

Validation of Monaco Treatment Planning System for Intensity-Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT[®]) on ELEKTA Infinity[™] Linear Accelerator

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Abstract. The objective of this study is to evaluate the dosimetric precision of the Monte Carlo (MC) algorithm to validate the Monaco[®] (Elekta) treatment planning system for the two radiotherapy techniques IMRT and VMAT[®] on the Infinity[™] Elekta linear accelerator. Several irradiation plans were created on the Monaco[®] treatment planning system (TPS) and calculated by the integrated MC algorithm for its validation. The same plans were applied experimentally using the Matrixx Evolution 2D array with its appropriate phantom. All measurements were performed by superimposition with those calculated on the Infinity[™] linear accelerator (ELEKTA). The calculated and measured dosimetric data were overlaid to make the comparison of what is realistic and what was simulated using the MyQA (IBA) software associated with the Matrixx. Good agreement was observed between calculated and measured data using 3%, 3mm distance to agreement (DTA) and low dose threshold 5% criteria. Global gamma analysis passing rates for all tests are greater than 95 %. An agreement less than 2 mm is shown for open fields and homogenous dose test. However, there was increase in the agreement criteria above 3 mm for chair and pyramid test as a result of high gradient dose regions especially at the edge of target volumes. Results obtained from this study allowed, in one hand to confirm the accuracy of our MC model dose calculation with Monaco[®] TPS, and in the other hand, the use of the matrix detector as a standard tool for IMRT/VMAT[®] patient quality control.

1 INTRODUCTION

Intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT[®]) are a modern radiotherapy delivery technique that allows a precise conformation of the radiation dose to the target volumes with a minimal dose to the surrounding normal tissue. Both techniques are based on the intensity variation of the used radiation beam, each one is divided into smaller radiation beamlets with a different intensity, the sum of the above beamlets enables the highly conformal dose distribution (1). IMRT employ the capability of the leaves motion control and VMAT[®] a simultaneous variation of the gantry rotation speed, beamlets shape and dose rate during treatment delivery (2) The dose modulation is obtained via an inverse planning system that adjusts the beam intensities and MLC control to find the best configuration for tumor

irradiation and organ at risk (OAR) sparing as requested by the planner. The inverse planning system is a computing program based on mathematical calculation algorithm; different algorithms are available Collapsed cone, AAA, and MC...etc. Before any use of the planning system, an accurate beam modeling is crucial, important and especially time-consuming task in the radiation therapy treatment process. This work aims are to present our experience with the implementation of new Monaco[®] TPS used for 3D conformal radiotherapy, IMRT and VMAT[®] techniques, in this work we focus on examining the TPS calculation algorithm accuracy under several conditions, for IMRT and VMAT[®] plan calculation.

2 MATERIALS AND METHODS

The linear accelerator used in this work is an Infinity™ (Elekta). The multileaf collimator (MLC) system Agility® (Elekta) contained 160 leaves with leaf width of 0.5 cm at the isocenter, maximum speed 65 mm/s, leaf transmission less than 0.5 % with an optical system for accuracy positioning (3). The above linac delivers photon energies of 6 MV and 18 MV, and electron energies of 6, 9, 12, 15, and 18 MeV. Models created for Monaco® TPS calculation are Collapsed Cone for photon energies only, and Monte Carlo model for both types of energies photon and electron.

All calculations in this study were calculated using Monaco® TPS (version 5.11) and Monte Carlo (MC) as calculating algorithm. IMRT plans validations were performed using Matrixx Evolution 2D array with its appropriate phantom and associated software MyQA (Figure 1). The above system composed of 1024 ionization chambers with individual volumes of 0.07 cm³, chambers are organized in a 32 x 32 matrix with about 7 mm gap between each other's, when ionized chambers release charge which is proportional to the dose rate falling into the matrix, which is converted then into digital signal thus giving information on the dose in each chamber. For absolute dose measurement in water, a BlueWater phantom® (IBA), an FC65P® (IBA) ionization chamber with 0.125 cm³ as active volume, and Doseone® (IBA) electrometer were used.

2.1 Matrix calibration

Before any measurement, the matrix required uniformity calibration and dose calibration prior its use as recommended by the manufacturer. The goal of the calibration here is the determination of an output calibration factor used to convert the fluency into dose at the isocenter of the Matrix using the readings of the four central ionization chambers of the above 2D detector. Calibration presented here is performed with the Matrix detector, in 6 MV photon beam, for the ELEKTA Infinity linear accelerator. The Matrix is inserted into the MULTICube lite water phantom, with 11 cm above and 10 cm under the Matrix. The dose at isocenter from a 10 x 10 cm² field size at 100 cm source to axis distance (SAD) for 100 UM was calculated using Monaco® TPS with MC model, and a second measurement for the same set up was calculated using a direct measurement on the Linac using a water phantom and an ionization chamber; FC 65 P. Both absolute doses matched correctly so we used the one from the TPS as requested by IBA as reference dose for the Matrix.

