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Beam Modeling in Commercial Treatment Planning System for IMRT and VMAT performance with an Elekta MLCI 2 Multileaf Collimator

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ABSTRACT

Introduction: Linear accelerator multileaf collimator (MLC) requires to be tested with best possible quality assurance tools and accordingly treatment planning system input with the data for appropriate modeling of MLC. Dose calculation is affected due to MLC modeling, especially when using the high standard treatment techniques like intensity-modulated radiation therapy (IMRT) or volumetric modulation arc therapy (VMAT).

Material and Methods: An MLCI 2 (Elekta Inc.) multileaf collimator is verified by 2D detector matrix (IBA dosimetry, Germany) using the quality assurance kit Express QA test package & clinical cases verification. The standard plan in QA mode is made in TPS and delivered under a medical linear accelerator like pre-treatment verification. The measured and calculated fluence is compared and accordingly the Gamma analysis is done.

Results: Express QA tests & clinical cases fields showed a great agreement with TPS calculations with 3% Dose Distribution (DD) and 3 mm Distance to Aggrement (DTA) Gamma criteria. The open field 10 x 10 cm^2 and 20 x 20 cm^2 found to be passed with 100% results for 3% &3mm criteria. 3ABUT test helped in setting the leaf offset value from default 0.0mm to 0.15mm. FourL test provides adjustment in leaf transmission value and leaf groove width from 0.012 to 0.0073 and 1.0mm to 0.7mm respectively. H&N and Prostate clinical cases passed with more than 95% for set criteria (3%DD&3mm). The absolute point dose measurement agreement was found to be more than 97%.

Conclusion: This study confirmed that the appropriate MLC check before starting IMRT and VMAT in a clinic and even after any repair is required thorough quality assurance check using Express QA and TG 119 package. Small changes in the MLC parameters like leaf offset, groove width and transmission n the TPS model can cause large changes in the calculated dose. At least annually Express QA test is recommended to every user to confirm the status of changed MLC parameters in due course of time.

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Introduction

Dose calculations for radiation therapy cases are done through a treatment planning system (TPS). The TPS model should be based on the dosimetric performance of the machine(s) that it represents. The medical physicist must ensure that a high agreement is achieved and maintained between the TPS model and physical Linear Accelerator (Linac) characteristics [1].

To achieve accuracy in dose calculation, Monaco TPS uses a tunable Multileaf Collimator (MLC) model, Nelms & Chan [2] indicated the necessity to characterize MLC's properties correctly at the time of commissioning. This study's first goal is to adjust a beam model for a commercial TPS Monaco 5.11(Elekta Limited, Crawley, UK). The beam model consists of the parameters a given dose calculation algorithm requires to determine a given dose contribution to a given point (voxel) in the patient body.

The MLCI 2 has 40 pairs of leaves with a 10 mm width at the isocentre. The minimum opposite leaf gap is 0.5 cm and the maximum field size is 40 × 40 cm. The maximum distance between leaves on the same leaf guide is 32.5 cm (12.5 cm over the central axis). They can move with a speed of 2.0 - 3.1 cm per second and can be interdigitated to deliver complex IMRT and VMAT plans.

IMRT and VMAT processes are more obscure to the user compared to 3-Dimensional Conformal Radiation Therapy (3DCRT) processes. Mechanical

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tolerances are significantly tighter for dynamic MLC than for static MLC treatments, small errors in the gap between opposing leaves may lead to a significant dose error in IMRT fields.

Boyer *et al*. demonstrated that a systematic leaf positioning error of 1 mm in IMRT plans could result in dose errors of up to 7.6% and 12.2% for the target and critical structures, respectively [3].

MLC calibration is critical step for IMRT and VMAT. There are different ways Elekta engineer can calibrate different types of multileaf collimators. The vendor provided MLC modeling procedures based on the type.

When leaf calibrations are performed, a variety of IMRT plans are usually performed and compared to TPS calculated dose distributions [4].

The second goal is to use this beam model to evaluate the performance for delivery of IMRT and VMAT, following manufacturer calibration procedures for an Elekta Synergy Linac equipped with an MLCI 2 head.

