

IMRT patient-specific QA using the Delta⁴ dosimetry system and evaluation based on ICRU 83 recommendations

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Abstract. Patient-specific IMRT QA is dependent on the dosimetry system and the evaluation procedure. The ICRU report 83 provides recommendations of tolerated deviations between measured and calculated absorbed dose distributions for QA of IMRT treatment plans. The result of doing IMRT patient-specific QA with the Delta⁴ dosimetry system and using the ICRU recommendations for evaluation is studied. To be able to investigate the QA procedure the original IMRT treatment plans were modified in the treatment planning system to create calculated dose distributions with dosimetric deviations from the original treatment plans. The modified dose distributions were compared to the dose distributions from the Delta⁴ measurements of the original treatment plans and the differences were evaluated with criteria and tolerance levels according to the recommendations from ICRU. The evaluation for all 28 modified dose distributions have gamma passing rates higher than the tolerance level recommended from ICRU and will therefore pass the patient-specific QA. More than half of the evaluations have a gamma passing rate of 100 %. Evaluation of the differences between the modified and the original calculated dose distributions revealed in several cases large unacceptable dose differences in the PTV volumes and the organs at risk, for example an increase in the near-maximum dose $D_{2\%}$ to the spinal cord of 5.5 Gy. This study indicates that patient-specific QA with the Delta⁴ dosimetry system and the ICRU recommendations for evaluation can not be used to distinguish differences between planned and measured dose of dosimetric relevance.

1. Introduction

In order to ensure the accuracy of the delivered absorbed dose distribution during intensity modulated radiation therapy (IMRT) treatment, a patient-specific quality assurance (QA) is often performed. The QA is most often based on measurements of delivered dose to find possible deviations between the planned and the delivered dose distribution. The method used for patient-specific IMRT QA measurements depends on the equipment available at the clinic but the result of the QA is also dependent on the evaluation procedure, for example the choice of acceptance criteria and tolerance levels. The QA could be designed to have different intentions, either to reveal major errors, such as no multileaf collimator (MLC) in the beam or use of the wrong plan, but it could also be designed to find smaller deviations between planned and delivered dose, due to for example inaccuracies in the absorbed dose calculation procedure, to keep the differences between planned and delivered dose within a specified uncertainty. It is important to understand what the combination of dosimetry system



and evaluation procedure implies in terms of what kind of deviations and/or errors that will be detected.

In the International Commission on Radiation Units and Measurements (ICRU) report 83^[1], recommendations of tolerated deviations between measured and calculated absorbed dose distributions for QA of IMRT treatment plans are suggested. In the recommendations, the tolerance levels are specified separately for high and low absorbed dose gradient regions. Low gradient regions are defined to have a relative absorbed dose change less than 20 %/cm. High gradient regions are defined to have a relative change in absorbed dose of more than 20 %/cm. The recommendation by the ICRU of tolerated dose difference between measured and calculated IMRT dose distributions is ± 3.5 % in low gradient regions. Assuming that the dose difference frequency histogram has a normal distribution centered on a dose difference of 0 % with a standard deviation of 3.5 %, it means that 85 % of the data in the low gradient region should have a dose difference within ± 5 %. In high gradient regions distance-to-agreement (DTA) is the suggested choice of accuracy criteria. Accuracy in DTA of 3.5 mm is recommended by ICRU 83, meaning that 85 % of the data in the high gradient region should be within 5 mm DTA.

The objective is to evaluate the result of doing IMRT patient-specific QA with the Delta⁴ dosimetry system from ScandiDos based on ICRU report 83 recommendations for evaluation.

2. Material and method

Three head and neck IMRT treatment plans, using dynamic MLC with sliding window, that were used for treatment of three different patients at Sahlgrenska University Hospital were selected for this study. The treatment plans were generated in the Eclipse treatment planning system (Eclipse version 10.0, Varian Medical Systems). Patient 1 and 2 were treated for malignancies in the nasopharynx, and patient 3 was treated for secondary and unspecified malignancies in the lymph nodes. All patients were planned for simultaneous treatment of two target volumes PTV-T (including the gross tumour volume) and PTV-N (including subclinical disease). The treatment plan for patient 1 was designed to also give a simultaneous boost dose to a smaller volume within PTV-T. To be able to investigate the QA procedure these original plans were modified by varying the MLC leaf transmission factor, dosimetric leaf gap, normalization and the isocenter position in the treatment planning system. The intention with the modifications was not to introduce actual possible errors likely to occur during treatment planning but to introduce different kinds of deviations between the dose distributions to be able to study whether unacceptable dose deviations would be detected by the QA procedure. A total of 28 modified dose distributions were created and studied.

