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# GAMMA DOSE DISTRIBUTION EVALUATION OF XiO TREATMENT PLANNING SYSTEM FOR STATIC FIELD IMRT, USING AAPM TG-119

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*Abstract*.The purpose of this work was to perform a comprehensive comparison of static field intensity modulated radiation therapy (IMRT) for patient specific quality assurance (QA) in order to investigate commissioning of a XiO treatment planning system (TPS). QA measurements were evaluated for three of four test geometries provided in American Association of Physicists in Medicine (AAPM) Task Group Report 119 (TG-119) on multitarget, prostate, head and neck. Using the XiO TPS, fixed-beam IMRT treatment plans were constructed based on the structure sets copied to a parallelepipedic phantom which consists of solid water slabs and the 2D array. The plans were delivered to the phantom using an Elekta Synergy Platform-MLCi2 and the resulting dose distributions were measured in the coronal plane. Measured planar dose distributions were analyzed using gamma index with criteria of 2 %/2 mm and 3 %/3 mm. Also, point measurements were taken five times each using a Farmer type ion chamber situated in the centre of a rectangular water phantom. Measured point doses were analyzed using percentage difference. This study evaluates the response of the XiO TPS for static fields IMRT (step and shoot) using the 2D-array 729, TG-119 geometry sets and gamma analysis. The results showed an adequate level of accuracy for all the analysed specific treatment plans, thus confirming the robustness of this radiotherapy treatment system as a whole.

*Key words*: quality assurance, treatment planing system, IMRT, gamma index.

## 1. INTRODUCTION

To implement a new treatment technology into routine clinical use, there are usually three distinct but closely related phases:

*Acceptance tests*. This is the initial set of tests that ensures the hardware and software meet the factory and/or customer provided specifications.

*Commissioning tests*. The IMRT commissioning is a process to implement IMRT treatments using the customer's hardware and beam data. The process

usually starts with collection of essential beam data for beam modeling. The parameters of the dose-calculation algorithm are then tuned to provide the best performance for the user's beam. Additional tests should be performed to evaluate the limitations of the treatment planning system. Then, IMRT phantom measurements should be performed to test the accuracy of the delivery system and data connectivity.

*Ongoing QA.* After the system is released to the clinic, it is important to establish a routine QA program. Fixed-beam IMRT treatment plans are dosimetric phantom checked before treatment, a process generally referred to as patient-specific QA. Each patient plan is copied to a phantom geometry and the resulting dose distribution calculated by the TPS. The dose distribution is then measured in the geometry of the phantom and compared with the calculation of the TPS for the same geometry. A number of methods for measuring the dose distribution in phantom geometry were used over the years. These usually make use of film radiographic/radiochromic planar dose measurements in conjunction with ionization chamber measurements or various arrays of diodes or microionization chambers.

For point dose measurements, the percentage difference between measured and planned doses is used. Regarding the plan distribution measurements, a combination of percentage dose difference (DD) and distance to agreement (DTA) is typically used to reduce the analysis to a single metric (*e.g.*, 95 % of the measurement points are within 3 % dose difference or 3 mm distance to agreement). If the analysis of patient-specific QA measurements produces a metric exceeding a predetermined level action, then the patient treatment area is delayed until the source of error is identified and treatment is replanned. The specific value of the action level is difficult to quantify for general purposes and often depends on a combination of experience and individual preferences.

A "reasonable" choice of a specific combination of gamma evaluation and acceptance criteria should be based on the accuracy of the applied measurement procedure, its workload, and the ability to detect problem areas in the intended dose distribution. Based on the analysis of extensive institutional QA results, Both *et al.* [2] recommended that the percentage of points passing 3 % dose difference, with 3 mm DTA, be greater than 95 % and 90 % for prostate and all patients, respectively, when using a commercially available 2D-array [2]. Task Group 119 (TG-119) [1] of the AAPM reported patient specific QA results from a multi-institutional study designed specifically to quantify the degree of agreement that should be expected from patient-specific IMRT QA measurements [16]. They recommended action levels of ± 4.5 % and ± 4.7 % for dose measurements in target and low-dose regions, respectively and percentage of points passing gamma (criteria 3 %/3 mm) of 90 % and 88 % to 90 % for per-field and composite dose measurements, respectively. The goal of this study was to perform a comprehensive and systematic analysis of fixed-beam IMRT patient-specific QA

measurements for a common set of geometries using typical measurement methods. Fixed beam IMRT plans were constructed for structure set geometries provided by TG-119. The plans were repeatedly delivered across multiple measurement sessions, and the resulting dose distributions were measured with ionization chamber and a commercial 2D ion chamber array. The resulting QA measurements from each delivery were then gamma analyzed.

