonly used criteria of 3%/3 mm.
Materials and methods: An in-house program was used to modified plans using information from log files, which can then be used to recalculate a new dose distribution. The recalculated dose volume histograms (DVH) were compared with the originals to assess differences in target and critical organ dose. The dose according to the differences in DVH was also compared with dosimetry from an electronic portal imaging device.
Results: In all organs at risk (OARs) and planning target volumes (PTVs), there was a strong positive linear relationship between MLC positioning and dose error, in both IMRT and VMAT plans. However, gantry positioning errors exhibited little impact in VMAT delivery. For the ten clinical cases, no significant correlations were found between gamma passing rates under the criteria of 3%/3 mm for the composite dose and the mean dose error in DVH ($r < 0.3$, $P > 0.05$); however, a significant positive correlation was found between the gamma passing rate of 3%/3 mm (%) averaged over all fields and the mean dose error in the DVH of the VMAT plans ($r = 0.59$, $P < 0.001$).
Conclusions: This study has successfully shown the sensitivity of the trajectory log file to detect the impact of systematic MLC errors and random errors in dose delivery and analyzed the correlation of gamma passing rates with DVH.

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1. Background

In conventional radiation therapy, techniques such as 3D conformal radiotherapy (3DCRT) deliver a sufficient dose to the tumor volume while sparing critical organs adjacent to it. To achieve this, the linear accelerator is equipped with multileaf collimators (MLC) to shape the radiation field to conform to the tumor volume while shielding normal healthy tissue. In modern radiotherapy equipment, complex techniques, such as intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT), are capable of delivering a much higher conformal dose to the tumor volume than can be achieved with 3DCRT, while still being able to spare nearby critical organs. In IMRT and VMAT, this is made possible by the use of dynamic MLC (sliding window), with each leaf of the MLC being able to constantly change its position to modulate the desired dose distribution while the radiation is on. By comparison, the MLC in 3DCRT are static during delivery. Therefore, both IMRT and VMAT are capable of generating a very steep dose gradient between the tumor and the healthy normal tissue. However, any deviation in the actual MLC position from its planned position can affect the accuracy of the dose delivery, and such errors can occur due to deterioration in the performance of each MLC motor.[1] The main difference between IMRT and VMAT is that each treatment field has a fixed gantry angle in IMRT, whereas in VMAT the gantry rotates continuously around the patient while the MLC modulates the radiation beam. Therefore, any deviation in the actual gantry position from that planned will affect the accuracy of the dose delivery from VMAT. The additional contribution of delivery parameters, such as the speed of gantry rotation, make VMAT delivery more complex than IMRT, and therefore, more susceptible to inaccuracies in dose delivery. To prevent such errors from happening during IMRT/VMAT delivery, patient specific quality assurance is performed before the actual delivery, to ensure that the calculated and measured doses agree, thereby indicating that all planned parameters are delivered within the tolerance limits.

Within our department, the currently implemented methods for patient specific quality assurance for IMRT/VMAT verification are point dose absolute measurement and 2D planar dose verification using an electronic portal imaging device (EPID), following the guidance of the American Association of Physicists in Medicine (AAPM) Task Groups 119 and 120,[2,3] The total dose in each treatment field of the IMRT or VMAT plan is delivered to a water equivalent slab phantom and measurement is performed using an ion chamber. For an IMRT or VMAT dose delivery to be considered accurate, the measured point dose must agree with the calculated point dose to within 3% using a point dose absolute measurement method.[2,3] A second method for the verification of an IMRT or VMAT plan is to deliver each treatment field to an EPID, and then use gamma analysis to compare the 2D predicted dose calculated by the Treatment Planning System (TPS) with the measured dose distribution. For IMRT or VMAT to be considered accurate, at least 90% of the 2D dose distribution delivered by each treatment field must agree with the predicted 2D dose distribution calculated by the TPS to within a 3% dose difference and a 3 mm agreement in distance.[2,3]

However, in a study described by Dong et al.,[4] it was reported that point dose measurements performed on 751 IMRT plans contained errors ranging from −12.7% to 11.7%. This was because IMRT delivery usually consists of a large number of fields, each of which is smaller than the size of the ion chamber; this can result in partial volume effects, which is one reason for such a large range of errors, as discussed in the ICRU Report 83.[5] Kruse et al.[6] also demonstrated that performing gamma analysis on per-field measurements using EPID does not guarantee dosimetric accuracy, and furthermore, Zhen et al.[7,8] also reported that the gamma passing rate only indicates the quantity of errors; it does not provide information on the location and magnitude (dose) of errors, which is clinically important. Therefore, there is a need for a new method for verifying the accuracy of IMRT and VMAT deliveries in clinically relevant terms, such that the actual patient dose can be investigated; several authors[9–14] have described methods for doing this. Patient specific quality assurance using the linear accelerator (linac) log file to generate a dose-volume histogram (DVH) of the patient during the actual delivery allows the possibility of monitoring the average MLC positional errors,[15–20] as well as providing information on the accuracy of the dose delivery to the patient's target and critical organ structures.

The aim of this study was to investigate the sensitivity of trajectory log file based Quality Assurance (QA) by introducing actual delivery parameters (random errors) and systematic errors in MLC and gantry position using in an house program. The sensitivity of the trajectory log file was analyzed by comparing original TPS calculated plan vs. error induced plan for both IMRT and VMAT. The potential of trajectory log file QA was detected by comparing 2D measured dose distribution with zero error vs. measured dose distribution with induced error. In addition, the trajectory log files were used to reconstruct the error induced plan and recalculated in TPS to assess the dose difference obtained in DVH by comparing it to the original plan. The in-house program works by entering the actual delivery parameters (e.g. MLC position, jaw tracking position, cumulative dose index (or fractional MU per control point), and gantry angle) recorded in the trajectory log files into the treatment plan. The new treatment plan with replaced parameters is then imported into the TPS to recalculate a new dose distribution for the tumor volume.

2. Materials and methods

2.1. A linear accelerator and treatment planning system

This study employed similar methods to those used in a previous study by Betzel et al.[21] All IMRT and VMAT plans were generated using a Varian Eclipse TPS using Anisotropic Analytical Algorithm (AAA) for dose calculation and optimized using Dose Volume Optimizer (DVO) and Progressive Resolution Optimizer (PRO) Version 13.0.26 (all produced by Varian Medical Systems, Palo Alto, CA). All calculated plans were delivered with a Varian TrueBeam Version 2.0 equipped