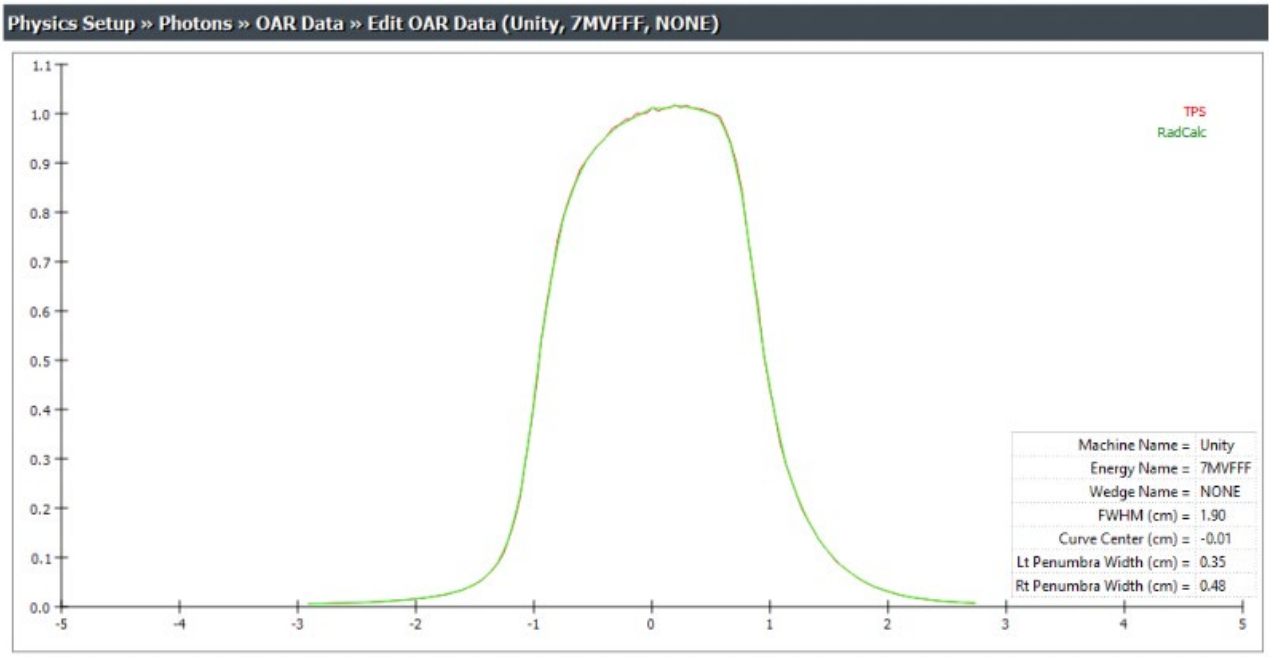
RadCalc Adds Support for MR-Linacs

RADCALC

This whitepaper explores RadCalc's addition of MR-Linac support. This additional support is part of the RadCalc Base Module and was first introduced in version 7.1.4.0 released in November of 2019.

Extensive clinical evaluations were performed to validate RadCalc's handling of the Lorentzian Force due to the magnetic field in MR-Linacs, increasing its commitment to accuracy and reliability.



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1.1 Introduction

As the field of radiation oncology rapidly evolves, the support and integration of new advanced treatment techniques in dependent software is paramount for enhancing treatment quality and efficient workflows. One recent advancement is the introduction of Magnetic Resonance (MR) Linacs, which combine the precision of MRI imaging with the effectiveness of linear accelerators for delivering radiation therapy. This complexity of MR-Linac systems necessitates a corresponding evolution in dose calculation tools, and as such, it became crucial to extend RadCalc's capabilities to accommodate these sophisticated systems.

Adding support for MR-Linacs to RadCalc addresses the need for precise and reliable dose calculations specific to the unique challenges presented by the effects of the magnetic fields in MR-Linacs. This enhancement ensures that the treatment plans designed using MR-Linac technology can be accurately verified. The inclusion of MR-Linac support in RadCalc represents a significant step forward in aligning dose calculation tools with the latest advancements in radiation therapy.