Combinations of gamma evaluation and acceptance criteria depend on many factors including the dosimetric equipment, calculation and measurement grid, and the data analysis software. It is therefore virtually impossible to provide general recommendations applicable for all situations [14]. This is to establish a protocol to present a complete QA process, evaluate the usefulness of the investigated methods and suggest the use of faster and more efficient dosimetric tools for the dose verification for IMRT technique.

## 2. MATERIALS AND METHODS

All plans were constructed for delivery on Elekta Synergy Platform radiotherapy accelerator (Elekta Ltd., Crawley, UK) utilizing the Desktop Pro R7.01 control system. The system features an 80-leaves multi leaf collimator (MLC) with 1 cm leaf width at isocentre and delivers IMRT plans using step-and-shoot technique.

All treatment plan dosimetric endpoints are shown in Table 1 and either met the planning objectives specific by TG-119 or were within one standard deviation of the mean of the planning values reported in the task group report.

The local dose measurements are done in a small rectangular water phantom (T41014 – ESTRO phantom) at 5 cm depth. The phantom dimensions are 20 cm × 20 cm × 10 cm, which makes it easy to use in routine daily QA. Ionization chamber is a 0.6 $cm^3$ Farmer type, model T30013 and Unidos E electrometer (PTW, Freiburg, Germany). For each structure set geometry (TG-119), point doses were measured at one location (Table 2). For each plan and point location, the absorbed dose was measured five times. Between each repeated measurement, the experimental geometry was perturbed and realigned in order to reduce systematic error associated with a single measurement session.

For 2D distribution a sandwich setup of polymethyl methacrylate (PMMA) slabs with a stack of 5 cm below and 4.5 cm above the ionization chambers of the detector is used. The phantom arrangement is scanned in CT with slice thickness of 0.3 cm. The scanned phantom is imported *via* DICOM protocol to XiO treatment planning system. 2D-array 729 consisting of a plan matrix of 27 × 27 air-filled ionization chambers is used (PTW, Freiburg, Germany). The detector spacing (centre to centre) is 1 cm. The dimensions of each detector are 0.5 × 0.5 × 0.5 $cm^3$ which gives a 0.125 $cm^3$ active volume.

*Table 1*

Results of the treatment plan. For each parameter, TG-119 objectives and results are presented together with the values obtained for IMRT plans created during this work. Most of the results are contained in an interval equal to one standard deviation of the mean relative to TG-119 (highlighted in green); the results which are outside this range are in yellow

| TPS objectives | Dose objective (cGy) | Mean (cGy) | Standard deviation (cGy) | XiO DVH (dose-volume histogram)values (cGy) |
|---|---|---|---|---|
| **MULTITARGET GEOMETRY** | | | | |
| Central target volume $D_{99}$ | >5,000 | 4,955 | 162 | 4,803 |
| Central target volume$D_{10}$ | <5,300 | 5,455 | 173 | 5,477 |
| Upper target volume $D_{99}$ | >2,500 | 2,516 | 85 | 2,715 |
| Upper target volume $D_{10}$ | <3,500 | 3,412 | 304 | 3,729 |
| Lower target volume $D_{99}$ | >1,250 | 1,407 | 185 | 1,603 |
| Lower target volume$D_{10}$ | <2,500 | 2,418 | 272 | 2,650 |
| **PROSTATE GEOMETRY** | | | | |
| Prostate volume $D_{95}$ | >7,560 | 7,566 | 21 | 7,525 |
| Prostate volume $D_5$ | <8,300 | 8,143 | 156 | 8,296 |
| Rectum $D_{30}$ | <7,000 | 6,536 | 297 | 6,350 |
| Rectum $D_{10}$ | <7,500 | 7,303 | 150 | 6,680 |
| Bladder $D_{30}$ | <7,000 | 4,394 | 878 | 4,154 |
| Bladder $D_{10}$ | <7,500 | 6,269 | 815 | 5,740 |
| **HEAD AND NECK GEOMETRY** | | | | |
| PTV $D_{90}$ | 5,000 | 5,028 | 58 | 4,879 |
| PTV $D_{99}$ | >4,650 | 4,704 | 52 | 4,610 |
| PTV $D_{20}$ | <5,500 | 5,299 | 93 | 5,431 |
| Spinal cord (max dose) | <4,000 | 3,741 | 250 | 3,976 |
| Parotids $D_{50}$ | <2,000 | 1,798 | 184 | 1,840 |

