Patient-Specific Quality Assurance in Radiotherapy: Prediction with Deep Hybrid Learning for VMAT plans on Rapid Arc and IMRT plans on Halcyon machines

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Introduction

Volumetric Intensity Modulated Arc Therapy (VMAT)

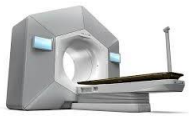
- Modulation of beam fluence during a rotation (or arc) of the accelerator arm in order to deliver a tumoricidal dose while preserving healthy tissue
- The multileaf collimators (MLC) must geometrically conform to the dynamic treatment volume while the tumor is being irradiated making arc therapy treatment more complex than conventional treatments

RapidArc Machine (VMAT)

Intensity Modulated Radiation Therapy (IMRT)

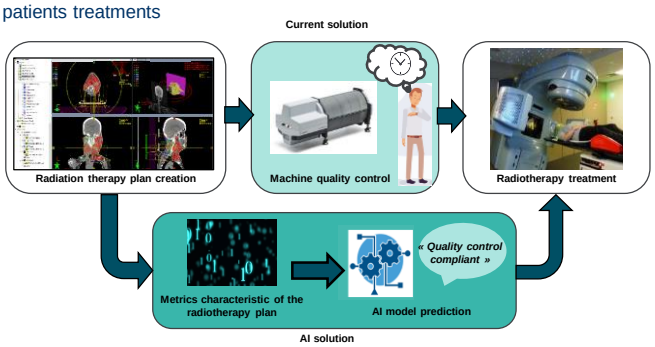
- IMRT have significantly improved target compliance while sparing normal tissue
- IMRT plan is very complex due to the numerous variable including the position of the MLC, speeds, gantry rotation and beam stability

Halcyon Machine (IMRT)



Objectives

The aim was to develop an innovative artificial intelligence (AI) model to predict the result of quality assurance based on complexity indices that characterise radiotherapy (RT) plans, without having to make the machine unavailable for patients treatments



Materials & Methods

VMAT

Patient cohort:

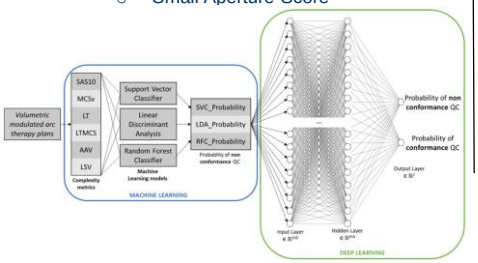
Tumor Location	Pelvis	Breast	H & N	Brain	Thorax	Digestive	Rachis	Other	Member	Skin
Number of plans	576	462	204	156	99	49	30	25	17	14

Complexity indices:

- Leaf Sequence Variability
- Aperture Area Variability
- Modulation Complexity Score
- Leaf Travel
- Combination of leaf travel and modulation complexity score
- Small Aperture Score

AI models:

Deep Hybrid Learning (DHL) is an innovative method that combines machine learning (ML) and deep learning (DL) models. This method combines the advantages of both techniques, enabling us to provide more accurate and robust solutions.



IMRT

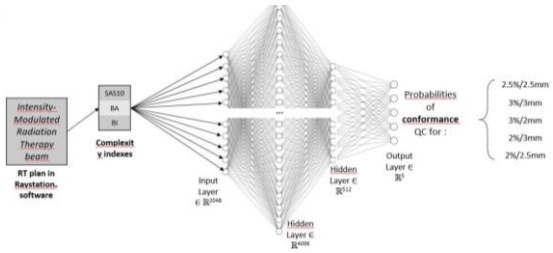
Patient cohort:

Tumor Location	Breast
Number of beams	318
Number of plans	576

Complexity indices:

- Modulation Complexity Score
- Small Aperture Score
- Beam Area
- Beam Modulation
- Beam Irregularity
- Collimator angles
- Gantry angles

AI models:



The DL model consists of a multilayer DL model to obtain probabilities of compliant and non-compliant QC for several dose difference/distance to agreement

Results

VMAT

AI models had to be adapted regarding the tumor location which involve more or less complex RT dosimetry plans. DHL models presented very accurate results. The DHL model for breast cancer reduced the number of FP from 9 with ML to 0, increasing the specificity to 97.7%. ML models were sufficient for less complex RT dosimetry plans (Brain and Thorax tumor location).

Tumor location	AUC	Sensitivity	Specificity	TP	TN	FP	FN	Architecture
All	0.989	0.99	0.98	0.91	0.08	0.0012	0.0061	DHL
Pelvis	0.987	1	0.90	0.96	0.03	0.0035	0	DHL
Breast	0.998	0.97	1	0.83	0.15	0	0.02	DHL
Brain	1	1	1	0.95	0.05	0	0	ML

IMRT

ML and DL models were trained using SAS10, BA and BM complexity indices. ML models did not show satisfactory performance with an AUC of 0.87 and specificity and sensitivity of 0.89 and 0.84. However, the optimized DL model showed better performance with an AUC of 0.96 and specificity and sensitivity of 0.98 and 0.92. Furthermore, DL model have been able to predict QA conformity in five cases of dose difference/distance to agreement: 2.5%/2.5mm, 3%/3mm, 3%/2mm, 2%/3mm, 2%/2.5mm.

	AUC	Sensitivity	Specificity	Accuracy	TP	TN	FP	FN
ML single class (2.5%/2.5mm)	0.87	0.84	0.89	0.86	120	155	20	23
DL single class (2.5%/2.5mm)	0.97	0.94	0.95	0.94	134	166	9	9
DL multiclass	0.96	0.92	0.98	0.96	335	1198	26	31

Clinical practice solution

A programming and application interface (API) has been developed so that these solutions can be easily used in clinical routine.

This solution is available to the scientific community via the following QR codes.

RapidArc Machine (VMAT) *Halcyon Machine (IMRT)*

Conclusion

Patient-specific QA requires time on the treatment machine, during which time it is impossible to treat patients. Therefore, the objective of this study was to propose an alternative solution for patient-specific QA that would make treatment machines more available to patients. To predict patient-specific QA compliance for treatments, we developed AI models based on complexity indices. The results were conclusive for the VMAT in Rapid Arc machine as well as for IMRT in Halcyon machine. To implement this study in clinical routine, APIs were developed.