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BEAM MODELING OF ELEKTA AGILITY MLC FOR MONTE CARLO AND COLLAPSED CONE CONVOLUTION COMPUTATIONAL ALGORITHMS IN MONACO TREATMENT PLANNING SYSTEM

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Abstract. *After the commissioning process of 8 beam matched linear accelerators from different clinics, the next step is beam modeling of Monte Carlo and Collapsed Cone Convolution computational algorithms in Monaco treatment planning system. This is done by measuring asymmetrical and irregular fields with the same number of monitor units (100 UM). These fields are predefined in the treatment plan system by the manufacturer. The maximum tolerance allowed by the manufacturer for the intercomparison of measurements with the values calculated by the system is ± 3%. The measurements were acquired with Semiflex 3D, Farmer, PinPoint ionization chambers in the BeamScan water phantom and processed with Mephysto software. These measurements and calculations shall be performed for each computational algorithm. In this treatment planning system 2 calculation models are used. The first one is collapsed cone convolution (CCC), used for the 3DCRT treatment technique in two variants: open fields and wedge filter fields. The second one is Monte Carlo (pMC), used for VMAT and IMRT treatment technique. A set of eight static and intensity modulated radiation therapy fields were used to verify the Agility MLC parameters. We know from experience that with Agility the 2 main parameters we need to touch are the Leaf offset and the Leaf Transmission. The measurements were performed with Octavius 4D system and PTW Octavius 1500 detector array. The beam modeling was verified using a homogeneous phantom for point dose measurements, post modelling MLC parameters and patient QA plans. All plan parameters pass the gamma criteria with an average percentage higher than 95%.*

Keywords: *collapsed cone convolution, Monte Carlo, treatment planning system, beam modeling, Agility MLC*

1. INTRODUCTION

One of the most crucial parts of radiotherapy is to verify the accuracy of the treatment planning dose calculation. Each linear accelerator is transposed in the treatment planning system through the beam models. The beam model is created and defined for each energy and each calculation algorithm after the beam data collection. A key step before going into clinical use is the beam modeling part, employed by the medical physicist team. To ensure the accuracy of the modeling, a dosimetric validation of the treatment planning system is performed in order to improve the patient's level of safety.

In this study, eight Elekta (Crawley, UK) medical linear accelerators are included, from 4 different clinics around Romania. 7 linacs are Elekta Infinity model, and one is Versa HD. The linacs are matched with each other using Elekta Accelerated Go Live (AGL) process.

The aim of this study is to verify the beam matching between 8 linacs in terms of treatment planning and quality assurance.

2. MATERIALS AND METHODS

Elekta linacs are able to deliver both photons and electrons beams. All 8 linacs involved delivers only photon beams (6 MV and 10 MV energy), 3 of them are also able to deliver flattening filter free photon beams (6 MV FFF and 10 MV FFF). The linacs are designed for a variety of treatment from conform 3D radiotherapy (3D-CRT), to intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) and also targeted treatments such are stereotactic radiotherapy (SRT) and radiosurgery (SRS). The modern design of the linac includes a multi leaf collimator system (Elekta Agility MLC) with an increased MLC speed (6.5 cm/s) dedicated for rapid treatment with reduced treatment time. Agility MLCs is formed from 160 tungsten leafs (80 pairs), 0.5 cm width, positioned with high precision using the Rubicon optical technology for real-time leaf positioning. The speed and reliability of the new MLC design bring important benefits to patients and medical team alike. Agility MLC's design allows clinicians to sculpt the radiation dose in the treatment planning system with extreme precision.

The beam models are predefined from the manufacturer (Elekta, Crawley, UK) according to AGL process and are the same for all the clinics. For each energy, two computational algorithms are available: Collapsed Cone Convolution (CCC) and Monte Carlo (MC). Collapsed Cone Convolution algorithm is used for static open fields and in case of wedge filters. 3D-CRT treatments can by optimized using CCC algorithm. Monte Carlo algorithm is employed for IMRT/VMAT treatment planning optimization, but can be also used in case of 3D-CRT for open fields without wedges.