2D-array are used for dose distribution verification of the commisioning of the treatment planning system [12, 14]. The phantom is irradiated using the same monitor units and the 0° gantry angle setup with Elekta Synergy Platform linear accelerator (step-and-shoot IMRT delivery). 2D-array system transfers the acquired data to the Verisoft software. Dose distributions for cases discussed in this work using XiO treatment planning system (ver.4.61, Elekta Ltd.) inverse planning optimization have 7 or 9 beams calculated for every plan.

The Verisoft software assists user in comparing dose distributions in IMRT verification phantom with dose distributions computed by radiotherapy treatment planning system. Matrices of measured and calculated points of an IMRT beam are compared by subtracting the matrices and visualizing the results. The software supports the gamma evaluation method, helping in locating hot and cold spots and determines maximum and average deviation between the calculated and the measured plan. In this study, the Verisoft verification software is used to compare gamma distribution for calculated dose distribution using TPS and measured dose

using 2D-array. This is to find out what percentage of points passing certain criteria imitates a good quality plan.

Two gamma analysis are performed for the comparison between measured dose from LINAC and calculated dose from treatment planning system. The first include gamma criteria 2 %/2 mm (DD/DTA) for local dose. The second one involves more relaxed criteria for local dose 3 %/3 mm, usually applied for clinical situations in patient-specific QA. All analysis are performed by the suppression of the dose below the 10 % from the maximum of the reference matrix.

**Data analysis**. Point doses measured with the ionization chamber were compared to point doses calculated by the treatment planning system, which were taken as the mean dose for a 0.6 $cm^3$ region of interest (representing the approximate volume of the Farmer type ionization chamber) centered around the midchamber position in the planning CT image set. For each point dose, a percentage difference was computed using the formula:

$$\text{diff} = \frac{D_{measured} - D_{calc}}{D_{prescrip}} \cdot 100 \text{ [\%]},$$

where $D_{measured}$, $D_{calc}$, and $D_{prescrip}$ are the measured, calculated, and prescribed doses, respectively. 2D-array measurements were compared to planar doses calculated by the treatment planning system at a dose grid resolution of $2 \times 2$ $mm^2$. Measured and calculated planar doses were compared using gamma analysis using a 2 % dose difference and a 2 mm distance to agreement criteria. The analysis was done for 3 % and 3 mm, also.

## 3. RESULTS

**Point dose measurements**. For local dose, this was measured five times in a row, delivering the same treatment plan. Table 2 shows the dosimetric measurements recorded for each of the points along with the dose calculated by XiO. Table 3 shows the percentage differences between each measurement, using the method described in Data Analysis.

The differences between the measured doses by ion chamber and that calculated using XiO TPS should be within 3 % for whole plan for all 3 geometries used in this study (multitarget, prostate, head and neck). If the result gives a variation higher than 5 %, the QA procedure is repeated. The present results show that 100 % of the measurements vary less than 3 % from calculated dose. Table 4 shows the means and standard errors of the percentage difference at each point dose measurement location.

