

Quasi 3D dosimetry (EPID, conventional 2D/3D detector matrices)

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Abstract. Patient specific pretreatment measurement for IMRT and VMAT QA should preferably give information with a high resolution in 3D. The ability to distinguish complex treatment plans, i.e. treatment plans with a difference between measured and calculated dose distributions that exceeds a specified tolerance, puts high demands on the dosimetry system used for the pretreatment measurements and the results of the measurement evaluation needs a clinical interpretation. There are a number of commercial dosimetry systems designed for pretreatment IMRT QA measurements. 2D arrays such as MapCHECK[®] (Sun Nuclear), MatriXX^{Evolution} (IBA Dosimetry) and OCTAVIOUS[®] 1500 (PTW), 3D phantoms such as OCTAVIUS[®] 4D (PTW), ArcCHECK[®] (Sun Nuclear) and Delta⁴ (ScandiDos) and software for EPID dosimetry and 3D reconstruction of the dose in the patient geometry such as EPIDose[™] (Sun Nuclear) and Dosimetry Check[™] (Math Resolutions) are available. None of those dosimetry systems can measure the 3D dose distribution with a high resolution (full 3D dose distribution). Those systems can be called quasi 3D dosimetry systems. To be able to estimate the delivered dose in full 3D the user is dependent on a calculation algorithm in the software of the dosimetry system. All the vendors of the dosimetry systems mentioned above provide calculation algorithms to reconstruct a full 3D dose in the patient geometry. This enables analyzes of the difference between measured and calculated dose distributions in DVHs of the structures of clinical interest which facilitates the clinical interpretation and is a promising tool to be used for pretreatment IMRT QA measurements. However, independent validation studies on the accuracy of those algorithms are scarce. Pretreatment IMRT QA using the quasi 3D dosimetry systems mentioned above rely on both measurement uncertainty and accuracy of calculation algorithms. In this article, these quasi 3D dosimetry systems and their use in patient specific pretreatment IMRT/VMAT QA will be discussed.

1. Introduction

Verification measurements for patient specific pretreatment intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) quality assurance (QA) has been recommended [1, 2]. A pretreatment measurement can only verify a correct treatment delivery to a phantom at that particular point of time. It was shown in a study on the efficacy of common quality control (QC) checks that the pretreatment IMRT QA was the least effective check and detected only 1.4% of 4407 incidence error reports recorded in the course of clinical operations in 2 academic radiation oncology departments [3]. However, this result is not surprising since it is not the purpose of the pretreatment IMRT QA to find errors like for example wrong position of isocenter in the patient, wrong treatment plan selected for the treatment or wrong PTV expansion used for treatment planning.



The primary purpose of the pretreatment QA is to verify correct data transfer of the treatment plan parameters from the treatment planning system to the treatment machine and to verify that the treatment will deliver the planned dose distribution within a specified tolerance. IMRT treatment fields includes irregularly shaped multi-leave collimator (MLC) openings sometimes with small sub-field components. Advanced clinical dose calculation algorithms in treatment planning systems (TPS) have difficulties to estimate a correct dose distribution for small and irregular beam apertures [4]. Furthermore the delivery of treatment fields with small sub-field components is sensitive to small errors (within tolerance) in the machine, such as the MLC position [5]. Treatment plans including a large amount of small sub-field components will result in increased uncertainties with larger differences between planned and delivered dose distributions and are regarded as complex treatment plans that should be avoided to be used for treatment. Such treatment plans should be detected in the pretreatment measurement QA.

