BJRS
BRAZILIAN JOURNAL OF RADIATION SCIENCES

doi.org/10.15392/2319-0612.2026.2985
Braz. J. Radiat. Sci., Rio de Janeiro
2026, 14(3) | 01-20 | e2985
Editor(s): Dr. (Prof.) Bernardo Maranhão Dantas
Dr. (Prof.) Alfredo L. Ferreira Filho
Dr. (Prof.) Ademir de Jesus Amaral
Submitted: 2025-07-18
Accepted: 2026-03-03

Original Article

Optimization of Geometric Components of Agility Multileaf to Improve Dose Delivery Accuracy

Oliveira[a*], C. T. *and* Potiens[b], M. P. A.

[a, b] Instituto de Pesquisas Energéticas e Nucleares, Avenida Lineu Prestes 2242, Cidade Universitária, São Paulo – SP, CEP 05508-000

*Correspondence: camila_fmedica@hotmail.com

Abstract: The Agility Multileaf Collimator (MLC) exhibits specific machining characteristics. These unique features, together with minor installation differences among various linear accelerators, produce dosimetric effects that are not accounted for by the Monaco Treatment Planning System (TPS). To address this, the manufacturer recommends that users perform post-modeling adjustments to better characterize the MLC according to the actual configuration of the clinical linear accelerator. Evidence in the literature indicates that, in techniques modulated by dynamic MLC motion, geometric positioning errors as small as 1 mm can result in dose delivery errors of 10% or more. Therefore, it is of great importance to study the behavior of the geometric factors of the MLC leaves through the concepts applied in radiation metrology. However, despite the widespread clinical use of Monaco, there is still limited literature with comprehensive information, which makes the work of medical physicists more challenging. Thus, the objectives of this study were to analyze the geometric components of the Agility MLC and to propose an efficient methodology for post-modeling—or fine-tuning—these components so that the calculated dose in the TPS is as close as possible to the dose delivered by the linear accelerator. The results showed that, with the post-modeling, for the same evaluation criteria, the calculated doses for the ExpressQA tests, TG-119 tests, and patient-specific cases were in closer agreement with the doses delivered by the linear accelerator in all situations. For the 7SegA and DMLCi fields the improvements in gamma pass rates were more than 10%. These results enable greater efficiency in dose delivery, leading to improved tumor control and reduced patient toxicity.

Keywords: Multileaf Collimators 1, Monaco 2, Modeling 3, Agility 4.

doi.org/10.15392/2319-0612.2026.2985
Braz. J. Radiat. Sci., Rio de Janeiro
2026, 14(3) | 01-20 | e2985
Editor(s): Dr. (Prof.) Bernardo Maranhão Dantas
Dr. (Prof.) Alfredo L. Ferreira Filho
Dr. (Prof.) Ademir de Jesus Amaral
Submitted: 2025-07-18
Accepted: 2026-03-03

Otimização dos componentes geométricos do Multileaf Agility para melhorar a precisão da administração da dose

Resumo: O Colimador multilâminas (MLC) *Agility* apresenta algumas características específicas de usinagem. Essas características exclusivas, além das pequenas diferenças no momento da instalação entre os diversos aceleradores lineares, produzem efeitos dosimétricos que o Sitema de Planejamento do Tratamento (TPS) Mônaco não considera em seu cálculo. Para isso, existem recomendações por parte do fabricante para que o cliente execute ajustes de pós-modelagem, para caracterizar melhor o MLC de acordo com as configurações reais do acelerador linear usado na clínica. Visto que, na literatura existem evidências de que, em técnicas moduladas por MLC dinâmico, erros na posição geométrica do MLC de apenas 1 mm podem resultar em erros de 10 % ou mais na entrega da dose, é de grande importância estudar o comportamento dos fatores geométricos das lâminas através dos conceitos aplicados na metrologia das radiações. No entanto, apesar de o Mônaco ser amplamente utilizado clinicamente existe ainda, pouca literatura com riqueza de informações, dificultando o trabalho do físico médico. Sendo assim, os objetivos desse estudo foram analisar os componentes geométricos do MLC Agility e trazer uma metodologia eficiente de pós-modelagem ou ajustes finos destes componentes para que, com os ajustes a dose calculada no TPS esteja tão próximo quanto possível da dose entregue pelo acelerador linear. Os resultados mostraram que com a pós modelagem, para os mesmos critérios de avaliação, as doses calculadas para os testes ExpressQA, bem como testes do TG-119, alem de casos pacientes específicos estiveram mais próximas das doses entregues pelo acelerador linear em todas as situações. Para os campos 7SegA e DMLCi as melhorias nas taxas de aprovação gama estiveram acima de 10 %. Estes resultados possibilitam maior eficiencia na entrega da dose, com consequente aumento no controle tumoral e redução na toxicidade ao paciente.

Palavras-chave: Colimador Multileaf 1, Mônaco 2, Modelagem 3, Agility 4.

1. INTRODUCTION

The Agility Multileaf Collimator (MLC) presents specific machining characteristics. These unique features, along with small installation differences among various linear accelerators, produce dosimetric effects that are not considered by the Monaco Treatment Planning System (TPS) (Elekta AB, Stockholm, Sweden) in its calculations. However, Monaco employs an adjustable MLC model for dose calculation in treatment planning [1]. This model is based on a Transmission Probability Filter (TPF) and contains parameters that can be modified by the user.

To achieve accurate dose calculations, it is necessary to adjust the parameters of the Agility MLC model implemented in the TPS. The adjustment of these MLC model parameters can be determined using vendor-designed test fields, known as the ExpressQA package [2], [3]. These test fields serve as tools to determine parameters such as MLC extension, dimension, and position within the TPS. The adjustments made using these tests constitute the post-modeling process, which aids in accurate MLC characterization.

With these fine adjustments, after post-modeling, the model implemented in the TPS can represent the machine's MLC with submillimetric precision, eliminating the need for mechanical corrections that would be impossible to perform physically.