Materials and Methods

A 6 MV beam model of an Elekta Synergy Linac outfitted with an MLCI 2 treatment head was mapped in Monaco TPS.

The Monaco TPS uses X-ray Voxel Monte Carlo algorithm (XVMC) to calculate dose distribution through three separately modeled virtual sources in the treatment head. The jaws and MLCs are characterized using a transmission probability filter (TPF) which facilitates faster calculation times. The TPF is characterized by geometric and probabilistic parameters, where the geometric parameters describe the dimensions of the collimators. In contrast, the parameters describe the probability of transmission through different parts of the collimators [5].

Our experience to model the Elekta MLCi2 in Monaco TPS includes the vendor-supplied modeling procedure based on the Express QA package, the clinical cases according to AAPM Task group 119 (TG 119) and point dose measurement according to IAEA technical report series 398 (TRS 398).

The dose grid size and statistical uncertainty were set in Monaco parameters to 0.3 cm and 0.5% per control point, respectively for all the calculations fields.

The MatriXX Evolution

The MatriXX Evolution produced by (IBA dosimetry, Schwarzenbruck, Germany) is the optimized 2D digital verification system for rotational therapy techniques. It operates with the intuitive and user-friendly myQA patient application software for complete plan verification and Quality Assurance (QA) of IMRT / VMAT [7].

The matrix system has air-vented pixel ionization chambers with the ability to give parallel read-out of all ionization chambers without dead time. A pixel-segmented ionization chamber used in MatriXX Evaluation was designed to ensure the 2-dimensional verification of fields with complex fields created in IMRT plans. The detector features a 32×32 matrix into 24×24 cm² active area divided into 1020 independent vented parallel plate ion chambers [6]. The central position of the MatriXX does not contain an ion chamber, so the four nearest ion chambers were used to find the dose average for the central position. The sensitive volume of each signal ionization chamber is 0.08 cm^3 (4.5 mm diameter × 5 mm height). The ionization chambers are equally spaced with a center to center distance of 0.76 cm. The device runs with two separate counters to avoid dead time [7].

The MatriXX device was inserted into the Multicube Lite phantom (figure 1). The phantom Multicube Lite was made with plastic water and was 31.4 cm long, 22 cm height, and 34 cm width.

A Computed Tomography (CT) slices set of the MatriXX was acquired using a Phillips CT 16 slices and imported to Monaco TPS, the relative electron density (RED) of the phantom was set to 1.045 g/cm^3.

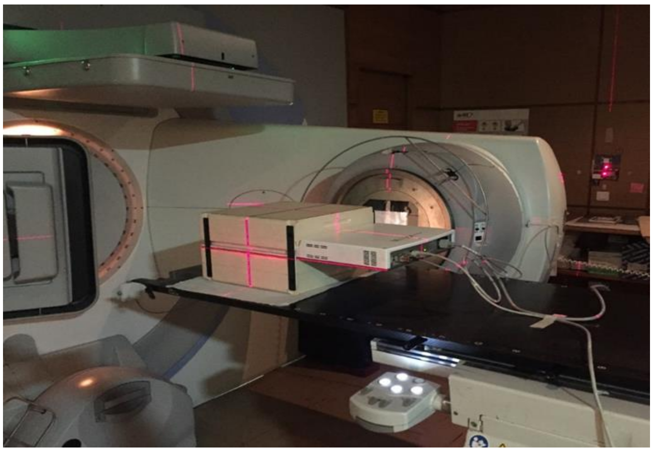

Figure 1. Combination of MatriXX and Multicube Lite phantom (Initial setup for all measurements).