*Table 2*

Point dose measurements. Measured dose data for all the five measurements. The absorbed dose calculated by XiO is given for each point

| Geometry | Point of measurement | Calculated dose (cGy) | Measured dose – Farmer type ion chamber (cGy) | | | | |
|---|---|---|---|---|---|---|---|
| **Multitarget** | Central volume | 214.08 | 210.01 | 210.11 | 210.39 | 210.77 | 210.77 |
| **Prostate** | PTV | 202.25 | 201.75 | 202.24 | 202.57 | 202.19 | 202.84 |
| **Head and Neck** | PTV | 203.84 | 208.63 | 208.41 | 208.90 | 208,79 | 208.36 |

*Table 3*

Measurements of local dose – the differences in percentage. The differences are given in percentage for all five measurements taken at each point from Table 2

| Geometry | Point of measurement | Calculated dose (cGy) | Difference (%) | | | | |
|---|---|---|---|---|---|---|---|
| **Multitarget** | Central volume | 214.08 | –2.04 | –1.99 | –1.85 | –1.66 | –1.66 |
| **Prostate** | PTV | 202.25 | –0.25 | 0.01 | 0.16 | –0.03 | 0.29 |
| **Head and Neck** | PTV | 203.84 | 2.34 | 2.26 | 2.53 | 2.46 | 2.26 |

*Table 4*

Means and standard deviations for point dose values and percentage differences. Local doses calculated are also shown for reference

| Dose prescription | Calculated dose XiO (cGy) | Mean ± σ (cGy) | Mean diff. ± σ (%) |
|---|---|---|---|
| **Multitarget** | 214.08 | 210.41 ± 0.36 | –1.84 ± 0.18 |
| **Prostate** | 202.25 | 202.32 ± 0.41 | 0.03 ± 0.20 |
| **Head and Neck** | 203.84 | 208.62 ± 0.23 | 2.37 ± 0.12 |

Dong *et al.* [5] reported that the mean difference between measured and calculated doses was greater than 3.5 %. Chung *et al.* [4] stated that the average difference between measured and computed dose at isocentre for 0° gantry angle for head and neck tumours was –0.55 ± 1.51 %. This corresponded to a range of variation of –4.1 % to +3.9 %. Fenoglietto *et al.* [8] reported a value of 1.33 ± ± 3.22 % for the difference between measured and calculated dose for head and neck tumours. Syam Kumar *et al.* [18] reported also that a 0.6 $cm^3$ ionization chamber gave 2.23 % of the measured isocentre absolute dose which was comparable to the calculated plan. In the present results, the differences have reached a maximum of 2.53 % for the whole IMRT head and neck plan.

It should be taken into consideration that the results could be quite different if the position of the ion chamber is in the penumbra region of intensity map of the field or in the area of high gradients inside the field due to of the variation in

intensities of modulated beam and due to the size of the ionization chamber or to the charged particles equilibrium around the ion chamber. The same observation is reported by several authors [6, 11, 17].

The standard error for each local measurement was generally small, indicating good reproducibility of measured point doses. Over all, the mean percentage difference for IMRT was −1.84 ± 0.18 % for multitarget, 0.03 ± 0.20 % for prostate, and 2.37 ± 0.12 % for head and neck.

*Table 5*

The results of analysis using gamma criteria of 2 % /2 mm and 3 % /3 mm. Results are given for each gantry angle and for each type of geometry approach

| Plan geometry | Gamma criteria 2 % and 2mm Index value (%) | Gamma criteria 3 % and 3mm Index value (%) |
|---|---|---|
| **MULTITARGET GEOMETRY** | | |
| 0° | 98.1 | 100.0 |
| 50° | 98.1 | 100.0 |
| 100° | 96.2 | 100.0 |
| 150° | 97.1 | 100.0 |
| 200° | 97.1 | 100.0 |
| 250° | 98.1 | 100.0 |
| 300° | 99.0 | 100.0 |
| **PROSTATE GEOMETRY** | | |
| 0° | 89.6 | 93.8 |
| 50° | 95.7 | 97.8 |
| 100° | 92.5 | 100.0 |
| 150° | 87.2 | 97.9 |
| 200° | 89.6 | 93.8 |
| 250° | 92.7 | 100.0 |
| 300° | 92.9 | 100.0 |
| **HEAD AND NECK GEOMETRY** | | |
| | | |
| 0° | 100.0 | 100.0 |
| 40° | 97.8 | 100.0 |
| 80° | 96.1 | 98.4 |
| 120° | 96.8 | 99.2 |
| 160° | 93.4 | 99.2 |
| 200° | 84.5 | 96.1 |
| 240° | 94.2 | 100.0 |
| 280° | 92.2 | 98.4 |
| 320° | 95.9 | 100.0 |