17 predefined asymmetrical and irregular fields are calculated in the Monaco TPS for all energies (6 MV and 10 MV photon beams are included in this study) and

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then measured in a homogeneous phantom. As homogeneous phantom, PTW (Freiburg, Germany) BeamScan water phantom was used for point dose measurements. BeamScan water phantom together with Mephysto mc^2 software allows fast measurements with 20 mm/s velocity of the detector in water and outside of treatment room adjustment of detector position which decrease the time spent for each measurement. Three different detectors were used (Table 1), depending on the measured field size.

Table 1. Ionization chambers used from PTW Freiburg and the relevant characteristics

Characteristics	***Farmer waterproof***	***PinPoint 3D***	***Semiflex 3D***
Detector type	Vented cylindrical ionization chamber	Vented cylindrical ionization chamber	Vented cylindrical ionization chamber
Nominal sensitive volume	0.6 mm^3	0.016 cm^3	0.07 cm^3
Reference point on chamber axis	13 mm from chamber tip	2.4 mm from chamber tip	3.45 mm from chamber tip
Chamber voltage	400 V	300 V	400 V
Direction of incidence	Radial	Radial	Radial, Axial
Wall of sensitive volume	0.335 mm RW3 0.09 mm graphite	0.57 mm PMMA 0.09 mm graphite	0.57 mm PMMA 0.09 mm graphite
Dimension of sensitive volume - radius	3.05 mm	1.45 mm	2.4 mm
Dimension of sensitive volume - length	23 mm	2.9 mm	4.8 mm
Central electrode (Al99.98) diameter	1.15 mm	0.6 mm	0.8 mm
Field size	5x5 cm^2 – 40x40 cm^2	2x2 cm^2 – 40x40 cm^2	2.5x2.5 cm^2 – 40x40 cm^2

A set of eight static and intensity modulated radiation therapy fields (Table 2) were used to verify the Agility MLC parameters in order to determine the parameters that best fit each installation. This set of fields is called Express QA package and is provided by Elekta for the users with the aim to optimize the TPS. We know, from experience, that Agility's 2 main parameters we need to touch are the Leaf offset and the Leaf Transmission which are adjusted for each machine defined in the planning system. In the case of beam matched linacs, in the TPS, only one machine is defined. Elekta recommend to keep the defaults values for the majority of the parameters, with an exception: the leaf off-set. Leaf off-set is meant to define the physical deviation from the "zero position" of the MLCs that might occur during the installation process. There are many more adjustable parameters that can be changed using the Express QA package, such are: leaf transmission, leaf groove width, interleaf leakage, leaf tip leakage. The measurements were performed with Octavius 4D system and PTW Octavius 1500 detector array. Octavius 1500 detector array is designed from 1405 vented ion chambers displayed on a field size of 27x27 cm^2 and 7.1 mm detector spacing.

Table 2. Test beams for MLC adjustments provided by Elekta

Beam	***Description***	***Purpose***
3ABUT	Step and shoot (6 cm wide fields)	MLC calibration and leaf offset
20x20	10x10 cm^2 open field	Beam symmetry. Response of the QA device
10X10	10x10 cm^2 open field	Asses the calibration of the device
DMLC1	Dynamic 10cm sweep with a 2 cm wide field	MLC position offset, leaf transmission, and calibration.
HIMRT	Head and neck step and shoot IMRT	Impact transmission probability filter of the MLC in clinical case
HDMLC	Head and neck sliding window IMRT	Impact transmission probability filter of the MLC in clinical case
7SegA	7 fields (step and shoot) 2 cm wide	MLC calibration and leaf offset
FOURL	4 L-shaped fields (step and shoot)	Leaf position offset, MLC transmission and MLC groove width settings

3. RESULTS

Collapsed Cone Convolution algorithm can be used only for 3D planning. All LINACS involved are able to deliver photon beams of 6 MV and 10 MV energy, and also unflattened photon beams. 100 MU were delivered for each field, equivalent to 1Gy at source to surface distance (SSD) 90 cm and 10 cm depth in water. Both energies show good agreement with the TPS system, with a maximum deviation of ±1.3%, for Asy04 and Asy07 fields due to beam shape situated at leaf limits, for both 6 MV and 10 MV energy (Figure 1 and Figure 2).