Table 1. MLC geometry parameters in Monaco 5.11

TPF Parameter	default setting	optimized setting
Leaf transmission	0.0120	0.0073
Leaf Offset (mm)	0.00	0.15
Leaf Groove width (mm)	1.00	0.7

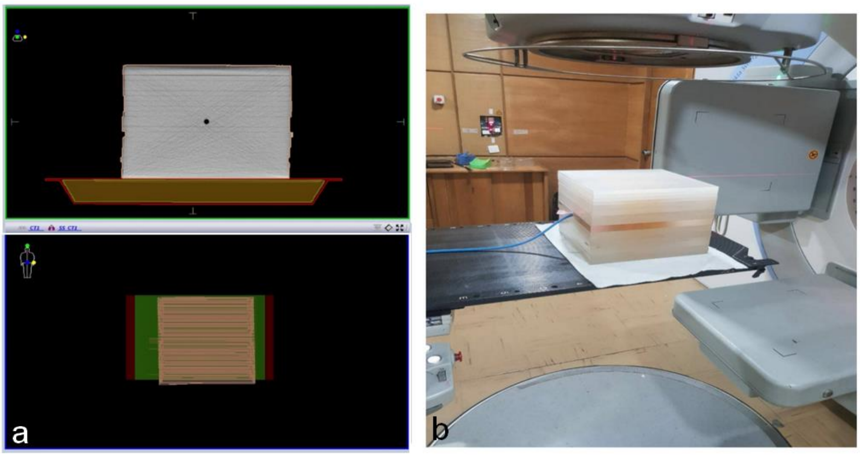

Figure 2. Virtual solid phantom (22 cm) in TPS (a); initial setup of solid phantom for point dose measurements (b).

For the initial setup, The MatriXX Evolution was placed on Elekta Beam Evo's couch, with the Source to Surface Distance (SSD) set to 89 cm. The laser was intersected to the Effective point of measurement of the device. The Matrixx has the capability to measure a radiation dose distribution from all three techniques (3DCRT, IMRT, VMAT).

My QA-patient software allows many valuable tools to apply computational analysis directly and analyze the measurement data.

Elekta ExpressQA beams

Elekta provides a test beams package with predefined MLC shapes and configurations in order to evaluate the machine. A set of eight static, open, step &shoot and dynamic MLC fields were available to characterize the MLC parameters in the photon Monte Carlo model. Two open fields 10 x 10 cm² and 20 x 20 cm² check the absolute dose calibration and field flatness, symmetry, respectively, and QA device detector's response. The "3ABUT" field with three abutting field segments and "7segA" field consisting of seven segments were used to validate MLC leaf offset position. The "FourL" field made of four L-shaped segments was used to adjust the MLC transmission. The dynamic MLC field "DMLC" was used to authenticate MLC leaves major and minor offset and leaf tip leakage. The high-density MLC field "HDMLC" and high-dose IMRT field "HIMRT" were representative clinical fields. Emphasis was placed on the 3ABUT and FOURL fields to characterize the MLC geometry parameters and Table 1 lists the adjustable MLC Geometry parameters in our experience.

Leaf Offset adjusting using the 3ABUT field.

The 3ABUT field is a combination of Three 6 cm wide fields via step-and-shoot delivery. The fields were designed to abut and created two junctions. This plan was used to evaluate MLC calibration and the leaf offset parameter.

In MLC Geometry settings by "leaf offset" we refer to the physical deviation from the calibrated "zero position" of the MLC leaves that might occur during the head installation process using the Autocal software (Elekta, Crawley, UK) by the Elekta's engineer.

In the TPS we can adjust this parameter from -0.5 to +0.5 [8], setting a negative value for this number effectively tells the planning system that a set gap between two opposing leaves is slightly smaller physically than the stated gap, whereas setting a positive value indicates to the planning system that the same gap is in reality, slightly larger physically that what is being set in the planning system.

Leaf transmission and groove width adjusting using the FourL Field.

The FOURL field was used to investigate changes to the leaf transmission and groove width parameters and for the MatriXX Evolution, the dose in the leaf groove region is sensitive to the setup like shift or rotation [8].

Clinical cases verification

Planar dose verification

After optimization and adjustment of the MLC Geometry parameter, to confirm that our adjustment answers the clinical constraints, 2 VMAT and 2 IMRT Step & Shoot and 2 IMRT Dynamic MLC were created for head & neck Simulated Integrated Boost (SIB) and prostate cases, all cases optimized to plan objectives included in the TG-119 report [9] as well as objectives based on clinically realistic goals for the given custom treatment type.