Although Monaco is widely used in clinical practice, there is still a lack of comprehensive literature rich in detailed information, which makes the work of the medical physicist more challenging. Therefore, the objectives of this study were to analyze the geometric components of the Agility MLC and to propose an efficient methodology for post-modeling or fine-tuning these components so that, after adjustment, the dose calculated in the TPS is as close as possible to the dose delivered by the linear accelerator.

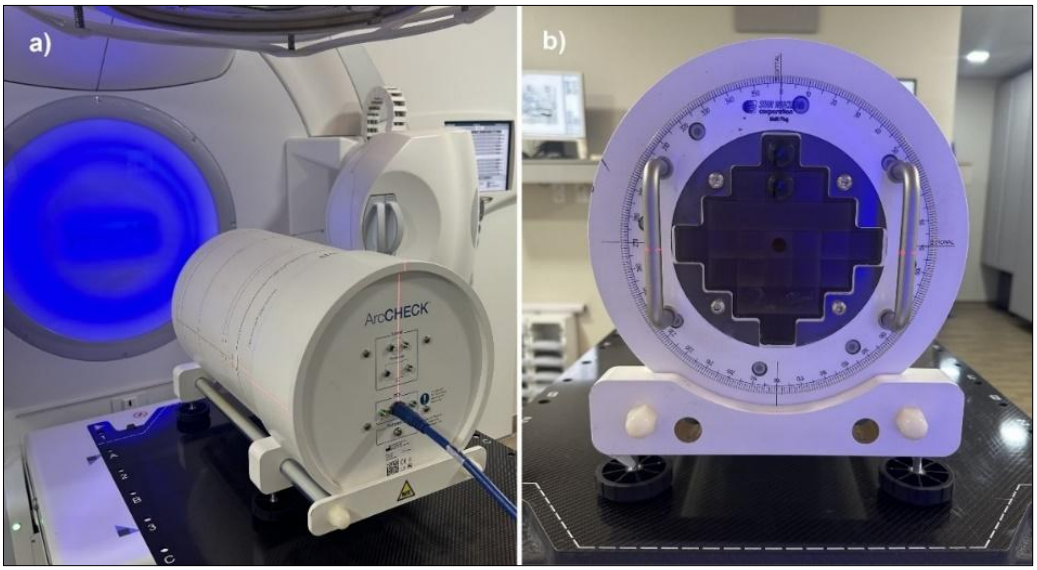
2. MATERIALS AND METHODS

For the development of this study, radiation-generating equipment (Versa HD), radiation measurement devices (ionization chamber and ArcCHECK), analysis software (SNC Patient), calculation software (Monaco), and management software (Mosaiq) were used.

All dosimetric evaluations of the geometric components of the multileaf collimator were performed on a Versa HD linear accelerator (Elekta AB, Stockholm, Sweden) equipped with the Agility™ MLC. The MLC consists of 160 tungsten leaves, each 0.5 cm wide, with a leaf speed of 6.5 cm/s, and delivers 6 MV photon beams.

For the post-modeling process, it is recommended to use the same measurement device that will be employed in routine clinical patient-specific quality assurance (PSQA), even if such devices present certain limitations and may not accurately represent the actual MLC dosimetry [4]. Therefore, the entire dosimetric study of the geometric components of the multileaf collimator leaves was conducted using the ArcCHECK quality assurance phantom (Sun Nuclear Corporation, Melbourne, FL, USA), as shown in Figure 1.

Figure 1: ArcCheck is a 4D measurement matrix that allows the identification of errors in the rotational delivery of the dose with the insertion of a solid acrylic accessory equivalent to water (MultiPlug). a) frontal view of the ArcCheck positioned on the base and b) view of the cranial portion of the phantom with MultiPlug inserted into its cavity.



The Monaco TPS was used for all dose calculations. This treatment planning system requires the user to define statistical uncertainty and voxel size to be used in the calculations. All plans were calculated using the Volumetric Modulated Arc Therapy (VMAT) technique, for which the available calculation algorithm is Monte Carlo. The statistical uncertainty and voxel size parameters were fixed at 1% and 2 mm, respectively, for all calculations. The literature reports that smaller voxel sizes and lower uncertainty values do not produce discernible differences in dose distributions but significantly increase calculation time [2].

The eight test plans that comprise the ExpressQAPlan were imported into the TPS using an ArcCHECK CT dataset. The plans were calculated and transferred to the linear accelerator through the Mosaiq Management System (v. 2.84; IMPAC Medical Systems, Inc., Maryland Heights, MO). The DICOM-formatted plan and calculated dose files were then transferred to the SNC Patient™ data analysis software.

The test fields included in the ExpressQA plan are 10×10 cm², 20×20 cm², 3ABUT, 7SegA, FourL, DMLC1, HIMRT, and HDMLC, as described in Table 1.

Table 1: List of test fields comprising the "ExpressQA Plan" and their configurations.

Description	Beam Configuration	Comments
10×10	10×10 cm² field (MLC + collimator)	Verify absolute dose calibration.
20×20	20×20 cm² field (MLC + collimator)	Check beam flatness and symmetry, and verify detector response of the QA device
3ABUT	Three segments of 6×24 cm²	Evaluate the primary MLC leaf offset
7 SegA	Seven segments of 2×24 cm²	Typical *picket fence* field.
FourL	Four MLC "L"-shaped segments, 20×20 cm² collimator	Assess MLC offset, leaf transmission, and tongue-and-groove effect
DMLC1	20×20 cm² collimator, 2×20 cm² MLC sweep from −10 to +10 cm	Evaluate primary and secondary MLC leaf offset.
HIMRT	33 segments, head-and-neck IMRT plan	Assess IMRT performance.
HDMLC	33 segments, head-and-neck DMLC plan	Assess DMLC performance.

Using the data analysis software associated with the ArcCHECK device, it was possible to process and analyze the measurements, which were performed in both relative and absolute dose values. The calculated DICOM data were imported into the software, enabling gamma comparison or analysis. The gamma analysis, which compares the calculated and measured radiation doses to verify treatment delivery accuracy, was used to compare the test fields calculated by the TPS with the measurements acquired on the linear accelerator, as well as to validate newly adjusted geometric parameter values during the MLC post-modeling process.