There are international recommendations to do 3D or at least quasi 3D measurements [1, 2] for pretreatment measurement QA but there are no specific recommendation on measurement and evaluation methods. The comparison of 3D dose distributions, i.e. the measured and the calculated dose distributions, require an evaluation method that include a large number of data points and preferably express the result in one or a few pass-fail criteria. A commonly used evaluation method is the gamma evaluation [6]. However, it has been shown that clinically relevant dose differences between planned and measured dose distribution are in some cases not detected based on common measurement procedures and gamma evaluation [7-10]. The international commission on radiation units and measurements (ICRU) have for IMRT/VMAT treatments replaced their previously recommended level of accepted uncertainty in delivered dose of 5% (1 standard deviation, SD) [11] by the recommendation that for low-gradient ($< 20\%/cm$) regions the difference between the measured and the planned dose, normalized to the prescribed dose, should be no more than 3.5% (1 SD) and for high-gradient ($> 20\%/cm$) regions the accuracy of distance to agreement should be within 3.5 mm (1 SD) [12]. During the implementation of pretreatment IMRT/VMAT QA in a clinic, the procedure, i.e. combination of dosimetry system, measurement and evaluation method, must be validated to be able to distinguish complex treatment plans. This must be done individually for treatment plans created at each clinic and therefore no general recommendation on measurement and evaluation criteria can be recommended [1, 2].

The ability to distinguish complex treatment plans puts high demands on the dosimetry system used for the pretreatment measurements. The results of the measurement evaluation needs a clinical interpretation. Besides phantoms for detector inserts, film and gel dosimetry (which will not be addressed in this paper) there are a number of commercial dosimetry systems designed for pretreatment IMRT QA measurements. 2D arrays such as MapCHECK[®] (Sun Nuclear), MatriXX^{Evolution} (IBA Dosimetry) and OCTAVIOUS[®] 1500 (PTW), 3D phantoms such as OCTAVIUS[®] 4D (PTW), ArcCHECK[®] (Sun Nuclear) and Delta⁴ (ScandiDos) and software for electronic portal imaging device (EPID) dosimetry and 3D reconstruction of the dose in the patient geometry such as EPIDoseTM (Sun Nuclear) and Dosimetry CheckTM (Math Resolutions) are available. These quasi 3D dosimetry systems will be discussed in this article.

2. Quasi 3D dosimetry systems

The quality of pretreatment IMRT QA measurements are dependent on the properties and the characteristics of the chosen measurement equipment. The measurements should give information on the accuracy of the delivery in 3D and preferably with high resolution to cover both regions of target and organs at risk. The evaluation, i.e. comparison of the measured and the calculated dose distributions, must be done in multiple points in 3D and therefore traditional point dosimeters are not applicable. The general specifications of different common commercial dosimetry systems designed for IMRT QA purposes are summarized in table 1. The advantage of using ionization chambers in the measurement systems is the well established method to estimate absorbed dose. The advantage of measurement systems using diodes in front of ionization chambers is the small detector size which

increase the resolution and the possibility to do more accurate measurements in regions with non-homogeneous dose distribution. A smaller detector will make it possible to decrease the distance between detectors. The detector distance and the number of detectors reveals the amount of information you can get from a measurement. A comparison of the measured and calculated dose distributions restricted to the measurement points is directly dependent on the distance between the detectors in the measurement. The 2D arrays MapCHECK[®], MatriXX^{Evolution} and OCTAVIUS[®] 1500 have all the measurement points in one 2D plane. For the ArcCHECK[®] the diode detectors are placed in a helical grid in the outer parts around a cylinder shaped phantom. The diode detectors in the Delta⁴ are placed in two orthogonal planes like a cross seen in a transversal slice of the cylinder shaped phantom. This means that for a comparison restricted to the measurement points there are volumes without measurement points. It is, for example, possible that an organ at risk might be situated in a volume that is not measured and that a dose difference between delivered and calculated dose will cause an undetected overdosage out of tolerance in that organ at risk. None of the dosimetry systems included in table 1 can measure the 3D dose distribution with a high resolution (full 3D dose distribution). Those systems can be called quasi 3D dosimetry systems. To be able to estimate the delivered dose in full 3D the user is dependent on a calculation algorithm provided in the software of the dosimetry systems.

Table 1. Summary of general specifications for different common commercial dosimetry systems designed for IMRT QA purposes.

