2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Standardizing radiotherapy treatment planning: the role of plan complexity

Victor Hernandez[1]; Íñigo Lara-Aristimuño[1]; Ruben Abella[1]; Jordi Saez[2]
[1]Hospital Universitari Sant Joan de Reus, Spain, [2]Hospital Clínic de Barcelona, Spain

ABSTRACT

Purpose: Most radiotherapy procedures follow standardized protocols to ensure quality. However, treatment planning and optimization still remain insufficiently standardized. This study evaluates the potential of incorporating plan complexity controls within class solution methodologies for reducing variability and improving the standardization of treatment planning across anatomical sites and delivery platforms.

Methods: VMAT plans were generated in Eclipse for lung stereotactic body radiotherapy (SBRT), stereotactic radiosurgery (SRS), and prostate with lymph node involvement. Plans were created for TrueBeam (all sites) and Halcyon (prostate). A three-stage optimization strategy was applied: (i) Off (no complexity control), (ii) ASC (Aperture Shape Controller set to Moderate), and (iii) MU (ASC plus monitor-unit limitation). Plans were required to remain dosimetrically equivalent using site-specific clinical acceptance criteria and were compared to assess variability and the impact of complexity control. Plan parameters and complexity were quantified using monitor units per cGy (MU/cGy), Plan Aperture Modulation (PAM), Plan Irregularity (PI), and Average Leaf Pair Opening (ALPO). Mean values, standard deviations, and relative differences were analyzed. ANOVA testing was applied to assess statistical significance

Results: ASC alone produced modest metric improvements and limited variability reduction, with negligible impact on Halcyon. In contrast, MU limitation significantly improved all metrics for all sites/platforms. Reductions of ~35–50% in MU/cGy and ~60–90% in PAM were observed, with decreases in PI and increases in ALPO, consistent with simpler and more regular beam apertures. Inter-plan variability decreased consistently at the MU stage for all metrics and sites; all MU-stage changes were significant ($p < 0.01$), indicating plan aperture control as the dominant driver of variability reduction and harmonization.

Conclusion: Complexity management integrated into class solutions significantly reduced treatment-plan variability within treatment sites and across treatment platforms, while preserving dosimetric equivalence. Complexity metrics provide a quantitative framework for standardizing and harmonizing radiotherapy treatment planning.

CONTACT

Victor Hernandez
Hospital Sant Joan de Reus, Catalonia, Spain

Victor.Hernandez@salutsantjoan.cat
Victor.Hernandez@urv.cat

INTRODUCTION

Modern radiotherapy workflows are highly protocolized for simulation, delivery, imaging and quality assurance. However, volumetric modulated arc therapy (VMAT) planning still allows a wide range of clinically acceptable solutions, because plan evaluation is commonly dominated by dosimetric objectives alone.

As a result, plans that meet the same dose constraints may differ substantially in modulation, aperture geometry, monitor units and expected deliverability.

The concept of class solutions provides a framework for reducing this variability, but its definition should extend beyond initial beam arrangements, optimisation templates and dose constraints. It should also include objective indicators of plan complexity, robustness and deliverability.

This study assessed whether incorporating complexity control into the planning process could generate simpler and more homogeneous treatment plans while preserving clinical dosimetric acceptability.

METHODS AND MATERIALS

A systematic optimisation workflow was applied to lung stereotactic body radiotherapy and stereotactic radiosurgery. All plans were generated in Eclipse for a TrueBeam linear accelerator. For each case, three dosimetrically equivalent plans were produced:

- Off: optimisation without complexity control.
- ASC: optimisation with the Aperture Shape Controller activated in Moderate mode [1].
- MU: optimisation with Aperture Shape Controller plus progressive monitor unit limitation.

Clinical acceptability was maintained according to predefined dosimetric criteria for each anatomical site. Many plan complexity metrics were evaluated [2], but for conciseness only the following four metrics were included in the present study:

- MU/cGy: Ratio of the Monitor Units to the prescribed dose, often used as a surrogate for plan modulation.
- PAM: Plan Aperture Modulation, a novel metric quantifying the modulation of beam apertures [3].
- ALPO: Average Leaf Pair Opening, which indicates the average opening between opposed leaves [4].
- PI: Plan Irregularity, which quantifies the non-circularity of the beam apertures [5].