Each institution should establish its own gamma analysis protocol for VMAT planning, defining the type of gamma evaluation and the gamma index criteria according to its specific linear accelerator and dosimeter. For all analyses—both prior to post-modeling and during fine-tuning—global and local gamma criteria of 3% dose difference and 2 mm distance-to-agreement (DTA) were applied. The dose was evaluated relative to the global maximum, with a minimum threshold set at 10% of this maximum. In all gamma analyses, the calculated field was considered the reference. These parameters were chosen because they are intended for subsequent implementation in the clinical QA routine.

All test fields were irradiated once and served as reference data for comparison with the recalculated values obtained after each submillimetric modification of a geometric parameter. Only a single irradiation on the linear accelerator was required, since its dose delivery capability remains consistent in the absence of mechanical variations. The purpose of the adjustments was to modify the geometric parameters within the TPS so that the calculated dose would correspond as closely as possible to the dose delivered by the accelerator. Each geometric parameter was adjusted individually, and after each modification, new calculations were performed for every test field to quantify the influence of each parameter on the dose distribution. According to the manufacturer, each test field has a specific function and must be evaluated within its region of interest and applicability [5].

Although the ExpressQA test measurements were performed only once, as recommended by the manufacturer, numerous sources of uncertainty may affect post-modeling results. The uncertainty assessment followed the guidelines of the International Standards Organization (ISO), as recommended by the International Atomic Energy Agency (IAEA) Technical Report Series No. 398 [6].

Therefore, for the dose measurements obtained with the linear accelerator, the following uncertainty parameters were considered: ArcCHECK positioning and calibration (estimated uncertainty of 0.600 %) [6], radiation beam calibration (estimated uncertainty of 1.400 %) [6], and ArcCHECK resolution (estimated uncertainty of 0.003 %, following the half-division rule). The phantom and connecting cables were kept in the treatment room long enough before measurements to ensure thermal equilibrium with the environment, thereby minimizing uncertainties related to ambient conditions.

As a result, the combined total uncertainty associated with the linear accelerator measurements was estimated to be approximately 2.0 %, while the uncertainty associated with the dose calculations in the TPS was set at 1.0 %, as previously mentioned. Table 2 summarizes the variables that may influence the reproducibility of the measurements and dose calculations

Table 2: Variables that may affect measurement reproducibility.

Description	Variable / Estimated Uncertainty
Physical phantom	ArcCHECK positioning and calibration (estimated 0.600 % [6])
	Resolution (estimated 0.003 %, half of the smallest reading division)
Radiation beam	Radiation beam calibration (uncertainty 1.400 % [6])
TPS planning	Mathematical dose calculation method (set to 1 % in the TPS)

3. RESULTS AND DISCUSSIONS

The protocol of the American Association of Physicists in Medicine (AAPM) – Report 85 [7] summarizes that a 5% difference between the prescribed and delivered dose can lead to drastically different outcomes, with changes of 10–20% in tumor control and 20–30% in complications in adjacent normal tissues. Accordingly, the evaluation of the ExpressQA test fields calculated with the initial TPF parameters provided by the manufacturer's modeling was highly unsatisfactory. The results for the points passing the gamma analysis (PP) indicated that the measured dose was higher than the calculated dose in all cases. Table 3 shows the gamma analysis for the ExpressQA fields using the geometric parameters from the manufacturer-provided modeling, where the percentage of points passing the gamma analysis was below 95% for most fields and, therefore, below the expected threshold for approval in patient-specific quality assurance (PSQA) analyses in clinical routine [8].

Table 3: Gamma analysis for ExpressQA fields using the geometric parameters of the modeling provided by the manufacturer.

	Express QA							
Fields	10X10	20X20	3ABUT	7SegA	DMLCi	FourL	HDMLC	HIMRT
PP (± 2.0 %)	97.9	94.1	94.5	84.1	88.3	91.6	95.8	94.9

Several post-modeling sets were then performed for the 6 MV beam. For each of these sets, multiple gamma analyses were carried out, as each parameter was modified individually. For each adjusted parameter, more than one attempt was often necessary, requiring iterative forward and backward adjustments. After each modification, a gamma analysis of all test fields was conducted. Table 4 presents the best gamma analysis results obtained for each geometric parameter (GP) during the first post-modeling. In this table, each gamma analysis reflects the cumulative effect of the currently modified parameter combined with the effect of the previously adjusted parameter(s). Therefore, the gamma analysis result following the change in leaf transmission represents the outcome of the first post-modeling

Table 4: Evolution of the gamma analysis for ExpressQA fields using the geometric parameters of the modeling provided by the manufacturer (default) and after every new change to the individual geometric parameters (PG) in first post modeling. The result of the gamma analysis after the change in leaf transmission is the result for first post modeling.

Description	Default	Off set (mm)	Leaf Tip Leakage	Leaf Groov Width (mm)	Transmission
PG	**-**	**0,1**	**1,05**	**0,2**	**0,07**
10 x 10	97.9 ±2.0%	99.6 ±2.0%	99.6 ±2.0%	99.6 ±2.0%	98.8 ±2.0%
20 x 20	94.1 ±2.0%	91.7 ±2.0%	93.3 ±2.0%	93.8 ±2.0%	92.0 ±2.0%
3ABUT	94.5 ±2.0%	97.3 ±2.0%	96.8 ±2.0%	96.5 ±2.0%	98.0 ±2.0%
7SegA	84.1 ±2.0%	98.5 ±2.0%	87.8 ±2.0%	88.5 ±2,0%	98,8 ±2.0%
DMLCi	88.3 ±2.0%	98.3 ±2.0%	91.6 ±2.0%	91.1 ±2.0%	99.2 ±2.0%
FourL	91.6 ±2.0%	96.1 ±2.0%	97.0 ±2.0%	96.6 ±2.0%	95.2 ±2.0%
HDMLC	95.8 ±2.0%	97.7 ±2.0%	98.0 ±2.0%	99.1 ±2.0%	98.9 ±2.0%
HIMRT	94.9 ±2.0%	95.8 ±2.0%	95.5 ±2.0%	97.7 ±2.0%	98.0 ±2.0%

After the first post-modeling, to further validate the process, all TG-119 test plans were recalculated. Results showing variations greater than 5%, and therefore below 95% of points passing were obtained. This demonstrated that a seemingly successful post-modeling outcome for the ExpressQA tests may not yield satisfactory results for clinical cases. The results for the TG-119 tests after the first post-modeling are listed in Table 5.