In the case of Wedge filter, the only computational algorithm available is Collapsed Cone Convolution. 9 irregular fields were measured. 100 MU were delivered for each field, equivalent to 1 Gy at SSD 90cm and 10 cm. The maximum deviation from reference can be seen for 6 MV photon beams (Figure 3), +1.97%. For 10 MV photons beams (Figure 4), the maximum deviation is +1.83%. Both energies show good agreement with TPS system below the maximum admitted of ±3%.

Photon Monte Carlo algorithm can be used for both, 3D and IMRT/VMAT planning, with higher accuracy than CCC algorithm. The same 17 field with 100 MU were delivered, with a maximum deviation of ±2.2% in case of 6MV energy (Figure 5). 10 MV photon beams (Figure 6) shows good agreement with TPS measurements, with a maximum deviation of ±1.7%.

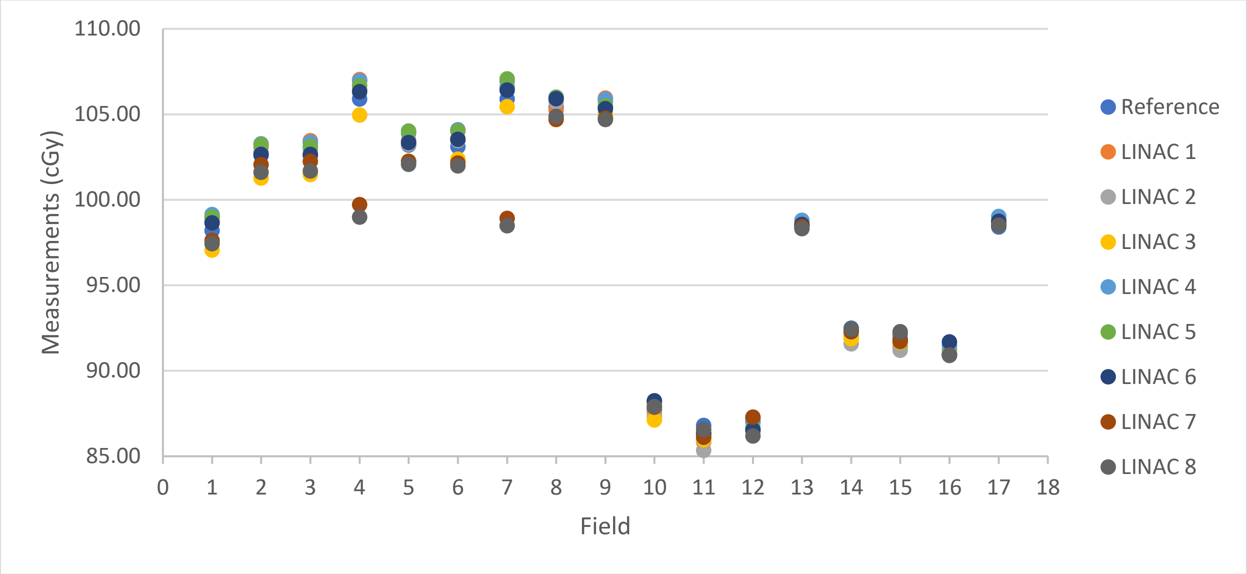

Figure 1. 3D CCC Algorithm post-modeling for 6MV energy photon beams open fields where field 1 - Asy01, field 2 - Asy02, field 3 -Asy03, field 4 - Asy04, field 5 - Asy05, field 6 - Asy06, field 7 - Asy07, field 8 - Asy08, field 9 - Asy09, field 10 - A0303, field 11 - 02x20, field 12 - 20x02, field 13 – Oval, field 14 – C, field 15 – T, field 16 – Circle, field 17 – Irreg.