For the IMRT plans created in this study, the total number of segments allowed for an individual beam was set to 30, with a minimum segment width set to 1 mm. For the VMAT plans, the total number of segments allowed in an individual arc was limited to 120, and a minimum segment width of 10 mm.

Once acceptable plans were created, they were recalculated on a simulated MatriXX and Multicube Phantom to evaluate planar dose distributions.

The QA plans were exported to the Mosaiq (Elekta Limited, Crawley, UK) record-and-verify system and delivered using an Elekta Synergy MLCI 2.

The planar dose comparisons were made by exporting dose plane information from Monaco to my QA patient software to evaluate any discrepancy in the measured distribution.

Point dose verification

We have also conducted measurements for the same clinical cases they were recalculated on a simulated solid water phantom (PMMA) with the IBA CC13 ion chamber 0.13 cm^3 (IBA dosimetry, Schwarzenbruck, Germany), relative electron density was set to 1.16 g/cm^3 in Monaco TPS, those plans were evaluated by comparing TPS-calculated mean point doses on the effective point of measurement and comparisons were performed at SSD = 90 cm (figure2).

Gamma Analysis

The gamma index is the IMRT gold standard QA tool for assessing agreement between phantom measurements and the calculated treatment plan [14].

It was developed to combine the two previous assessment criteria dose difference (DD) and distance to agreement DTA. This important quantity is essential in confirming the correct delivery of the complex dose distributions seen in modern IMRT.

The gamma analysis results were tabulated for 3% DD, 3 mm DTA, and 10% dose threshold based on a global normalization, as proposed by Palta et al. [10] and be validated if at least 95% of pixels have $\gamma \leq 1$.

For all gamma comparisons, the measurement profiles are to be selected as the reference profile.

Results

Express QA tests

We started the measurements with the MatriXX output calibration factor, ultimately by the 10 x 10 cm² field; we checked the device setup and the absolute calibration if it meets the requirements.

The 10 x 10 cm² and 20 x 20 cm² fields as proven in figures (3, 4), respectively had a good agreement with the calculated fields.

The subsequent step is measuring the 3ABUT field. In myQA patient software, we consider the integral measurement as reference field and the calculated 3ABUT Field in Monaco as compare field, and we start the comparison with the default value of the offset, increasing/decreasing it until having the best match between MatriXX measured dose and TPS calculated dose. In our experience, the best agreement was found by adjusting the leaf offset from 0.0 mm to 0.15 mm figure (5,6).

The same processes for the FourL field until having the best matching. The 'leaf transmission' parameter was adjusted from the default value of 0.0120 to 0.0073. The 'Leaf Groove Width' parameter was adjusted from the default value of 1.00 mm to 0.7 mm, figures (7,8).

Gamma pass rates for measurement versus calculation for the Elekta Express QA tests fields were greater than 95% for gamma criteria of 3% and 3mm (table 2).