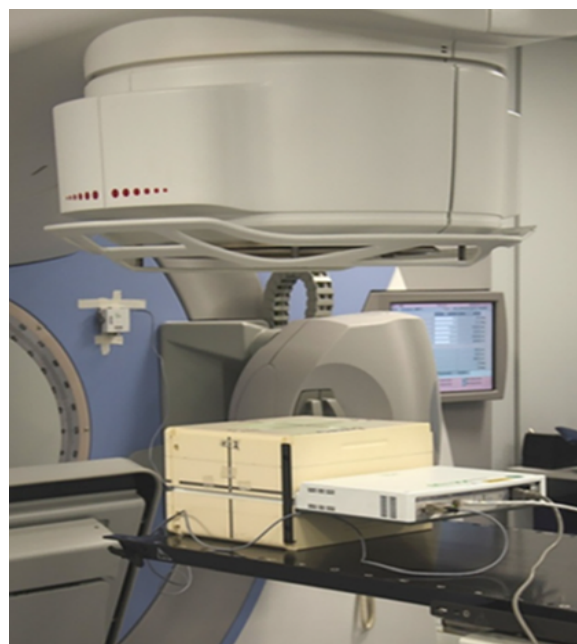


Fig. 1. Positioning of the Matrixx Evolution 2D array with its appropriate phantom under the Infinity™ ELEKTA accelerator head.

Once the setup of the Matrix is done, before starting the calibration it was warmed up for fifteen minutes as recommended by IBA, then a 20 second background is performed. Then, a uniformity is done as described by the manufacturer. Finally, the reference dose calculated for 100 UM was delivered and the output factor is calculated using the MyQA software (IBA).

2.2 Planning Test Plans

For the final modeling of the beams of the MC model dedicated to IMRT and VMAT® planning, the dose output, the offset position of the MLC sheet end, the MLC transmission and the end of the sheet leakage were verified by a series of acceptance testing and quality control of the implementation of IMRT (4). This after performing a 3D validation for the two collapsed models cone and MC for the two energies 6 MV and 18 MV, by IAEA TEC DOC 1583 (5), and QA plans express provided by ELEKTA.

Before any calculation, the MULTICube phantom (IBA); (Length 31.4 cm, Width 34 cm, Height 21 cm); with mass density of 1.04 g/cm³ with matrix detector inside, 11cm above and 10 cm under the Matrix; was scanned using GE Optima® (General Electric) CT scan at 120 kV with slice thickness of 3 mm. once scanned, images were transferred via local network and saved into Monaco® treatment planning system.

On the acquired CT images an external contour was created, and manual electron density equivalent water was override in the TPS to have an accurate homogeneity of the phantom. Then, a series of verification plans were created (4), for an accurate comparison all plans were isocentric, calculation parameters are shown in Table 1.

Table 1. Calculation properties for Monte Carlo algorithm on Monaco® TPS.

Item	Parameter value
Grid spacing	3 mm
Statistical uncertainty	1%
Max of control points per beam	30
Min segment width	5 mm

2.2.1 Uniform dose test

For the final modeling of the beams of the MC model dedicated to IMRT and VMAT® planning, the dose output, the offset position of the MLC sheet end, the MLC transmission and the end of the sheet leakage were verified by a series of acceptance testing and quality control of the implementation of IMRT (4). This after performing a 3D validation for the two collapsed models cone and MC for the two energies 6 MV and 18 MV, by IAEA TEC DOC 1583 (5), and QA plans express provided by ELEKTA.

2.2.2 Homogenous dose test

To verify the accuracy and capability of the dose calculation using the IMRT dose constraints in Monaco® TPS with MC algorithm, various configurations were created in the MULTICube phantom. The first configuration consisted on drawing rectangular adjacent target volumes at the same depth (Figure.1A) to have a different but homogenous dose, while the aim of the second configuration created is to have the same dose in a three rectangular target volumes drawn at different depths (Figure.1B) For the first configuration prescribed doses were 10, 15, and 5 Gy for PTV 1, PTV 2, and PTV 3 respectively, the constraint used into our IMRT module were the prescribed dose at 97 % of the target volume using. For the second configuration the dose prescribed for all volumes was 5 Gy.

2.2.3 Chair test

This test configuration allows an accurate measurement of both MLC parameters leaves transmission and leaf Gap during leaves motion with a synchronized movement. The upper part allows verification of leaf transmission, while the upper left part is irradiated the right one is all the time covered by the leaves of the right MLC carriage. The central is a homogenous area which allow an absolute dose verification using an ionization chamber. The lowest one used to verify the leaf gap, while irradiating the two legs, the leaves are forced to move between them at maximum speed to get minimal dose in this area. The dose from this chair configuration at 89 cm source to skin distance (SSD) was calculated in

the direction of leaf motion using Monaco® TPS and the coronal dose plane is transferred to MyQA software. The constraint entered into our IMRT module was the prescribed dose 5 Gy at 97 % of the target volume (Figure.1C). The process of data measurement and accepting criteria are the same as described in the uniform test field.