1.2 Adding an MR-Linac in RadCalc's Base Module

Adding an MR Linac can be done as easily as any other machine, but with one main difference being the need to specify the direction of the magnetic field. The dose calculations take the presence of the magnetic field into account through the imported measurement profiles. All of the calculation methods included in the RadCalc base module are available for MR Linac configurations including the Clarkson Integration. Additionally, the Modified Clarkson Integration (MCI)[1] algorithm is available with the IMRT module for MR Linac configurations. All calculations can be automated together with RadCalc's import, export and reporting features. Additionally, for Elekta Unity, RadCalc provides a plan integrity check with the plan comparison tool.

RadCalc uses both *Inplane* and *Crossplane* off-axis profile data if the energy selected is using the magnetic field. Based on the direction of the magnetic field, the direction of the Lorentz force is identified as the MR-Linac's sensitive data, and separate set of boundary factors are determined from these profiles. Furthermore, instead of using the correction factors normally determined from the profile data, the calculation is based on the actual unadjusted measured data so that the effect of the magnetic field can be fully accounted. The other set of profile data is used as the conventional set of off axis profile data.

1.3 Clinical Evaluation Evidence

The foundational criteria for achieving agreements within +/- 5.0% have remained a benchmark despite evolving standards, published[2,3] and in currently in the works by the AAPM. The development team at RadCalc has continually aimed to tighten these criteria as much as possible, striving for the highest levels of precision in dose verification. For the initial MR-Linac implementation, several phantom tests were used in the validation to support the methods developed. Of these, a Pelvis plan with seven beams containing 42 control points was used as a benchmark test.

Beam Data for CalcPt_1

Gantry Angle	Depth (cm)	Equi. Path (cm)	SSD (cm)	OADz (cm)	OADr (cm)	Dose % Diff.
175	12.90	11.00	125.74	5.04	-0.26	3.5%
30	23.78	11.05	126.57	-1.10	-0.24	7.2%
0	20.51	10.83	128.41	-4.26	-0.24	1.7%
330	21.75	10.58	124.32	-6.39	-0.25	1.5%
240	25.98	18.50	111.04	-2.54	-0.26	0.0%
220	26.90	14.93	109.66	-0.06	-0.26	-1.3%
195	13.18	11.03	124.04	3.02	-0.26	8.4%

	RadCalc (cGy)	RTP Dose (cGy)	% Diff.
CalcPt_1 (-4.6, -14.86, 130.5) Total Dose	**213.22**	**207.60**	**2.7%**

Table 1: Results of benchmark Pelvis plan for each individual beam and total point dose.

1.3.1 Academic Reviews of RadCalc's MR-Linac Support

Prior to incorporating support to account for the effects of magnetic fields, RadCalc was utilized to quality assure treatment plans designed for MR-Linacs, as there were no commercial solutions at this time. One study employed a series of tests to integrate and validate RadCalc with the Elekta Unity system[4]. This included testing the software's ability to accurately verify dose calculations across a range of treatment plans, including complex treatment plans. Even without accounting for the magnetic field effects, RadCalc demonstrated a high level of accuracy and could consistently verify dose calculations.

With the release of MR-Linac support in RadCalc version 7.1.4.0, there was a surge of clinical implementations of RadCalc for MR-Linacs. This led to additional publications, some of which are outlined below, that confirmed its reliability as a patient specific quality assurance (PSQA) tool for MR-Linacs. However, the special constraints of the MR-Linacs bore sizes limited scan data that can be acquired. Due to this, RadCalc provides preconfigured machines with data provided from either Monaco for Elekta Unity or ViewRay TPS.

A Washington University publication focused on the commissioning and evaluation of RadCalc for a 0.35 T MR-Linac[5]. The study investigated the impact of a 0.35 T magnetic field on monitor unit calculations, finding minimal effects. RadCalc version 7.1.4.0 was successfully commissioned for the ViewRay MRIdian system, demonstrating accurate dose calculations. The software was tested on various geometries and clinical plans, showing it can perform within accepted practice tolerances.