	MapCHECK [®] 2 (Sun Nuclear)	MatriXX ^{Evolution} (IBA Dosimetry)	OCTAVIUS [®] 1500 /OCTAVIUS [®] 4D (PTW)	ArcCHECK [®] (Sun Nuclear)	Delta ⁴ (ScandiDos)
Phantom shape	2D array	2D array	2D array/Cylinder	Cylinder	Cylinder
Detector	Diode	Ion chamber	Ion chamber	Diode	Diode
Detector area (mm ²)	0.64	15.9	19.4	0.64	0.78
Detector vol. (cm ³)	0.000019	0.08	0.06	0.000019	0.000039
Detector dist. (mm)	7.07	7.62	7.1	10	5/10
No. of detectors	1527	1020	1405	1386	1069
Detector pattern	Plane	Plane	Plane	Cylinder	2 orth. planes
Max field size (cm)	32 x 26	24.4 x 24.4	27 x 27	27	20
Weight (kg)	7.1		6/29	16	27

Measurements with the 2D arrays MapCHECK[®], MatriXX^{Evolution} and OCTAVIUS[®] 1500 as well as 2D measurements using the EPIDs are well suited to verify irradiation of a single beam direction, i.e. per beam verification of IMRT with fix beam angles. Such measurements can be used to identify systematic errors and can be an important part of the IMRT commissioning process. However, for pretreatment IMRT QA measurements, the composite dose distribution of all fields need to be measured to be able to do a clinical interpretation of the difference between the measured and the calculated dose distribution of the whole treatment plan. For a 2D array or an EPID, the composite dose can be measured as a sum of all beam directions directed perpendicular to the 2D array. This can be done either by delivering the whole treatment with the gantry angle at 0 degrees or to mount the 2D array, like the EPID, to the gantry to make the array follow the gantry rotation but always be positioned perpendicular to the beam direction. Such dose distribution cannot directly be related to the composite 3D dose of all beams but needs a calculation algorithm to reconstruct the measured dose to the dose in a 3D phantom or the patient geometry. The vendors of the all dosimetry systems in table 1 including those based on 3D phantoms, i.e. OCTAVIUS[®] 4D, ArcCHECK[®] and Delta⁴, all provide calculation algorithms to reconstruct the full 3D dose in the patient geometry. A full 3D dose reconstruction of the measurement in the patient geometry enables, for example, analyzes of the difference between measured and calculated dose distributions in dose volume histograms (DVH) of the structures of clinical interest. This makes the clinical interpretation clear and straight forward and is an efficient tool to be used for pretreatment IMRT QA measurements.

Different software for full 3D dose reconstruction in the patient geometry for 2D arrays, EPIDs and 3D phantoms are listed in table 2. In three of the software, COMPASS (IBA Dosimetry) described by Godart *et al* (2011) [13], Dosimetry CheckTM (Math Resolutions) described by Renner (2007) [14] and the Delta^{4DVH} described by Gustafsson (2013) [15] reconstruction algorithm is based on an estimation of the delivered fluence, based on a measurement, that is used as input in a forward dose calculation algorithm to calculate the dose in the patient geometry. The estimation of the delivered fluence is done in different ways in the different software. Dosimetry CheckTM and Delta^{4DVH} are stand-alone systems which estimates the delivered fluence without the need for information on the calculated dose distribution in the treatment planning system (TPS). The COMPASS system determines the delivered fluence by scaling the predicted response as calculated based on the calculated dose distribution from the TPS to the measurement. The estimated delivered fluence is used as input into a forward dose calculation algorithm to calculate the 3D dose distribution in the patient geometry. Those 3D dose calculation algorithms are different for the three software mentioned. The Dosimetry CheckTM and Delta^{4DVH} software uses a generic pencil beam algorithm without the need for a full commissioning procedure while the COMPASS software are based on the Collapsed Cone algorithm [16] which require a full commissioning procedure the same as for any treatment planning system.