Table 5: Gamma analysis results for the TG-119 tests after the first post-modeling, using evaluation criteria of 3 % dose difference with 3 mm distance and 3 % dose difference with 2 mm distance.

Description	PP 3 % / 3 mm (± 2.0 %)	PG 3 % / 2 mm (± 2.0 %)
Cshape (easy)	85.5	79.4
Cshape (hard)	82.2	75.9
HN	80.8	70.5
Prostate	98.7	95.8
Multi Targuet	99.3	97.6

Based on the thorough investigation of the geometric parameters, a more careful post-modeling process was initiated. Unlike in patient-specific quality assurance (PSQA) cases, where visual evaluation is important but the global percentage of passing points is the key metric, post-modeling must be analyzed in specific regions of interest for each field; therefore, visual inspection is essential. In all gamma analysis fluence figures, blue points indicate that the measured dose is below the calculated dose, red points indicate that the measured dose is above the calculated dose, and yellow points in the dose profiles represent agreement between measured and calculated doses within the established gamma criteria.

The TPF parameter with the greatest relative impact on dose levels for the MLC test fields was Leaf Transmission, where small variations in values cause substantial effects on dose delivery. When adjusting this parameter from its minimum (0.0001) to maximum (1.0000), dose differences of nearly 20% can be observed. To investigate Leaf Transmission, the FourL field was measured, and the "L"-shaped dose fluence shown in Figures 3A and 4A was obtained to evaluate the field along the X and Y axes, respectively. In the vertical portion of the "L," the Offset plus transmission was assessed, whereas in the horizontal portion, the Leaf Groove Width plus transmission was evaluated. The green line above the fluences represents the region from which the profiles were collected, serving as an example of evaluation.

For the FourL field, horizontal evaluation (green line along the X-axis) corresponds to the Offset plus transmission parameter (Figure 2), while vertical evaluation (Y-axis, Figure 3) corresponds to Leaf Groove Width and transmission. In Figure 2, the yellow-highlighted region in the dose profile corresponds to the Offset, and in Figure 3, the yellow-highlighted region corresponds to the Leaf Groove Width. The blue-highlighted regions in both Figures 2 and 3 correspond to the leaf transmission regions, which were the TPF parameters evaluated using this test field.

By measuring the FourL field and analyzing all possible profiles for this gamma analysis, a need to increase the dose in the region of interest was identified. Although all

points within the region of interest met the evaluation criteria, there was a slight trend of measured dose exceeding the calculated dose. To address this, the TPF value was increased. Following this adjustment, improved agreement between calculated and delivered doses was also observed in the profiles for the 3ABUT, 7SegA, and particularly DMLC1 fields.

In Figures 2 to 8, those identified in 'A' present the measurements before adjustments and those identified in 'B' show the results after post-modeling. The images in "a)" show the dose fluences and in "b)" an example of the dose profiles obtained from the fluence. There was no need to remove the profile from the same fluence point before and after the adjustments, since the comparison between the fluences already provides clear information about the dose agreement for the evaluation criteria used for all profile possibilities.

Figure 2: Gamma analysis for the FourL field calculated with the geometric modeling parameters provided by the manufacturer (A) and after post modeling (B). In a) example of dose fluency measured on the X axis (green line), where the dose profile from figure b) was removed and this highlights the discrepancy between the measured dose (dotted curve) and the calculated dose (solid curve) for Offset (yellow) and Transmission (blue) regions.