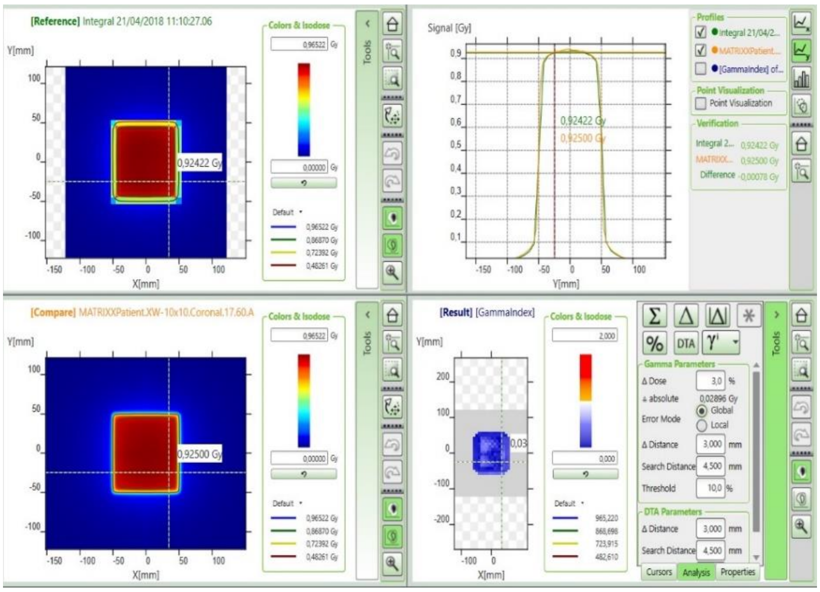

Figure 3. MyQA Patient interface for the field measured and calculated dose for 10 x 10 cm^2.

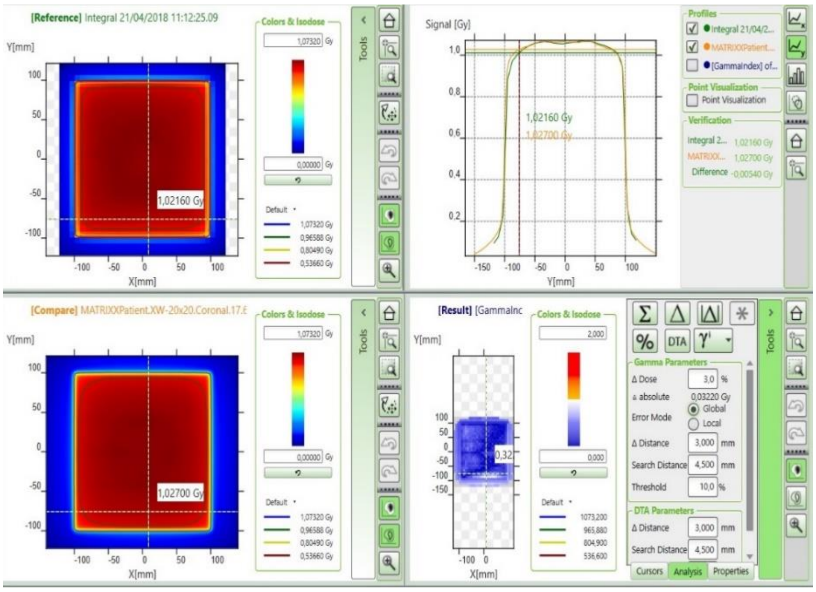

Figure 4.MyQA Patient interface for field measured and calculated dose for 20×20 cm^2

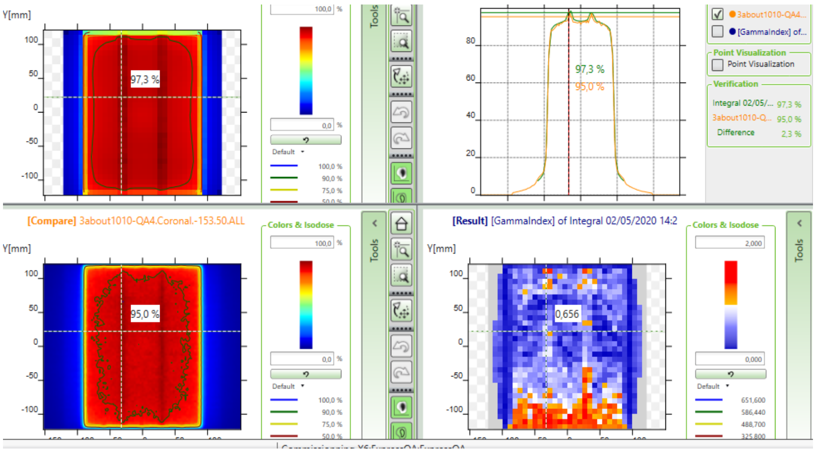

Figure 5. MyQA Patient interface for 3ABUT Field measured and calculated dose (default value)