- The simple geometries included various open field arrangements in simple phantoms. Calculations were within 2% of treatment planning system (TPS) values, except for a single off-axis comparison.
- For complex geometries Multi-leaf collimator (MLC) patterns were generated in more complex phantoms, including a lung phantom. Calculations were within 5%, except for a single field within a lung phantom at a distal point.
- The clinical plans included 25 different Patient-Specific treatment plans. All results were within 5% for the method.

These tests demonstrate the software's accuracy and reliability in various scenarios, ensuring it meets clinical standards.

Yonsei University published an additional study evaluating various beam modeling options, including the previously discussed preconfigured Unity Machine[6]. Six different beam models were evaluated with the best option utilizing smoothed calculated PDDs from the TPS and measured Sc, Sp and OARs. The study found that the preconfigured machine did not perform well, mainly because the reference dose was not adjusted to match the site's value, and thus the results were off by that same magnitude. During this study, the accuracy of RadCalc was assessed for 575 adaptive plans in prostate, liver, and breast cancer patients. Calculated doses were compared with those from the Monaco TPS.

Plan distribution:

- Prostate Cancer: 15 patients, 360 plans
- Liver Cancer: 14 patients, 140 plans
- Breast Cancer: 15 patients, 75 plans

Results With Model 1:

- **Prostate Plans**: The average difference between RadCalc and the MONACO TPS was -0.71% (SD 1.0), indicating high accuracy.
- **Liver Plans**: The average difference was also good at 0.91%, (SD 0.9) and within acceptable limits overall.
- **Breast Plans**: The average difference was 3.50% (SD 1.2), which was higher compared to prostate and liver plans.

The study highlights RadCalc's reliability in calculating doses for different cancer types, with the highest accuracy observed in prostate plans. The results emphasize the importance of considering MR effects in dose calculations, especially for breast cancer plans.

The study also investigated the correlation between calculation-based PSQA and measurement-based PSQA. The average difference between measurement-based PSQA and TPS calculation was **1.66%**, while the average difference between calculation-based PSQA and TPS calculation was **-0.46%**, an average difference of **2.11% ± 0.80%**. This result indicates that RadCalc calculations follow a similar trend to measurement-based PSQA, suggesting that it may be feasible to use RadCalc calculations as a substitute for measurements.

These results highlight the potential of RadCalc to provide reliable calculation-based PSQA, which could streamline the quality assurance process in radiation therapy. The findings underscore RadCalc's accuracy in calculating doses at 1.5 T magnetic fields, making it a valuable tool for PSQA in adaptive plans. The study also emphasizes the importance of considering MR effects in dose calculations.

REFERENCES

1. Bohorquez. *Whitepaper on RadCalc Classic: The Original Comprehensive Secondary Dose Calculation Software for Radiation Therapy*. Lifeline Software Inc. (2024).

2. Kutcher, et. al., Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40, Medical Physics, 21, pp. 581-618, (1994).

3. Stern et. al., AAPM Task Group 114. Verification of monitor unit calculations for non-IMRT clinical radiotherapy: report of AAPM Task Group 114. Med Phys. 2011 Jan;38(1):504-30.

4. Graves SA, Snyder JE, Boczkowski A, St-Aubin J, Wang D, Yaddanapudi S, Hyer DE. Commissioning and performance evaluation of RadCalc for the Elekta unity MRI-linac. J Appl Clin Med Phys. 2019 Dec;20(12):54-62. doi: 10.1002/acm2.12760.

5. Price AT, Knutson NC, Kim T, Green OL. Commissioning a secondary dose calculation software for a 0.35 T MR-linac. J Appl Clin Med Phys. 2022 Mar;23(3):e13452. doi: 10.1002/acm2.13452.

6. Sung, J., Cho, Y., Kim, J. W., & Lee, H. (2024). Dose calculation accuracy of beam models in RadCalc for a 1.5 t MR-Linac. *Cancers*, *16*(3), 526. doi: 10.3390/cancers16030526