2.2.4 Pyramid test

IMRT/VMAT® techniques consist on complex treatment plans, i.e. hundreds of small segments with high and low dose gradient dose regions for tumor and organs at risk respectively. So a very important care for dosimetric accuracy should be taken into account to verify the systematic changes in intensity levels (6). Due to this, we created a called pyramid test to verify the accuracy and capability of our IMRT dose constraints in Monaco® TPS with MC model to produce the requested dose. The configuration consisted on drawing three rectangular target volumes with different sizes (Figure.1D) with an objective of three dose levels to have a dose distribution as pyramid fluency. The constraints entered into our IMRT module were the prescribed dose at 97 % of the target volume. We used three dose levels 5, 10 and 15 Gy.

2.3 Gamma index

In order to determine the accuracy of the dose distribution for the different calculated tests. Comparison between calculated and measured distribution were performed by using in line and crossline dose profile and gamma global index. The gamma test is one of methods used for comparing dose distributions, the reference (calculated) versus the measured one equation 1.

$$\text{Gamma}(\vec{r}_{ref}, \vec{r}_m) = \min \left\{ \sqrt{\frac{|\vec{r}_{ref} - \vec{r}_m|^2}{DTA^2} + \frac{|D(\vec{r}_{ref}) - D(\vec{r}_m)|^2}{\Delta D^2}} \right\} \quad (1)$$

Where:

$|\vec{r}_{ref} - \vec{r}_m|$ is the distance between reference point and evaluated point.

$D(\vec{r}_{ref})$ is reference dose at a point.

$D(\vec{r}_m)$ is evaluated dose at a point.

DTA is Distance to Agreement.

ΔD is dose deviation.

The aim of the above test is to determine if the reference and evaluated dose distributions agree to within fixed limits (9-10).

3 RESULTS AND DISCUSSION

3.1 Dose profile analysis

The uniform test field profiles superposition shows an agreement within 1 mm, 2 mm for 10 x 10 cm² (Figure 2), and 20 x 20 cm² (Figure 3), respectively. Dose difference increase in border of the field especially for largest field 20 cm x 20 cm².

For the homogenous dose test, agreement of 2 mm is shown, dose differences increases in the edge of the fields (Figure 4-5).

For the chair test, profiles superposition shows an agreement more than 2 mm (Figure 6), dose difference increase in the high gradient regions; edge of the upper chair region and the region between legs.

For the pyramid test, profiles superposition shows an agreement more than 2 mm (Figure 7) for 1 mm agreement dose differences increases at the edge of each target volume due to the high gradient dose.

Obtained results show a good agreement for MLC parameters, especially leaves position, leaves transmission, leaves gap and speed we used to model our Monaco[®] TPS. Parameters which already measured separately with appropriate tests garden fence, leaf speed, and open versus blocked field for MLC transmission.

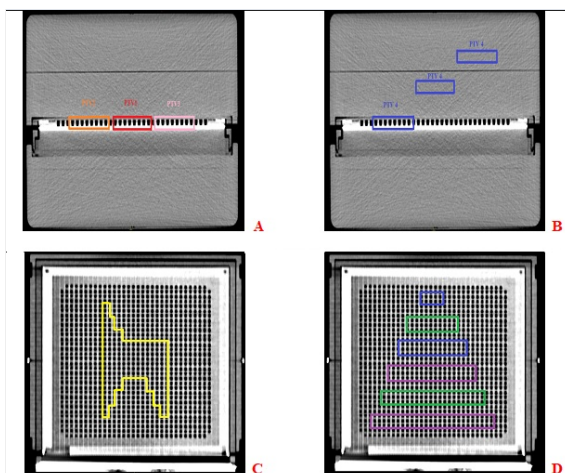


Fig. 2. Test plans on CT image in Monaco[®] TPS; (A) Uniform dose test 3 dose levels, (B) Uniform dose test, (C) Chair test, (D) Pyramid test (Violet 15 Gy, Green 10 Gy, blue 5 Gy).

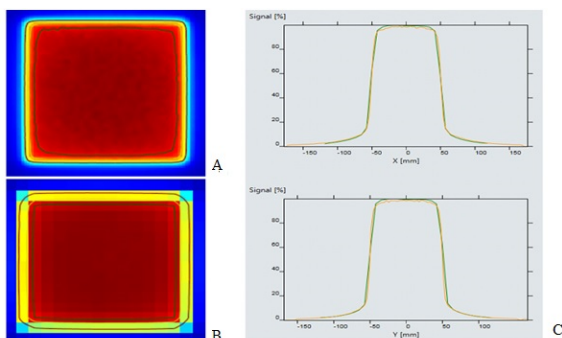


Fig. 3. Field 10 x 10 cm²; (A) Calculated isodose, (B) Measured isodose, (C) isodoses profiles (measured (green), calculated (orange)).