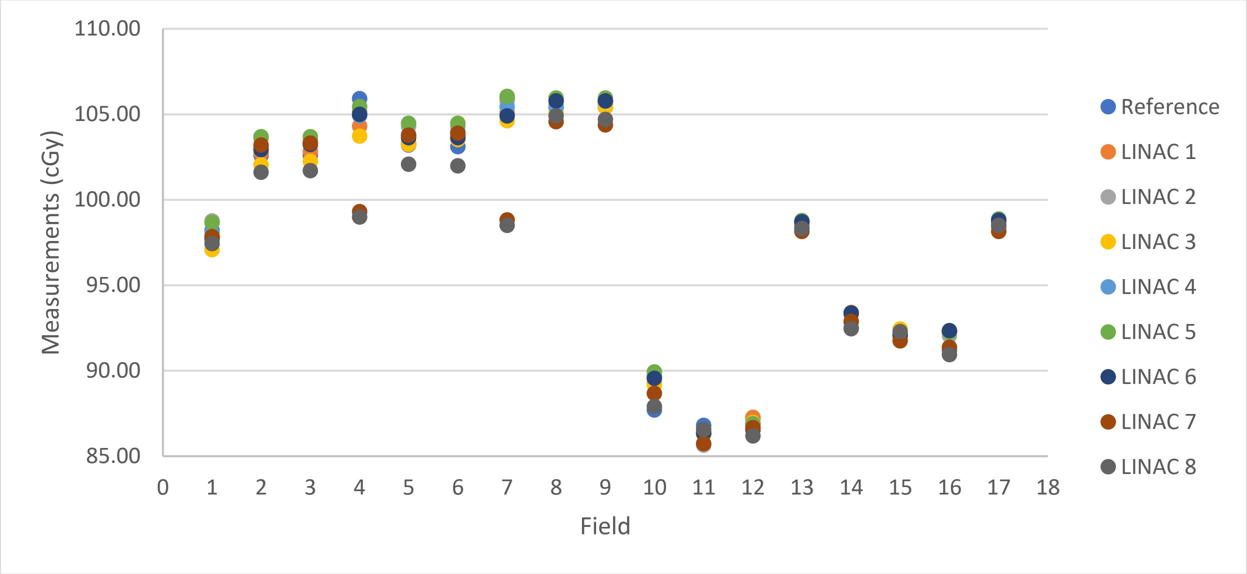

Figure 2. 3D CCC Algorithm post-modeling for 10MV photon beams open fields where field 1 - Asy01, field 2 - Asy02, field 3 -Asy03, field 4 - Asy04, field 5 - Asy05, field 6 - Asy06, field 7 - Asy07, field 8 - Asy08, field 9 - Asy09, field 10 - A0303, field 11 - 02x20, field 12 - 20x02, field 13 – Oval, field 14 – C, field 15 – T, field 16 – Circle, field 17 – Irreg.