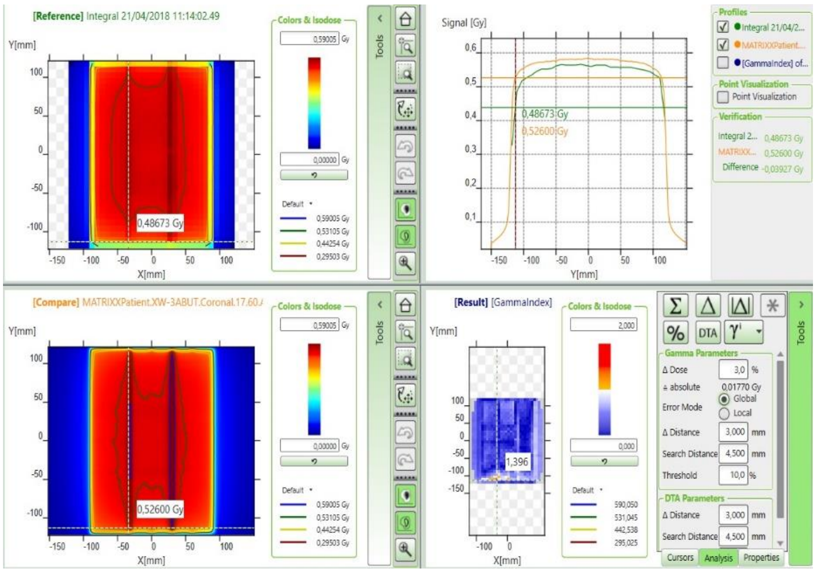

Figure 6. MyQA Patient interface, 3ABUT Field measured and calculated dose (optimized value)

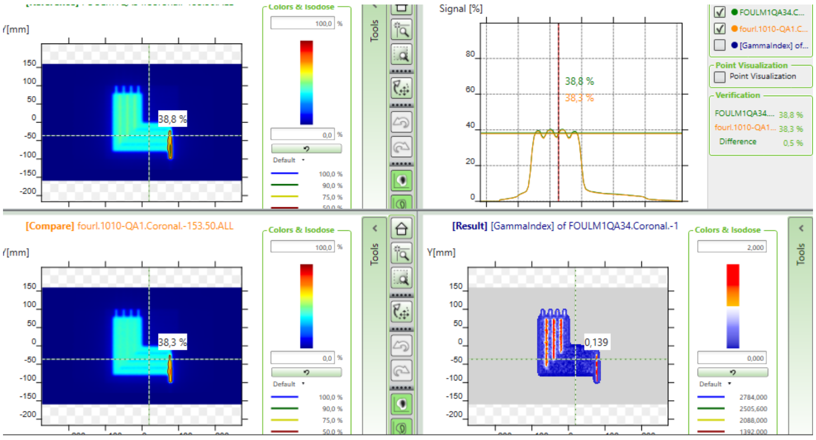

Figure 7. MyQA Patient interface, FourL field measured and calculated dose (default value)

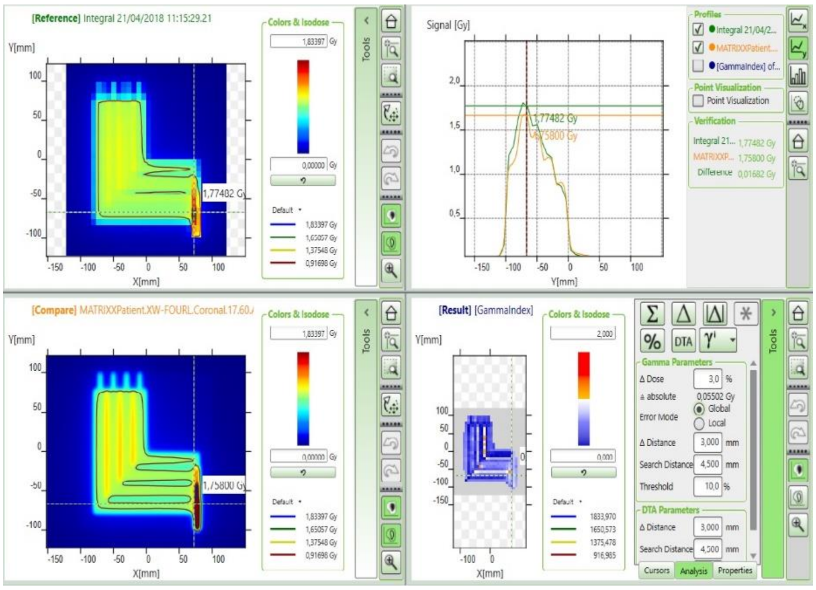

Figure 8. MyQA Patient interface, FourL field measured and calculated dose (optimized value)

Table2. Gamma analysis Express QA results for measured versus calculated dose.