Metrics were calculated using a MATLAB-based PlanAnalyzer tool and an Eclipse Scripting Application Programming Interface (ESAPI) script.

Statistical analysis was performed with repeated-measures methods, including normality testing, repeated-measures analysis of variance or Friedman testing, and appropriate post hoc comparisons.

RESULTS

The progressive introduction of complexity controls showed a consistent shift towards simpler and less variable treatment plans. The Aperture Shape Controller mainly affected local aperture geometry, with a clearer effect on aperture regularity, whereas monitor unit limitation produced the dominant reduction in global modulation and inter-plan variability. In stereotactic plans MU control had a stronger impact than ASC alone, with all metrics progressively improving and the most pronounced effect observed in the final MU-controlled stage.

When both mechanisms were combined, complexity metrics converged towards narrower and more stable ranges, indicating a transition from conventional optimization to a more controlled planning process. Figures 1 and 2 illustrate this effect, showing reduced modulation, more regular aperture geometry, and lower dispersion between plans. Overall, these findings provide direct evidence that complexity management is an effective and practical extension of class solution strategies for stereotactic planning.

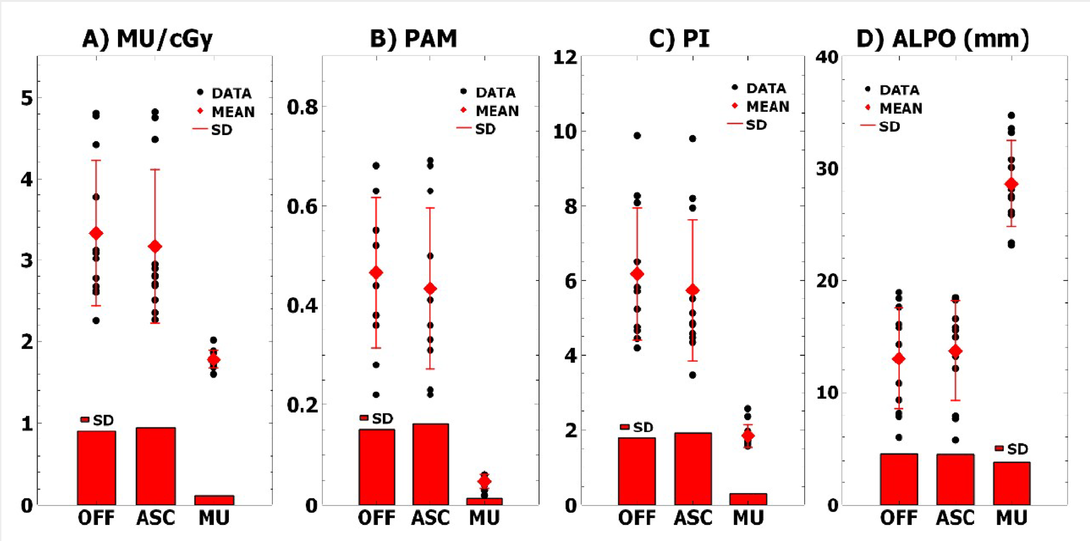

Figure 1. Complexity metrics for the lung SBRT as a function of the complexity control (Off, ASC, MU). Black dots represent the individual values for each case, red rhomboid symbols indicate the mean value at each stage, and the red whiskers represent the standard deviation. The thick lower bars illustrate the progression of the standard deviation at each step. A) Monitor units per cGy (MU/cGy). B) Plan Aperture Modulation (PAM). C) Plan Irregularity (PI). D) Average Leaf Pair Opening (ALPO).