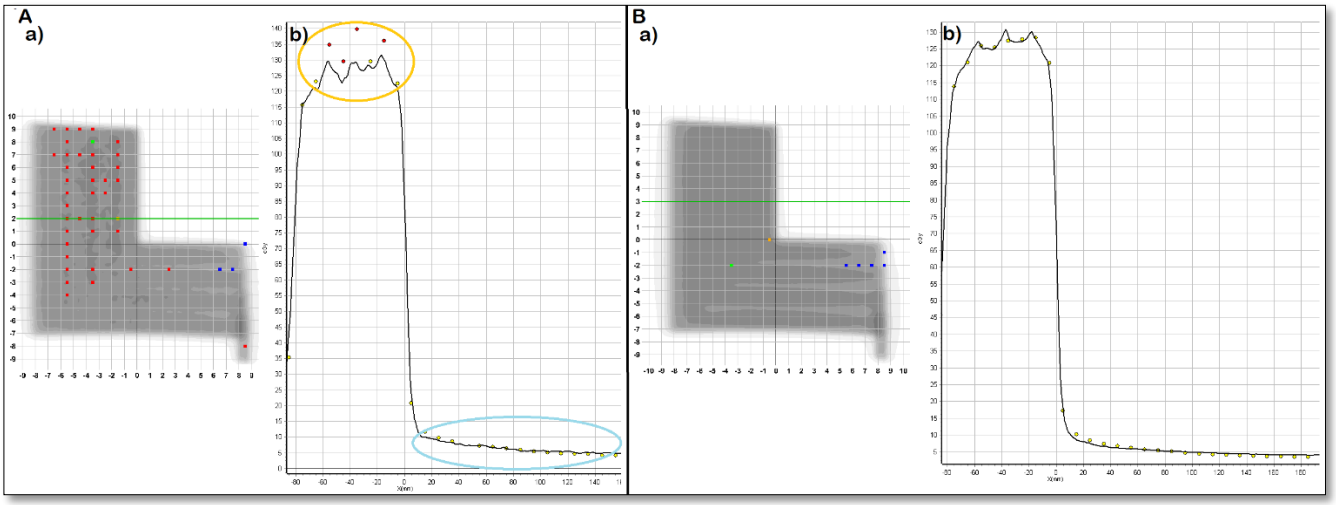
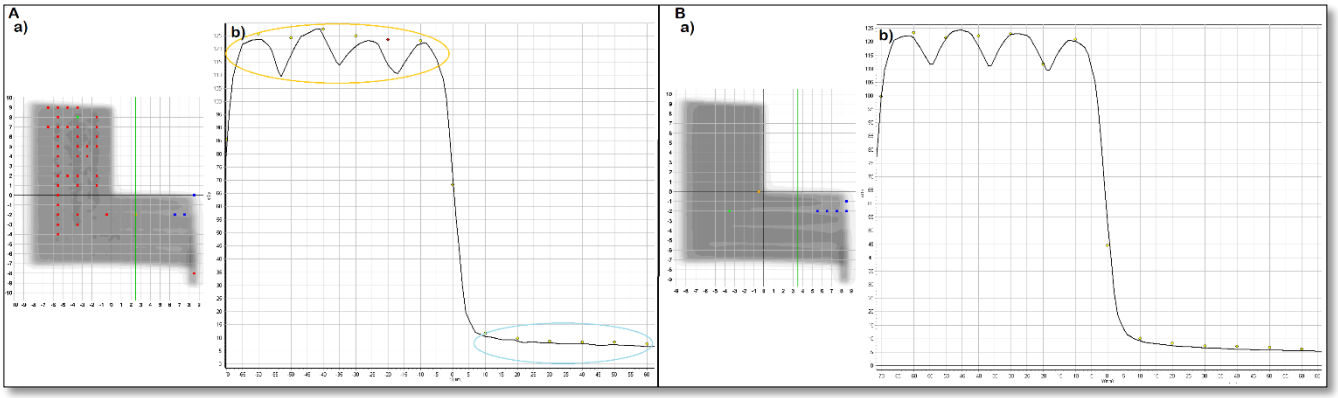
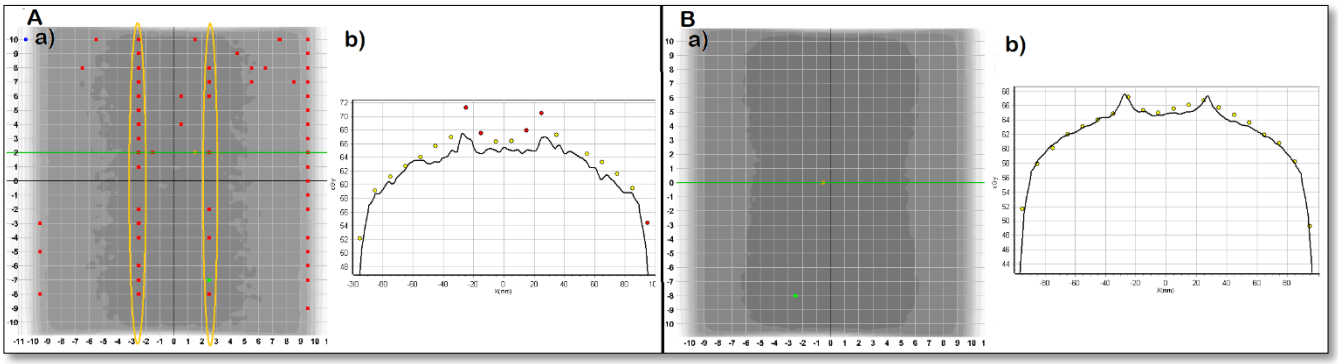


Figure 3: Gamma analysis for the FourL field calculated with the geometric modeling parameters provided by the manufacturer (A) and after post modeling (B). In a) example of dose fluency measured on the Y axis (green line), where the dose profile from figure b) was removed and this highlights the discrepancy between the measured dose (dotted curve) and calculated dose (continue curve) for Leaf Groove (yellow) and Transmission (blue) regions.



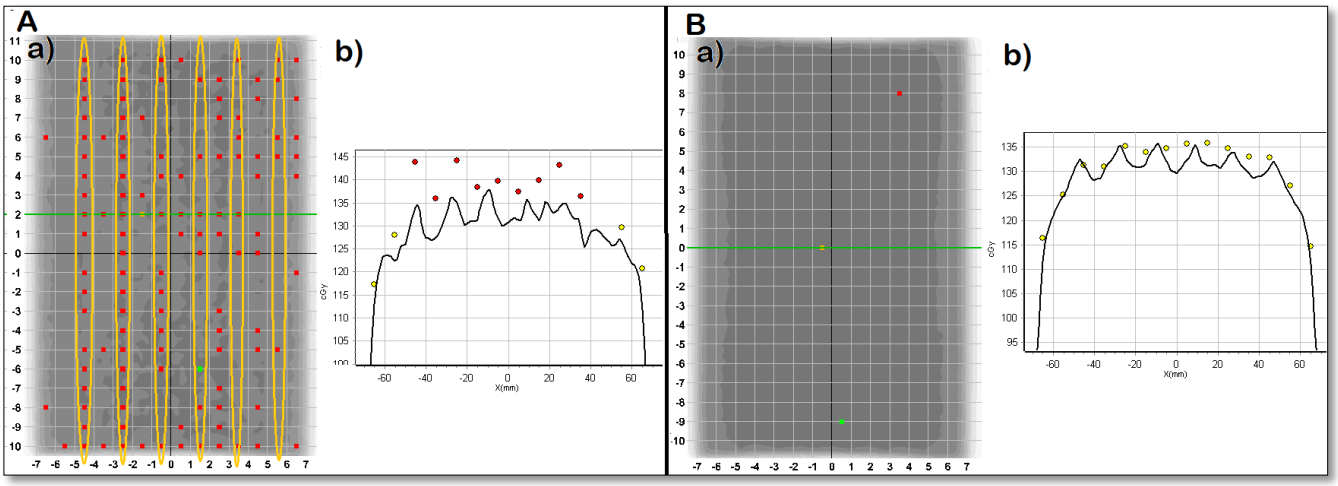
The 3ABUT field contains a region of interest for post-modeling in Offset adjustment. However, after adjusting the leaf transmission, it was observed that the entire dose profile, although the failures remained within the Offset region, shifted toward the planned distribution, approaching closer in terms of absolute dose. Similarly, in the FourL field evaluated along the X-axis (Offset region), the same behavior was observed following the TPF adjustment.