**Dose measurements using 2D-array**. Two different gamma criteria DD/DTA for all the three geometries are compared: 2 %/2 mm, 3 %/3 mm. The choice of the criteria is made so that more information can be obtained to observe

the limitation of the commissioning process and the system as a whole. The dose differences between measured dose (LINAC delivery) and calculated dose (TPS) are evaluated while suppressing the dose of 10 % of the maximum dose distribution. The criteria of 2 %/2 mm shows that the gamma passed rates are greater than 84.5 %. On the other hand, the criteria of 3 %/3 mm shows that gamma passed rates are greater than 93.8 %. The best results where obtained for multitarget geometry. All values are shown in Table 5.

## 4. DISCUSSION AND CONCLUSION

The QA results of each modality in this study are consistent with values previously reported in the literature. The mean and standard deviation of percentage of the highest difference between calculated and measured point doses was 2.37 ± 0.12 %, which are within the range of means (−1.7 % to 4.5 %) and standard deviations (0.4 % to 4.4 %) reported by TG-119.

In some isolated cases (prostate fields 0°, 150°, 200° and head and neck field 200°) there is some evidence to suggest that further model optimization may slightly improve the results reported here. Nevertheless, for the present work, the current treatment-planning model was judged to provide a good accuracy. Furthermore, results of all point dose measurements were within the range of mean values reported by TG-119.

The most important concept is the clinical significance. Statistically, it is relatively easy to be defined by taking a significance level suitable for a given assay. However, the clinical interpretation of the results can be more subjective in case of differences, whether or not they have an important impact on use in daily clinical practice. The clinical significance may be attained even if no statistical significance was observed, and vice versa.

In terms of TPS, the commissioning process requires a series of measurements that allow it to accurately calculate the dose distribution in the tumour volume. In general, the commissioning dosimetry measurements are done for field sizes from 1 $cm^2$ to 40 $cm^2$ (the choice of detectors is very important during beam data aquisition). The present study involves testing the entire system from end to end by measurements according to TG-119, in situations close to the clinical ones.

The gamma analysis shows points that do not meet the gamma criteria. In most cases, these points are located on the edge of the field or high dose gradients, which could be considered a normal behaviour due to the effect of the ion chambers volumetric averaging effect. A better option would be to use a semiconductor array, which has a much smaller detection volume.

Another element involved in the optimization process is the choice of segmentation parameters to obtain the desired fluence modulation. Treatment plan

allows choosing the minimum number of units that can be delivered to each segment (minimum segment area: 2 $cm^2$) and the minimum number of monitor units (MU) per segment. Optimization parameters for minimum number of monitor units and minimum field size for multitarget and prostate geometries, were 5MU/segment and 2 $cm^2$, respectively. It is worth to mention that, according TG-119 constraints, for head and neck geometry it was possible to obtain good results using 3 MU/segment for the same minimum field size. These set-up makes the TPS more or less flexible in finding the optimum solution for a particular treatment plan.

Repeated QA measurements of fixed-beam IMRT plans have been compared using ion chamber and 2D-array measurements for three target geometries. No statistically significant differences were found for any target geometry and measurement approach during the study.

This work also had several limitations. For example, the agreement between planned and measured dose distributions was assessed in orthogonal planes. Several recent studies have suggested that the use of planar dose measurements may conceal meaningful volumetric dose discrepancies in some cases [10, 15]. Future investigations should explore the use of 3D analysis to assess the impact of planar dosimetric differences on volumetric dose [20].

For the further work we consider that the use of anthropomorphic phantoms will favour a better approximation of real conditions for defining a QA system for the TPS and overall radiotherapy system. Also, it will be possibile to consider the tissues with different densities (lung, adipose tissue, bone, etc.) and various locations of the ionization chambers more suitable for this kind of measurements.