The absorbed dose distributions of the three original IMRT treatment plans were measured with the Delta⁴ dosimetry system. The Delta⁴ phantom consists of two orthogonal planes with a total of 1069 diodes in a cylindrical PMMA phantom. The spacing between the diodes is 0.5 cm in the central area of 6 cm x 6 cm in each plane and 1 cm outside this area. The measured dose distributions were normalized by a mean value of the relative dose deviation in all measurement points between the measured and calculated original dose distributions of the treatment plans. The measurements constitute the basis for the evaluation study and were compared to the modified calculated dose distributions to investigate the ability of the evaluation method to distinguish dosimetric deviations.

The recommended evaluation criteria from the ICRU 83 are specified separately for low and high absorbed dose gradient regions and evaluation using the dose difference and DTA is recommended for the low and high gradient regions, respectively. This is not strictly the same as using the gamma evaluation (Low et al. 1998)^[2] with the same criteria, but according to the ICRU; “setting the gamma criterion to the same values would result in a more conservative test”. The Delta⁴ software is provided with a tool to separate dose distributions in high gradient regions to evaluate with a DTA criterion. It is not possible to evaluate low gradient regions separately in the Delta⁴ software. Therefore the recommendation from the ICRU must be transformed to the gamma evaluation with the criteria 5 % / 5 mm and passing rate 85 % if the Delta⁴ software is to be used. The Delta⁴ software also provides an

interpolation algorithm that estimates the dose to regions where no detectors are located. However, the gamma evaluated passing rate is only given for the measurement points in the two detector planes wherefore the analysis is limited to the measurement points. The evaluation was carried out both with all the diodes included, but also when excluding diodes that receive less than 20 % of the absorbed dose in the isocenter. For comparison, the dose distributions were also evaluated strictly according to ICRU by separating the dose distributions in high and low dose gradient regions. Data of relative dose difference and DTA for the measurement points were exported from the Delta⁴ software and the high and low dose gradient regions were separated and evaluated separately outside the Delta⁴ software.

Evaluation of the QA results is done by analyzing the dose differences between the modified and the original calculated dose distributions in structures of interest. The investigated dose values are the near-minimum ($D_{98\%}$), mean and near-maximum ($D_{2\%}$) dose to the PTV-T and PTV-N volumes, near-maximum dose ($D_{2\%}$) to the spinal cord and the brainstem (brainstem were only evaluated for patient 1 and 2) and the mean dose to the parotid glands. The dose values are obtained from dose volume histograms generated by the treatment planning system. This analysis was done with the assumption that it is reasonable to desire less than 5 % absorbed dose difference in these dose values, and larger dose differences are considered as relevant for the treatment of the patient, and should be detected by the QA procedure.

3. Results and discussion

When using the gamma evaluation in the Delta⁴ software and the criteria 5 % / 5 mm, the evaluation of all 28 modified dose distributions have a gamma passing rate higher than 85 % and 18 of the evaluations have a gamma passing rate of 100 %. Only one of the evaluations has a gamma passing rate below 90 %. This means that all of the investigated dose distributions passed the gamma evaluation according to the recommendations of the ICRU report 83 with the use of the Delta⁴ dosimetry system.

The analysis of the dose differences in structures of interest show, on the other hand, large unacceptable dose differences in some cases. Four of the evaluated modified dose distributions have more than a 5 % increase of the $D_{2\%}$ for the spinal cord compared to the original plan. A 5 % increase in $D_{2\%}$ for the spinal cord corresponds to a mean absorbed dose of 2.2 Gy for the whole treatment, for the three plans studied. The maximum dose increase in $D_{2\%}$ found for the spinal cord was 12.5 %, which corresponds to an absorbed dose of 5.5 Gy for the whole treatment. Seven of the modified dose distributions have an increase of more than 5 % in the mean dose to one or both of the parotid glands. Nine of the evaluated modified dose distributions have more than a 5 % decrease of the minimum dose to one or both of the PTV volumes studied. Overall it was found that 15 of the 28 IMRT modified dose distributions have large dosimetric differences >5 % that are not detected in the QA procedure based on the gamma evaluation and the Delta⁴.