Figure 4: Gamma analysis for the 3ABUT field calculated with the geometric modeling parameters provided by the manufacturer (A) and after post modeling (B). In a) example of dose fluency measured on the X axis (green line), where the dose profile from figure b) was removed and this highlights the discrepancy between the measured (curve dotted) and calculated doses (continue curve).



As shown in the profile in Figure 4, the measured dose obtained prior to post-modeling was higher than the calculated dose across the entire 3ABUT field profile. With the 3ABUT field already improved after leaf transmission adjustment, the Offset was then investigated by focusing not on the entire profile but specifically on the peak regions of 3ABUT, highlighted in yellow. Negative Offset values decrease the calculated dose in this region (valleys), whereas positive values increase the calculated dose (peaks). Therefore, the Offset value was increased so that the calculated dose in this region (dashed line) would rise to achieve agreement with the measured dose (solid line).

Figure 5: Gamma analysis for the 7SegA field calculated with the geometric modeling parameters provided by the manufacturer (A) and after post modeling (B). In a) example of dose fluency measured on the X axis (green line), where the dose profile from figure b) was removed and this highlights the discrepancy between the measured (curve dotted) and calculated dose (continue curve).

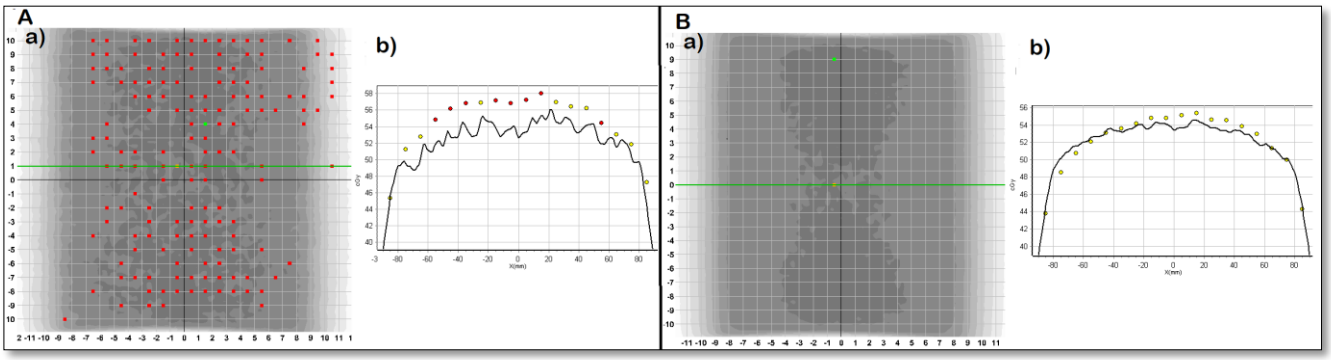


The 7SegA field complements 3ABUT in the investigation of the TPF Offset, differing only in having seven segments instead of three. The region of interest in this case is also the junctions between segments and their connections. In Figure 5, the gamma analysis and dose profile for 7SegA measured with the manufacturer-provided modeling are shown, exhibiting the same behavior observed with the 3ABUT field and confirming the need to increase the Offset parameter value.

The DMLC1 field, being a sliding window technique, is highly sensitive and strongly affected by any changes to geometric parameters. Just as altering the leaf transmission

impacted the beam profile for this field, the Offset adjustment could also be investigated using DMLC1, in parallel with the 3ABUT and 7SegA fields. The results for the measurement of this field prior to post-modeling are shown in Figure 6, where, as observed, failure points indicating higher dose (red points), like those in the 3ABUT and 7SegA fields, were present.

Figure 6: Gamma analysis for the DMLC1 field calculated with the geometric modeling parameters provided by the manufacturer (A) and after post modeling (B). In a) example of dose fluency measured on the X axis (green line), where the dose profile from figure b) was removed and this highlights the discrepancy between the measured (curve dotted) and calculated doses (continue curve).



The geometric parameter Leaf Tip Leakage has a significant impact on the test fields, especially DMLC1 and 7SegA. This can be observed by varying the values between the minimum (1.00) and maximum (1.25) possible values, where the dose variation between these extremes can reach up to 10 % [9]. In some analyses, this parameter was adjusted during post-modeling and was observed to complement the leaf transmission, contributing to the same direction. By decreasing the Leaf Tip Leakage value, the calculation allows more dose to be delivered through the leaf tips, and in dynamic fields with many segments, this geometric parameter effectively increases the overall delivered dose. However, lowering its value requires a compensatory increase in the Offset, indicating the need for a balance between these two parameters, considering both Offset and agreement of the globally delivered absolute dose.

The HDMLC and HIMRT fields with manufacturer-provided modeling are shown in Figures 7 and 8. These fields served as examples of clinical cases where a global gamma pass rate of approximately 95 % was desired. Results consistent with this requirement were obtained, as observed in Figures 7 and 8, with 95.8 % and 94.9 % pass rates for HDMLC and HIMRT, respectively. However, when extending the validation of the manufacturer-provided modeling to the TG-119 tests, unsatisfactory results for clinical routine expectations were obtained. This indicates that these two isolated fields sample only a limited range of leaf movements and dose distribution and cannot be used exclusively for validation. A small number of test fields may mask difficulties that arise in more complex cases.