## REFERENCES

1. American Association of Physicists in Medicine, *TG-119 IMRT Commissioning Tests Instructions for Planning, Measurement and Analysis*, Med. Phys. **36**, 5359–5373 (2009).
2. S. Both, I. M. Alecu, A. R. Stan, M. Alecu, A. Ciura, J. M. Hansen, *A study to establish reasonable action limits for patient-specific quality assurance in intensity-modulated radiation therapy*, J. Appl. Clin. Med. Phys. **8**, 1–8 (2007).
3. N. L. Childress, R. A. White, C. Bloch, *Retrospective analysis of 2D patient-specific IMRT verifications*, Med. Phys. **32**, 838–850 (2005).
4. H. Chung, J. Li, S. Samant, *Feasibility of using two-dimensional array dosimeter for in vivo dose reconstruction via transit dosimetry*, J. App. Clin. Med. Phys. **12**, 3370–3406 (2011).
5. L. Dong, J. Antolak, M. Salehpour, *Patient specific point dose measurement for IMRT monitor unit verification*, Int. J. Radiat. Oncol. Biol. Phys. **56**, 867–877 (2003).
6. L. Escudé, D. Linero, M. Mollà, R. Maralbell, *Quality assurance for radiotherapy in prostate cancer: point dose measurements in intensity modulated fields with large dose gradients*, Int. J. Radiat. Oncol. Biol. Phys. **66**, S136–140 (2006).
7. G. A. Ezzel, J. M. Galvin, D. Low, *Guidance document on delivery, treatment planning, and clinical implementation of IMRT: report of the IMRT Subcommittee of the AAPM Radiation Therapy Committee*, Med. Phys. **30**, 2089–2115 (2003).

8. P. Fenoglietto, B. Laliberté, N. Aillères, *Eight years of IMRT quality assurance with ionization chambers and film dosimetry: experience of the Montpellier Comprehensive Cancer Center*, Radiat. Oncol. **6**, 85–93 (2011).
9. International Commission on Radiation Units and Measurements, *Prescribing, Recording and Reporting Photon Beam Intensity Modulated Radiation Therapy (IMRT)*, ICRU-Report 83 (2010).
10. J. J. Kruse, *On the insensitivity of single field planar dosimetry to IMRT inaccuracies*, Med. Phys. **37**, 2516–2524 (2010).
11. W. U. Laub and T. Wong, *The volume effect of detectors in the dosimetry of small fields used in IMRT*, Med. Phys. **30**, 341–347 (2003).
12. D. A. Low, J. M. Moran, J. F. Dempsey, *Dosimetry tools and techniques for IMRT*, Med. Phys., **38**, 1313–1338 (2011).
13. D. A. Low, W.B. Harms, M. Sasa, J. A. Purdy, *A technique for the quantitative evaluation of dose distributions*, Med. Phys. **25**, 656–661 (1998).
14. B. Mijheer, D. Georg, *Guidelines for the verification of IMRT*, ESTRO BOOKLET **9**, Brussels, Belgium, 2008.
15. B. E. Nelms, H. Zhen, W. A. Tome, *Per-beam planar IMRT QA passing rates do not predict clinically relevant patient dose errors*, Med. Phys. **38**, 1037–1044 (2011).
16. S. Saminathan, R. Manickam, V. Chandraraj, S. Supe, *Dosimetric study of 2D ion chamber array matrix for the modern radiotherapy treatment verification*, J. Appl. Clin. Med. Phys. **11**, 3076–3091 (2010).
17. F. Sánchez-Doblado, G.H. Hartmann, J. Pena, *Uncertainty estimation in IMRT absolute dosimetry verification*, Int. J. Radiat. Oncol. Biol. Phys. **68**, 301–10 (2007).
18. S. A. Syam Kumar, P. Sukumar, P. Sriram, *A patient specific quality assurance study on absolute dose verification using ionization chambers of different volumes in Rapid Arc treatments*, Med. Dosimetry **37**, 436–441 (2012).
19. S. Vynckier, WRDTH3120 – *Dosimétrie en radiothérapie et contrôle de qualité*, Cours dispensé à l'UCL, 2011–2012.
20. H. Zhen, B. E. Nelms, W.A. Tome, *Moving from gamma passing rates to patient DVH-based QA metrics in pretreatment dose QA*, Med. Phys. **38**, 5477–5489 (2011).