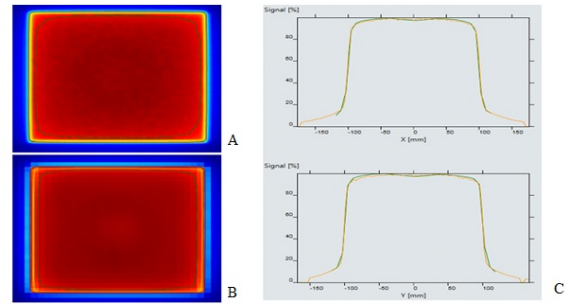


Fig. 4. Field 20 x 20 cm²; (A) Calculated isodose, (B) Measured isodose, (C) isodoses profiles (measured (green), calculated (orange)).

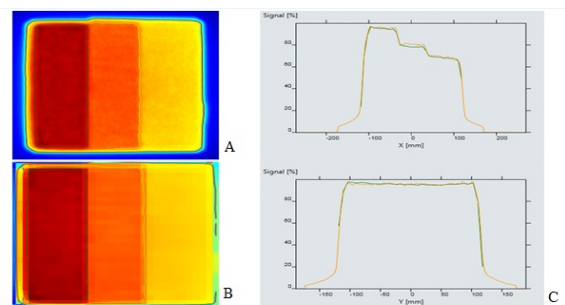


Fig. 5. Homogenous dose test D₀; (A) Calculated isodose, (B) Measured isodose, (C) Isodoses profiles (measured (green), calculated (orange)).

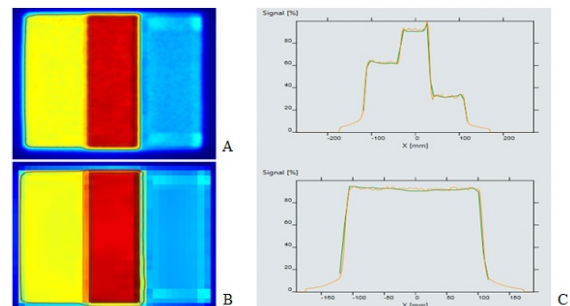


Fig. 6. Homogenous dose test; (A) Calculated isodose, (B) Measured isodose, (C) Isodoses profiles (measured (green), calculated (orange)).

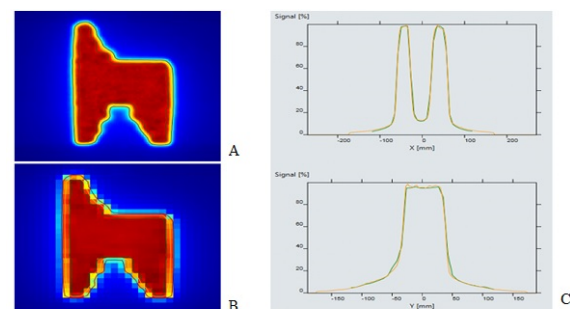


Fig. 7. Chair test; (A) Calculated isodose, (B) Measured isodose, (C) Isodoses profiles (measured (green), calculated (orange)) with x line profile between the legs of the chair.

3.2 Gamma index analysis

Good agreement was observed between calculated and measured data using 3%, 3 mm and low dose threshold 5% criteria (7). Gamma analysis passing rates for almost tests are greater than 95 % as indicated in table 2. Before any analysis an overlapping of the calculated and measured data profiles is performed to have a best match, then the global gamma index is calculated via MyQA software. Even if the gamma analysis result depends on the detector array configuration and resolution (8), results from these qualitative patterns show high passing rates for all performed tests within 2D global gamma index at 3% 3 mm.

Table 2. Values of gamma index for different tests.

Tests	Gamma index
Uniform dose test	98,7%
Homogenous dose test	99,2%
Chair test	97,8%
Pyramid test	96,8%

4 CONCLUSION

In conclusion, it has been demonstrated how to evaluate the dosimetry of the treatment planning system by applying several tests to simulate future different radiotherapy plans without any error. Results obtained from this study allowed us, to confirm the accuracy of our MC model dose calculation with MONACO® TPS and it's ready for clinical use. This study also allowed us to use this 2D detector as a standard tool for IMRT/VMAT® quality control of patients with more than 97% success rate for patients with less than 3% 3 mm as validation criteria, while it was already confirmed that the differences between the success rates of 2D and 3D gamma analyses were not so significant from 1 to 2%.

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