Figure 7: Gamma analysis for the HDMLC field calculated with the geometric modeling parameters provided by the manufacturer (A) and after post modeling (B). In a) example of dose fluency measured on the X axis (green line), where the dose profile from figure b) was removed and this highlights the discrepancy between the measured (curve dotted) and calculated doses (continue curve).

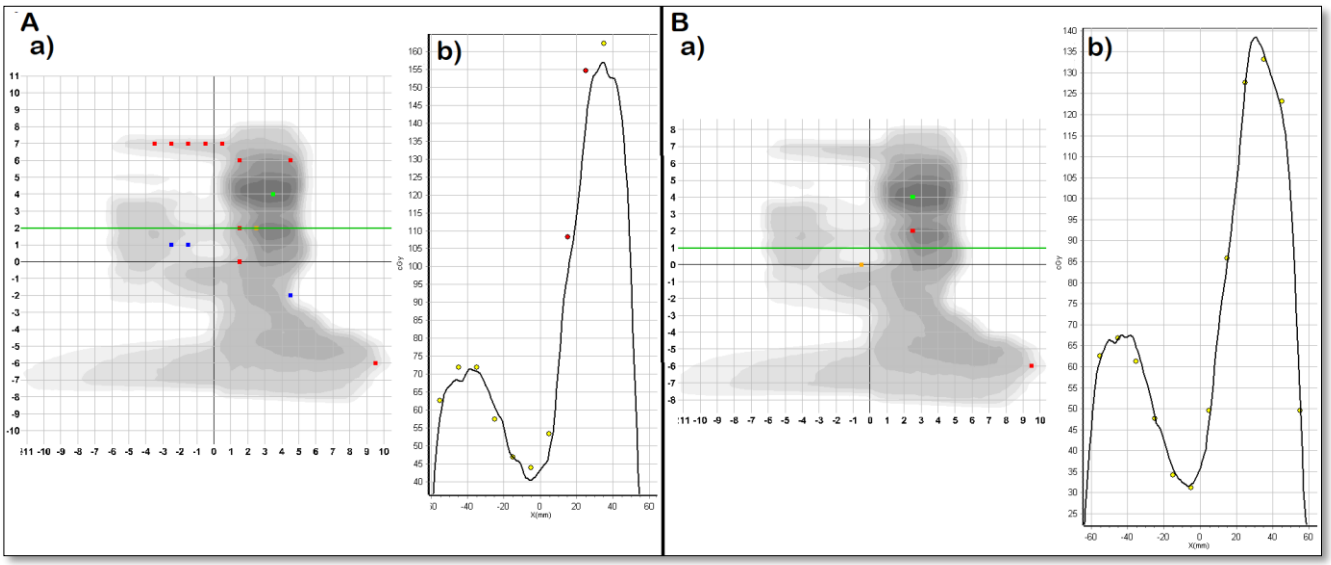
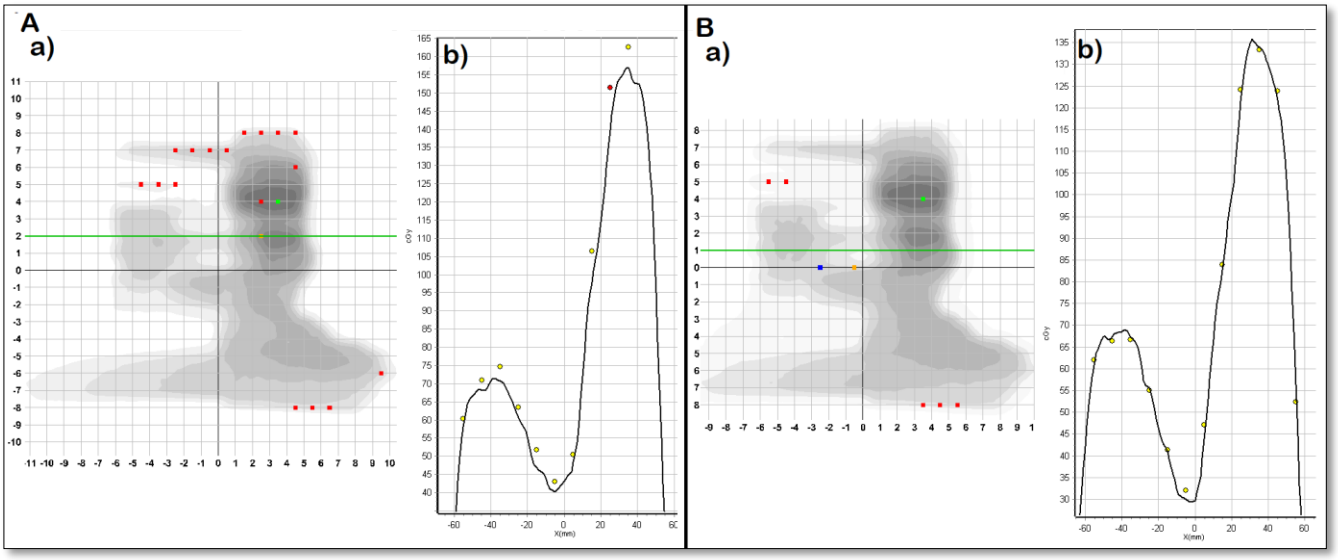


Figure 8: Gamma analysis for the HIMRT field calculated with the geometric modeling parameters provided by the manufacturer (A) and after post modeling (B). In a) example of dose fluency measured on the X axis (green line), where the dose profile from figure b) was removed and this highlights the discrepancy between the measured (continue curve).



Thus, while HDMLC and HIMRT fields met the >95 % gamma pass rate requirement before and after post-modeling, their limited sampling of leaf motion and dose distribution means they cannot serve as the sole basis for validation.

Table 6 below shows the final TPF values used for post-modeling, and Table 7 presents the percentage of points passing the gamma analysis for the ExpressQA test fields after the final post-modeling for the 6 MV beam.

Table 6: Result found for the values of the geometric parameters after the post-modeling.