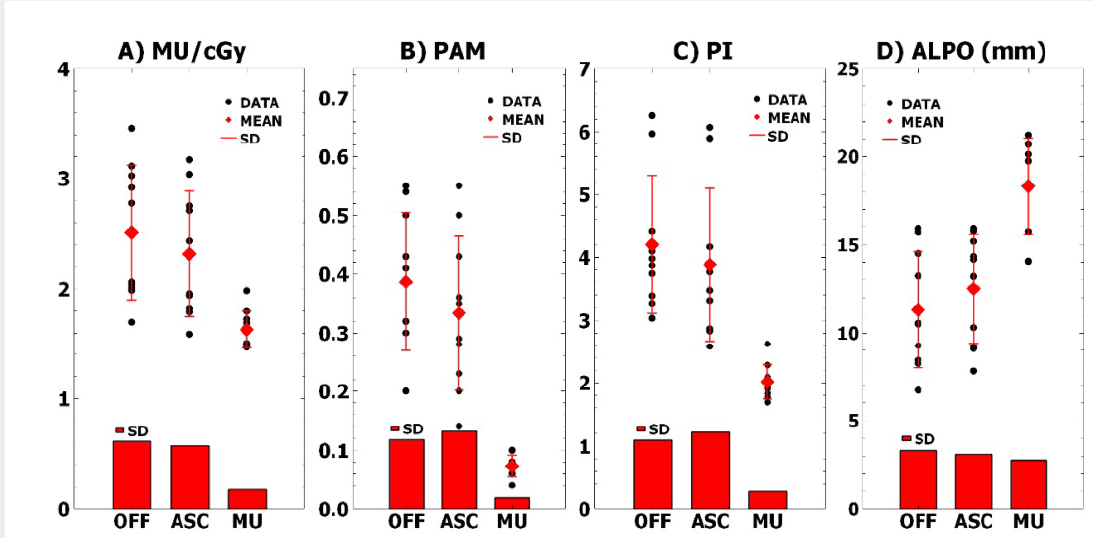

Figure 2. Complexity metrics for stereotactic plans with various complexity controls (Off, ASC, MU). Black dots represent the individual values for each case, red rhomboid symbols indicate the mean value at each stage, and the red whiskers represent the standard deviation. The thick lower bars illustrate the progression of the standard deviation at each step. A) Monitor units per cGy (MU/cGy). B) Plan Aperture Modulation (PAM). C) Plan Irregularity (PI). D) Average Leaf Pair Opening (ALPO).

DISCUSSION

The results indicate that complexity control can reduce unnecessary modulation while maintaining dosimetric equivalence. Aperture Shape Controller slightly reduced aperture irregularity, but its effect in stereotactic plans was limited due to its lower impact for small target volumes. In contrast, monitor unit control consistently reduced complexity and dispersion across the evaluated conditions, suggesting that it should be prioritised when defining robust and reproducible planning workflows for stereotactic treatments.

The observed reduction in variability supports the use of complexity metrics as quantitative descriptors of class solutions. Establishing pathology-, technique- and machine-specific reference values could guide optimisation, facilitate plan evaluation, identify outlier plans requiring additional verification, and improve consistency between planners and institutions.

This approach may also support more selective and risk-based pretreatment quality assurance.

CONCLUSIONS

- ✓ Complexity metrics provide clinically relevant information that is not captured by dosimetric indices alone. Their integration into treatment planning enables the generation of simpler, more robust and more standardized treatment plans.
- ✓ Monitor unit limitation combined with aperture-shape control reduced plan complexity and variability while preserving dosimetric acceptability.
- ✓ Implementation of complexity-based class solutions may improve planning, optimisation, delivery, verification and inter-institutional harmonization, representing a natural progression towards more systematic radiotherapy workflows.

REFERENCES

1. Scaggion A, Fusella M, Agnello G, et al. Limiting treatment plan complexity by applying a novel commercial tool. J Appl Clin Med Phys 2020;21:27–34. https://doi.org/10.1002/acm2.12908.
2. Hernandez V, Saez J, Pasler M, et al. Comparison of complexity metrics for multi-institutional evaluations of treatment plans in radiotherapy. Phys Imaging Radiat Oncol 2018;5:37–43. https://doi.org/10.1016/j.phro.2018.02.002.
3. Hernandez V, Lara-Aristimuño I, Abella R, Saez J. Quantification of the aperture modulation in radiotherapy treatment plans. Med Phys. 2025 Dec;52(12):e70144. https://doi.org/10.1002/mp.70144
4. Zygmanski P, Kung JH. Method of identifying dynamic multileaf collimator irradiation that is highly sensitive to a systematic MLC calibration error. Med Phys 2001;28:2220–6. https://doi.org/10.1118/1.1408284.
5. Du W, Cho SH, Zhang X, et al. Quantification of beam complexity in intensity-modulated radiation therapy treatment plans. Med Phys 2014;41:021716. https://doi.org/10.1118/1.4861821.

© Poster Template by Genigraphics® 1.800.790.4001 www.genigraphics.com