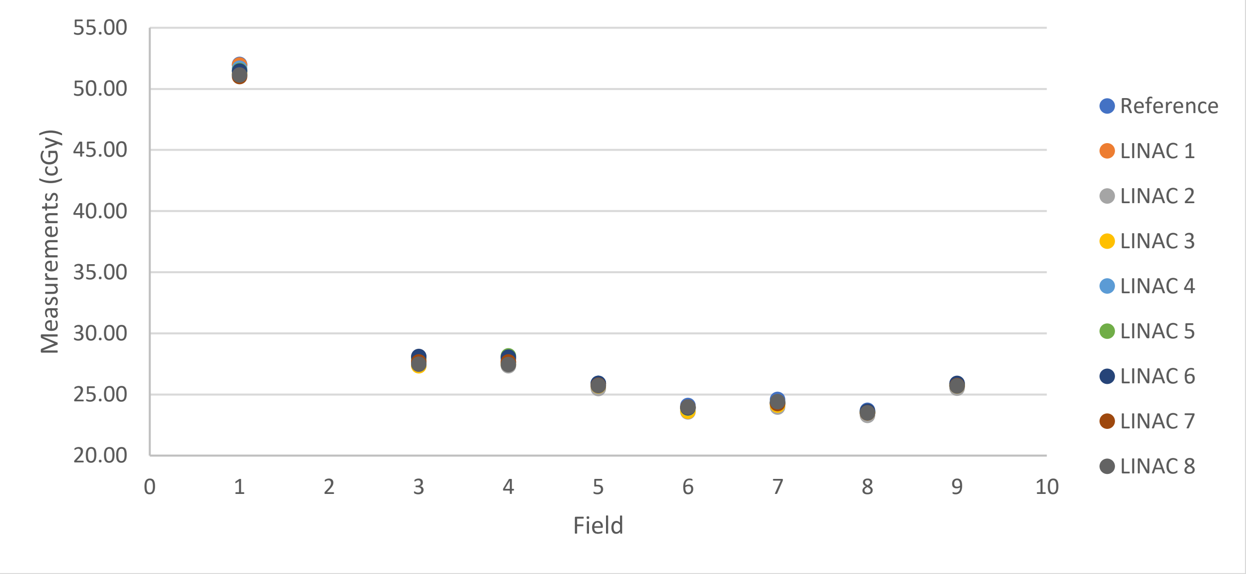

Figure 3. 3D CCC Algorithm post-modeling for 6MV photon beams with wedge filter where field 1 – AsyUL, field 2 – AsyLL, field 3 – AsyLW, field 4 – AsyRW, field 5 – Oval, field 6 – C, field 7 – T, field 8 – Circle, field 9 -Irreg.