Description	Default	Adjusted
Transmission	0.0030	0.0043
Off-Set (mm)	0.0000	0.0500
Leaf Tip Leakage	1.1000	1.1300

Table 7: Gamma analysis for ExpressQA fields using the geometric parameters of the modeling provided by the manufacturer.

	Express QA							
Fields	10X10	20X20	3ABUT	7SegA	DMLCi	FourL	HDMLC	HIMRT
PP (± 2.0%)	100.0	95.6	97.0	100.0	99.3	100.0	99.4	99.3

4. CONCLUSIONS

According to the objectives, an efficient post-modeling methodology was established based on a theoretical understanding of the influence of each geometric parameter on the position, movement, and extension of the Agility MLC, as well as their respective impacts on dose delivery.

The study demonstrated that it is possible to achieve similar gamma passing results for the ExpressQA test fields using different combinations of geometric parameters, since some parameters exert comparable effects on the ExpressQA test fields. Moreover, optimal results in the ExpressQA tests may induce unrealistic outcomes in clinical fields, primarily due to the spatial resolution limitations of the ArcCheck used for measurements in high-dose gradient regions, such as in modulated fields.

The established post-modeling approach allowed for a better approximation of the MLC characterization in the TPS to the actual MLC installation on the linear accelerator. Consequently, the doses calculated by the TPS more closely matched the measured doses on the linear accelerator. A significant increase in the percentage of points passing the gamma analysis was observed after the adjustments.

After post-modeling, the gamma passing rate increased by approximately 15% for the 7SegA test field. The DMLC1 field, being highly sensitive to TPF parameters, can serve as a proxy for the results expected in treatments using the VMAT technique. The agreement between the dose calculated by the TPS and measured on the linear accelerator for this field increased by over 10% in terms of gamma passing points after post-modeling.

The HIMRT and HDMLC fields, which already exhibited gamma passing rates close to 95% prior to post-modeling—thus complying with the recommended dose variation of up to 5% for optimal tumor control—also showed increased passing rates after post-modeling. These results demonstrate that post-modeling enables a better characterization of

the Agility MLC in the TPS, even for linear accelerators that already exhibit good gamma passing agreement.

ACKNOWLEDGMENT

The authors acknowledge the CLINRADI for the space and equipment shared during the study of this research.

FUNDING

The authors acknowledge the partial financial support of the CAPES, FAPESP, CNPq, CNEN and PCI (Institutional Training Program).

CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

Interview transcripts and qualitative data are not publicly available due to confidentiality commitments made to research participants. Aggregated data supporting the findings are available from the corresponding author upon reasonable request and subject to participant privacy protections.

REFERENCES

[1] Lee, J.; Choi, K.; Hong, S.; et al. Effects of static dosimetric leaf gap on MLC-based small-beam dose distribution for intensity-modulated radiosurgery. **Journal of Applied Clinical Medical Physics**, Hanguk-AB, vol. 8, n. 4, p. 54-64, 2007.

[2] Snyder, M.; Halford, R.; Knill, C.; et al. Modeling the Agility MLC in the Monaco treatment planning system. **Journal of Applied Clinical Medical Physics**, Detroit-USA, v.17, n. 3, p.190-202, 2016.

[3] Roche, M.; Crane, R.; Powers, M. and Crabtree, T. Agility MLC Transmission Optimization in the Monaco Treatment Planning System. **Journal of Applied Clinical Medical Physics**, Quuenslândia-AU, v.19, n. 5, p.473-482, 2018.

[4] Elekta Medical Systems Inc. **Monaco Post Modeling Adjustment of MLC Parameters**. Document ID: LRMMON0003. 2013.

[5] Katlapa, A. Post-modeling Agility MLC model in Monaco Treatment Planning System Using Different 2D Detectors. **Master's Degree Program in Medical Physics**, Finland, 2023.

[6] Elekta Medical Systems Inc., Monaco Technical Reference Post Modeling Adjustment of MLC Parameters. 2012.

[7] Kry, S. F.; Molineau, A.; Kerns, J. R.; et.al. Institutional Patient-Specific IMRT QA does not Predict Unacceptable Plan Delivery. **International Journal of Radiation Oncology, Biology, Physics.** Texas-USA, v. 90, n. 5, p. 1195-201, 2014.

[8] Khalid, E. O.; Mustapha, Z.; Yassine, H.; Raoui, Y. and Pandey, V. P. Validation of monaco TPS for an ELEKTA synergy MLCi2: Using gamma index for eElekta full package beams," Materials Today: Proceedings. **Elsevier**. Oujda- Morocco, vol. 45, p. 7685-7689, 2021.

[9] Muñoz, L., McLoone, P., Metcalfe, P., Rosenfeld, A. B., & Biasi, G. Evaluating Monaco 6.2.2 in complex radiotherapy across matched LINACs: improved MLC modelling and dose accuracy with virtual source model 2.0. **Physical and Engineering Sciences in Medicine**. 2025.

[10] Hernandez, V., Angerud, A., Bogaert, E., Hussein, M., Lemire, M., García-Miguel, J., Saez, J. Challenges in Modeling the Agility Multileaf Collimator in Treatment Planning Systems and Current Needs for Improvement. **Medical Physics**, vol. 49, n. 12, p. 7404-7416, Dec. 2022.

[11] Elekta Medical Systems Inc. **Monaco Physics Training MLC Geometry Parameters.** Power Point. Document ID: 20211129. 2021.

[12] Wang, C.; Zhu, X.; Hong, J. C.; Zheng, D. Special Collection on Artificial Intelligence Based Treatment Planning for Radiotherapy–Review Artificial Intelligence in Radiotherapy Treatment Planning: Present and future. **Technology in Cancer Research & Treatment,** vol. 18, p. 1-11, sept. 8, 2019.

[13] Mzenda, B.; Mugabe, K. V.; Sims, R.; Godwin, G.; Loria, D. Modeling and dosimetric performance evaluation of the Ray Station treatment planning system. **Journal of Applied Clinical Medical Physics.** vol. 8; 15, n. 5, 08 Sept. 2014. DOI: 10.1120/jacmp.v15i5.4787.

LICENSE