	Gamma Index %	
Test Field	2%DD 2mm DTA	3% DD 3mm DTA
10 x 10	100	100
20 x 20	99	100
3ABUT	89.20	99.4
FourL	96.60	98.4
7SegA	87	95
DMLC	89	99.8
HDMLC	91.2	95.40
HIMRT	92	96

Table 3. Planar dose and point dose verification for the clinical cases

Planar dose	Verification	Point dose Verification		
Site / Delivery	Gamma index 3 % / 3 mm	Calcluted Dose [Gy]	Measurement Dose [Gy]	Standard Deviation %
H&N VMAT	99,8	1.72	1.73	0.57
H&N DMLC	99,6	1.71	1.72	0.58
H&N S&S	96,9	1.66	1.69	1.77
Prostate VMAT	100	3.055	3.09	1.13
Prostate DMLC	100	3.014	3.05	1.18
Prostate S&S	97,4	2.979	3.07	2.96

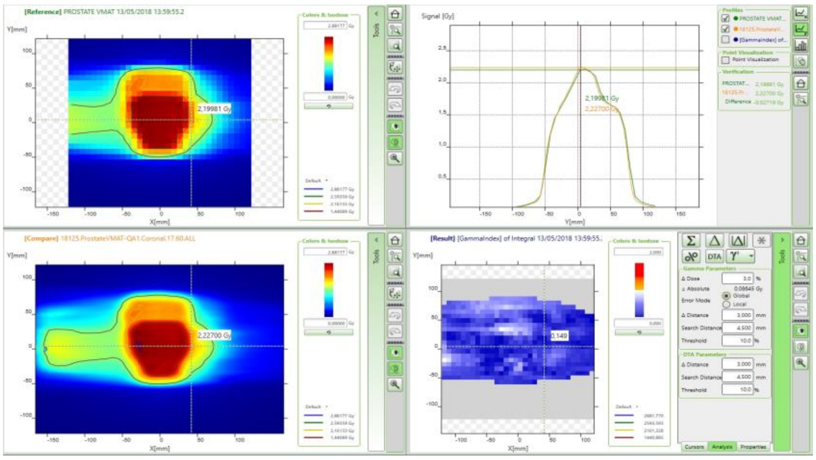

Figure 9. MyQA Patient interface, Prostate VMAT case comparison using X6 MonteCarlo optimized beam Model

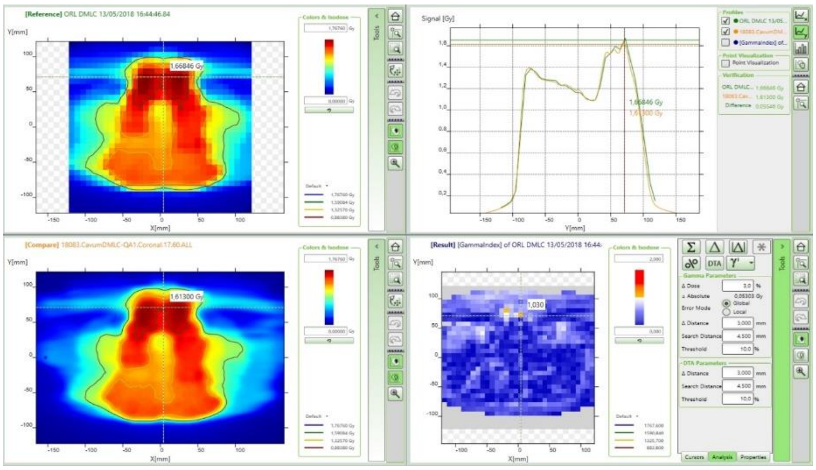

Figure 10: MyQA Patient interface, H&N DMLC case comparison using X6 MonteCarlo optimized beam Model

Clinical cases verification

Monaco TPS calculated dose distribution was compared against MatriXX measurements on Prostate, H&N cases (figures 9,10). The gamma passing rates (3% DD, 3 mm DTA) is tabulated in Table 3. The percentage of points passing the gamma criteria, averaged across the sites, was superior 95% for VMAT, IMRT S&S and IMRT dMLC.