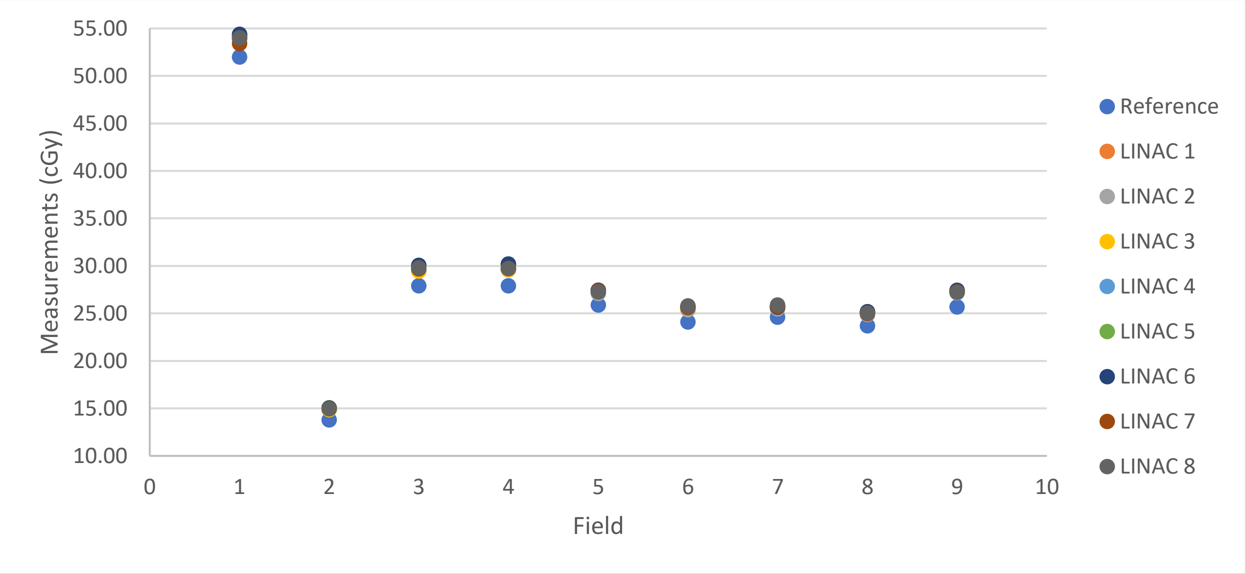

Figure 4. 3D CCC Algorithm post-modeling for 10MV photon beams with wedge filter where field 1 – AsyUL, field 2 – AsyLL, field 3 – AsyLW, field 4 – AsyRW, field 5 – Oval, field 6 – C, field 7 – T, field 8 – Circle, field 9 -Irreg.

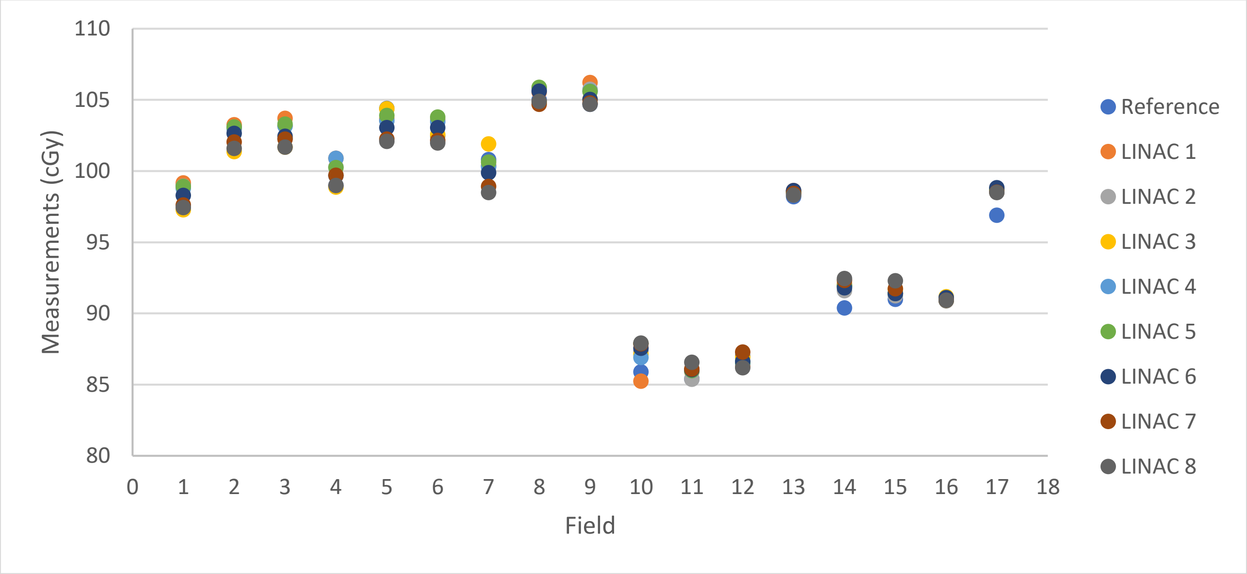

Figure 5. Photon MC Algorithm for 6MV photon beams where field 1 - Asy01, field 2 - Asy02, field 3 -Asy03, field 4 - Asy04, field 5 - Asy05, field 6 - Asy06, field 7 - Asy07, field 8 - Asy08, field 9 - Asy09, field 10 - A0303, field 11 - 02x20, field 12 - 20x02, field 13 – Oval, field 14 – C, field 15 – T, field 16 – Circle, field 17 – Irreg.