The algorithms in the software VeriSoft[®] (PTW) described by Allgaier *et al* (2013) [17] and 3DVH[®] (Sun Nuclear) described by Zhen *et al* (2011) [9] are based on scaling a known dose distribution along each beam ray through the phantom according to the measurement in one detector point along the ray. The relative dose distribution along each beam ray are in VeriSoft[®] based on depth dose curves that are measured and entered to the software during commissioning and for 3DVH[®] it is based on the dose distribution of the treatment plan in question as calculated in the TPS. The VeriSoft[®] is a stand-alone system since no dose information from the TPS is needed in the process of the 3D dose reconstruction. The cross section of the beam ray will be determined by the distance between the measured data points. The data points of the 2D arrays and the 3D phantom need to be interpolated to increase the number of data points for the 3D dose reconstruction. The VeriSoft[®] software uses a linear interpolation and 3DVH[®] is based on a more sophisticated interpolation called “smartinterpolation”. Therefore the accuracy of the 3D dose reconstruction using VeriSoft[®] is directly dependent on the distance between the detectors in the measurement [17].

Table 2. Commercial software for full 3D dose reconstruction in the patient geometry.

Software	3DVH [®] /EPIDose TM (Sun Nuclear)	COMPASS (IBA Dosimetry)	Dosimetry Check TM (Math Resolutions)	VeriSoft [®] (PTW)	Delta ^{4DVH} (ScandiDos)
Compatible with	MapCHECK [®] , ArcCHECK [®] and EPIDs	MatriXX ^{Evolution}	EPIDs and other 2D arrays and 3D phantoms	OCTAVIUS [®] 4D	Delta ⁴

Efficient pretreatment IMRT QA measurements using the quasi 3D dosimetry systems mentioned above is not based on measurements only but rely heavily on calculation algorithms. Those algorithms need to be carefully validated before clinical use. Unfortunately the independent validation studies on the algorithms included in the software mentioned in table 2 are scarce and further studies are needed.

3. Summary and Conclusion

There are a number of commercial quasi 3D dosimetry systems designed for pretreatment IMRT QA measurements. Those systems does not measure the full 3D dose distribution. The full 3D dose needs to be reconstructed from the limited number of measurement points. To be able to evaluate the clinical relevance of the differences between measured and calculated dose distributions, algorithms for full 3D dose reconstruction in the patient geometry are available. This makes the QA rely not only on the measurement but also on a calculation algorithm in the software. Those algorithms need to be carefully validated before clinical use. Unfortunately the independent validation studies on those algorithms are scarce and there is a need for further studies.

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5. References

- [1] ESTRO 2008 *Guidelines for the verification of IMRT. ESTRO Booklet no. 9* Brussels, Belgium
- [2] Moran J M, Dempsey M, Eisbruch A, Fraass BA, Galvin JM, Ibbott GS and Marks LB 2011 *Safety considerations for IMRT* (full report). Available from: <http://www.practicalradonc.org>
- [3] Ford E C *et al* 2012 *Int. J. Radiat. Oncol. Biol. Phys.* **84** e263-9
- [4] Das I J *et al* 2008 *Med. Phys.* **35** 206-15
- [5] LoSasso T *et al* 1998 *Med. Phys.* **25** 1919-27
- [6] Low D A *et al* 1998 *Med. Phys.* **25** 656-61
- [7] Kruse J J 2010 *Med. Phys.* **37** 2516-24
- [8] Nelms B E *et al* 2011 *Med. Phys.* **38** 1037-44
- [9] Zhen H *et al* 2011 *Med. Phys.* **38** 5477-89
- [10] Nilsson J *et al* 2013 *J. Phys.: Conf. Ser.* **444** 012048
- [11] ICRU 1976 *Determination of absorbed dose in a patient irradiated by beams of X or gamma rays in radiotherapy procedures. ICRU REPORT 24* Oxford University Press
- [12] ICRU 2010 *Prescribing, recording, and reporting photon-beam intensity-modulated radiation therapy (IMRT). ICRU REPORT 83* Oxford University Press
- [13] Godart J *et al* 2011 *Phys. Med. Biol.* **56** 5029-43
- [14] Renner W D 2007 *Med. Dosim* **32** 157-65
- [15] Gustafsson A 2013 *Patient dose calculation based on ScandiDos Delta^{4PT} measurements. ScandiDos White Paper*
- [16] Ahnesjö A 1989 *Med. Phys.* **16** 577-92
- [17] Allgaier B *et al* 2013 *Dose reconstruction in the OCTAVIOUS 4D phantom and in the patient without using dose information from the TPS. PTW White Paper*