As well as the comparisons between TPS calculated absolute dose and ion chamber measurements are shown in Table (3). All standards deviations are less than 3%.

Discussion

The MLC model in the planning system is robust and efficient in predicting accurate dose calculations for IMRT and VMAT plans at rational clinical MC calculation parameters. The vendor-provided Express QA package can be a vital tool to use in model parameter determination. However, it seems that tuning based on point dose measurements is inevitable to ensure maximum plan accuracy.

The differences between the vendor-provided model and that evaluated in the house most likely have a diffuse explanation, partially associated with our choice of QA equipment and parts associated with the natural limitations of dose distribution comparison as a method for tuning a head model. The spatial resolution of the dosimeter makes the visibility of small structures in the distributions difficult, and due to the higher physical density of the device with respect to water, absolute calibration of the device requires careful consideration concerning dose to medium, dose to water, and effective relative electron density assigned to the image set. These additional considerations need to be carefully coordinated with the vendor, and a more straightforward QA system would likely provide less room for unintentional inaccuracies in head modeling. The vendor likely assisted procedure could have provided a parameter set that produced point doses closer to those found in an ion chamber measurement if we had originally chosen a water equivalent system.

The MC dose calculation algorithm is considered to be the gold standard and more accurately

Calculates dose in areas of electronic disequilibrium such as heterogeneity interfaces [11].

1. Despite the Monaco MC calculation algorithm does not support the physical motorized wedge

2. which is commonly employed in many 3DCRT plans, but it shows great accuracy in the
3. Heterogeneities area [11].

Monaco TPS uses the MLC geometric parameters during segmentation and dose calculation [5]. Our study emphasizes focusing just on three parameters: leaf offset, leaf transmission, and Leaf groove width due to the extended calculations times of MC algorithm.

MLC transmission is crucial, particularly for low doses [12]. MLCI 2 has an MLC transmission of 0.60% measured under leaves. However, it has two jaw pairs that are parallel and perpendicular to the leaf direction. These jaws are movable during the dose delivery and allow decreasing the whole-body dose. In our study, as is shown from figure 5 and figure 7, the impact of using the default value of MLC geometry in the TPS for the 3ABUT field and FourL field while optimizing those values increase the agreement in the gamma analysis and also the disappearing of red pixels and appearance of a blue pixel in the dose map which it means a high agreement between the two maps was found.

On the other hand, according to our experience, we suggest to the users of Elekta MLCI 2 to limit the Monaco calculation parameters of leaf sequencing and the leaf width from 120 to 140 and

1 cm respectively to avoid all kinds of modulation complexity and risks of discrepancy with the dose distribution delivered by the Linac.

Conclusion

Accurate dose calculation is a fundamental thing in the radiotherapy system that helps ensure that the delivered dose meets the physician's prescribed dose.

MLC calibration is a critical step for IMRT and VMAT. There are different ways how Elekta engineer can calibrate MLCi2. Therefore the QA procedures have to be established by the physicist to monitor the MLC calibration; the test plans used during the commissioning have to be run after each MLC recalibration.

In our institution experience, Elekta Express QA tests, Clinical cases fields showed a significant agreement with TPS calculations with 3%DD and 3mm DTA gamma criteria. Elekta MLCI 2

6MV photon beam model has been successfully commissioned and is ready for clinical implementation.

This study confirmed that the MatriXX IBA was a suitable device for optimizing the MLC geometry parameters in Monaco 5.11 TPS due to its accuracy and simple detector geometry.

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