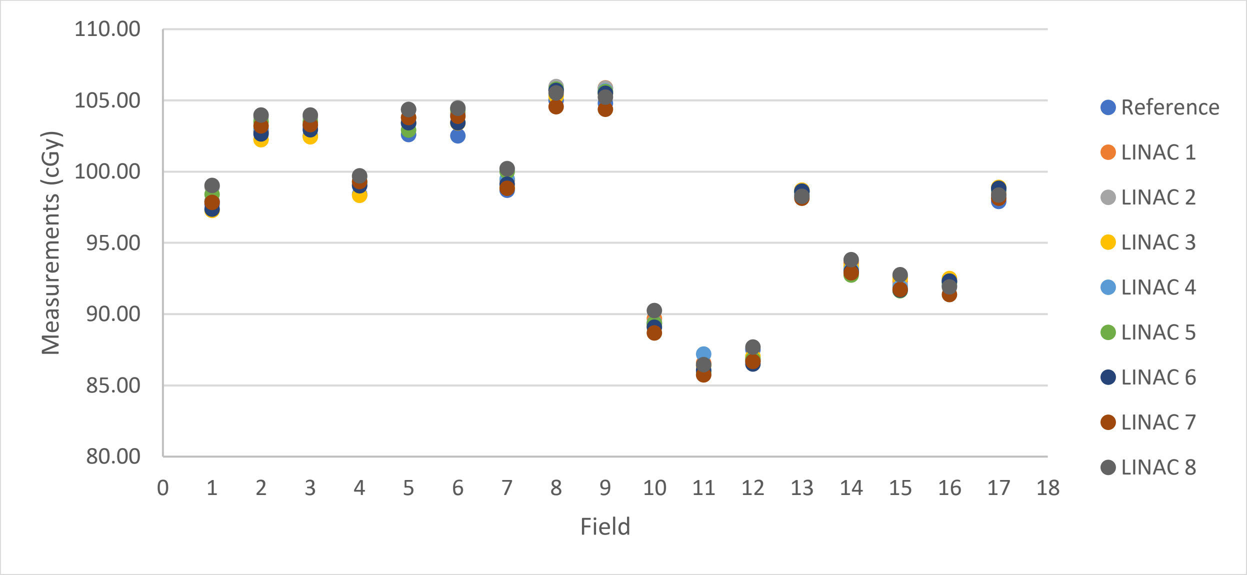

Figure 6. Photon MC Algorithm for 10MV photon beams where field 1 - Asy01, field 2 - Asy02, field 3 -Asy03, field 4 - Asy04, field 5 - Asy05, field 6 - Asy06, field 7 - Asy07, field 8 - Asy08, field 9 - Asy09, field 10 - A0303, field 11 - 02x20, field 12 - 20x02, field 13 – Oval, field 14 – C, field 15 – T, field 16 – Circle, field 17 – Irreg.

Table 3. MLC parameters adjustment in the treatment planning system

MLC Parameter	**Clinic 1**		**Clinic 2**		**Clinic 3**		**Clinic 4**	
	6MV	10MV	6MV	10MV	6MV	10MV	6MV	10MV
Leaf Transmission	0.0052	0.0048	0.0048	0.0040	0.0048	0.0032	0.0045	0.0032
Leaf Groove Width (mm)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Interleaf leakage	3	3	3	3	3	3	3	3
Leaf offset	-0.03	-0.03	-0.02	-0.09	-0.02	-0.02	-0.02	-0.02

MLC analyzed parameters shows small variation between involved linacs. The 8 linacs are installed in 4 clinics around Romania, 2 linacs per clinic. Due to the fact that the machines are beam-matched, only one machine is defined for each clinic in the Monaco TPS. The leaf transmission is higher for 6 MV energy beams, as expected. The leaf off-set values are similar, with a higher variation in Clinic 2 for 10 MV photon beam energy (-0.09).

5. CONCLUSION

Beam modeling was successfully performed using PTW Beam Scan water tank and Octavius 4D phantom.

MLC parameters were adjusted with small differences between clinics. The proper values of the parameters play an important role in the treatment planning and quality assurance of the plans.

Post modeling part of the commissioning process where 17 fields were measured shows small deviation between linacs, therefore we can conclude that all 8 linacs involved in this study are beam matched and allows patients interchange without replanning. In the same time, quality assurance of the treatment plans can be performed on any of the linacs with no additional labor for the medical team.

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