When the modified dose distributions were evaluated separately for the high and low absorbed dose gradient regions the result is somewhat different. In this case the evaluation for 6 of the 15 modified dose distributions with large dosimetric differences were found to have passing rates lower than 85 %. For all 6 cases this was found for the evaluation in the low gradient region with the criterion of relative dose differences $< \pm 5\%$. The passing rate in the high gradient region using criterion of DTA < 5 mm was higher than 99 % in all cases. In the 6 cases with passing rates lower than 85 %, between 24 - 48 % of the points failing in the low gradient region will pass the gamma evaluation due to the included DTA criteria. This indicates that for the cases evaluated in this study, the gamma evaluation in the Delta⁴ software with the criteria 5 % / 5 mm is not more conservative than evaluation with separate criteria for low and high gradient regions but rather the contrary. There are, however, several dose distributions with large dosimetric deviations that will not be detected with either evaluation method.

Examples of the relative dose differences in the PTV volumes and the organs at risk together with the passing rates for the different evaluation methods are shown in table 1 for 5 of the worst cases that had large dose differences between the original and the modified dose distributions. For one case, an increased dose of 12.5 % to the spinal cord will pass both the gamma evaluation and the evaluation

separated in high and low gradient regions. Another case have a decreased absorbed dose in all investigated values, D_2 %, mean and D_{98} %, to both PTV volumes but pass both evaluations with high passing rates. Two of the examples shown in table 1 did not pass the evaluation when the high and low absorbed dose gradient regions were separated.

Table 1. Examples of the relative dose difference analysis in structures of interest and the passing rates of the QA based on gamma evaluation (see column labeled "Gamma") and the evaluation separated in the high and low gradient regions (see column labeled "ICRU") for five of the evaluated modified dose distributions. The relative dose difference [%] between the modified and the original dose distributions where the modified plans have more than a ± 5 % dose difference in the PTV volumes and the organs at risk are marked with a grey shade. Passing rates below 85 % are marked with bold numbers.

Patient	Relative dose difference in PTV [%]						Relative dose difference in organs at risk [%]				Passing rate [%]		
	PTV-T			PTV-N			Spinal cord	Left parotid	Right parotid	Brainstem	Gamma	ICRU	
	D_2 %	Mean	D_{98} %	D_2 %	Mean	D_{98} %	D_2 %	Mean	Mean	D_2 %	Total ^a	Low ^b	High ^c
1	6.8	7.0	6.6	6.6	7.6	7.2	12.5	16.8	16.3	8.2	100	98.6	100
1	0	-0.7	-5.6	-0.3	-0.9	-6.0	2.5	5.7	-12.7	3.0	100	99.3	100
2	-5.7	-6.1	-6.3	-5.9	-6.2	-6.2	-7.3	-9.2	-7.1	-6.5	94.5	78.2	100
3	5.6	5.0	5.4	5.9	5.8	5.4	11.6	19.0	9.6		100	98.7	100
3	-6.0	-6.3	-6.3	-5.8	-5.6	-5.9	-6.2	-11.6	-9.0		92.0	69.5	99.0

^aGamma evaluation when all the diodes are included.

^bLow gradient region, dose change less than 20 %/cm, evaluated with dose difference criterion of ± 5 %.

^cHigh gradient region, dose change more than 20 %/cm, evaluated with distance to agreement criterion of ± 5 mm.

4. Conclusion

Patient-specific QA with the Delta⁴ dosimetry system, using the evaluation limited to the diode measurement points, and the ICRU 83 recommendations for evaluation can not be used with the intention to distinguish differences between planned and measured dose of dosimetrical relevance for the treatment of the patient.

References

- [1] International Commission on Radiation Units and Measurements, ICRU Report 83 2010 *Prescribing, Recording, and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT)*
- [2] Low D A *et al* 1998 *Med. Phys.* **25** 656-6