Monte Carlo Evaluation of Magnetic-Field Effects in Prostate Step-and-Shoot IMRT on a 0.5 T Inline Linac-MR

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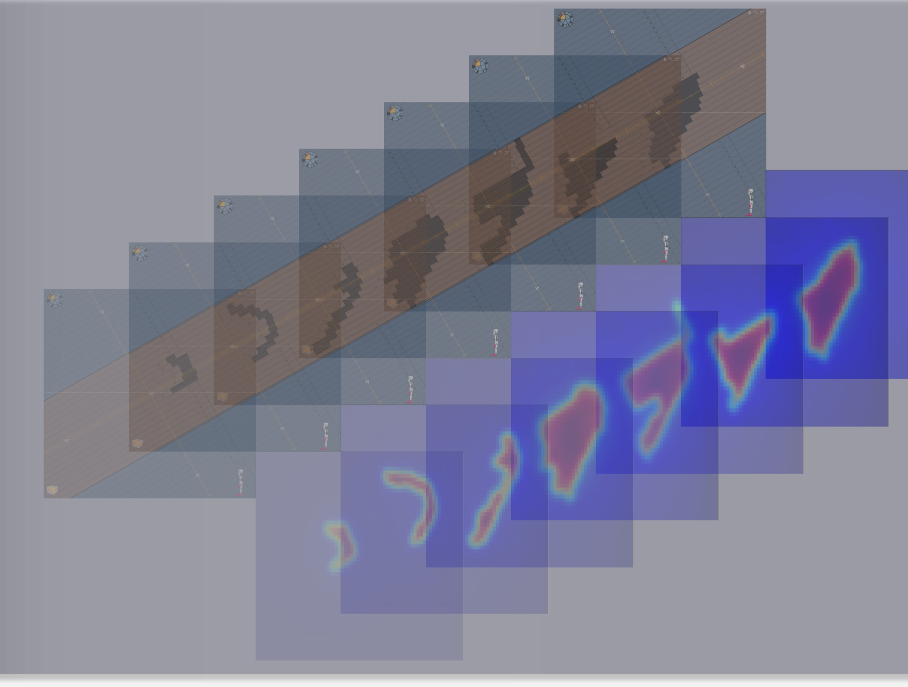


Background

- Alberta Linac-MR (LMR) [5]
  - 0.5 T magnetic field
  - 6 MV FFF beam
  - Parallel magnetic and radiation fields
  - Designed to support commercially available treatment planning systems (TPS)
- Minimal magnetic field dose perturbations compared to other commercial systems [6, 7]
  - Conventional dose calculation algorithms, such as collapsed cone (CC), may be suitable for selected clinical scenarios

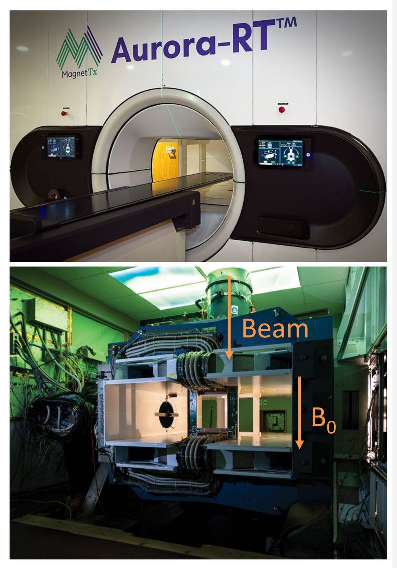


Fig 1. Alberta Linac MR

Purpose

- To simulate step and shoot IMRT(sIMRT) prostate treatment plans with Monte Carlo (MC) model of LMR with and without magnetic field
  - Investigate magnetic field-induced dose perturbations by comparing MC calculated dose
  - Compare MC dose calculations with RayStation 11B (RS-11B), CC algorithm, that does not account for magnetic field effects

Method

- Treatment plan are generated in RS-11B TPS:
  - Clinically commissioned beam model for the LMR (PO-DPV-T-48)
  - Five sIMRT Plans are generated based PROFIT trial criteria
    - Each plan consists of five fields
- MC model of the LMR [1] is developed and validated in TOPAS [2, 3]
  - Full integrated Multileaf Collimator (MLC) module
  - Validated 3D magnetic vector field
  - sIMRT specific validation tests based on AAPM MPPG 5.a.
- Treatment Plan Simulation Workflow:

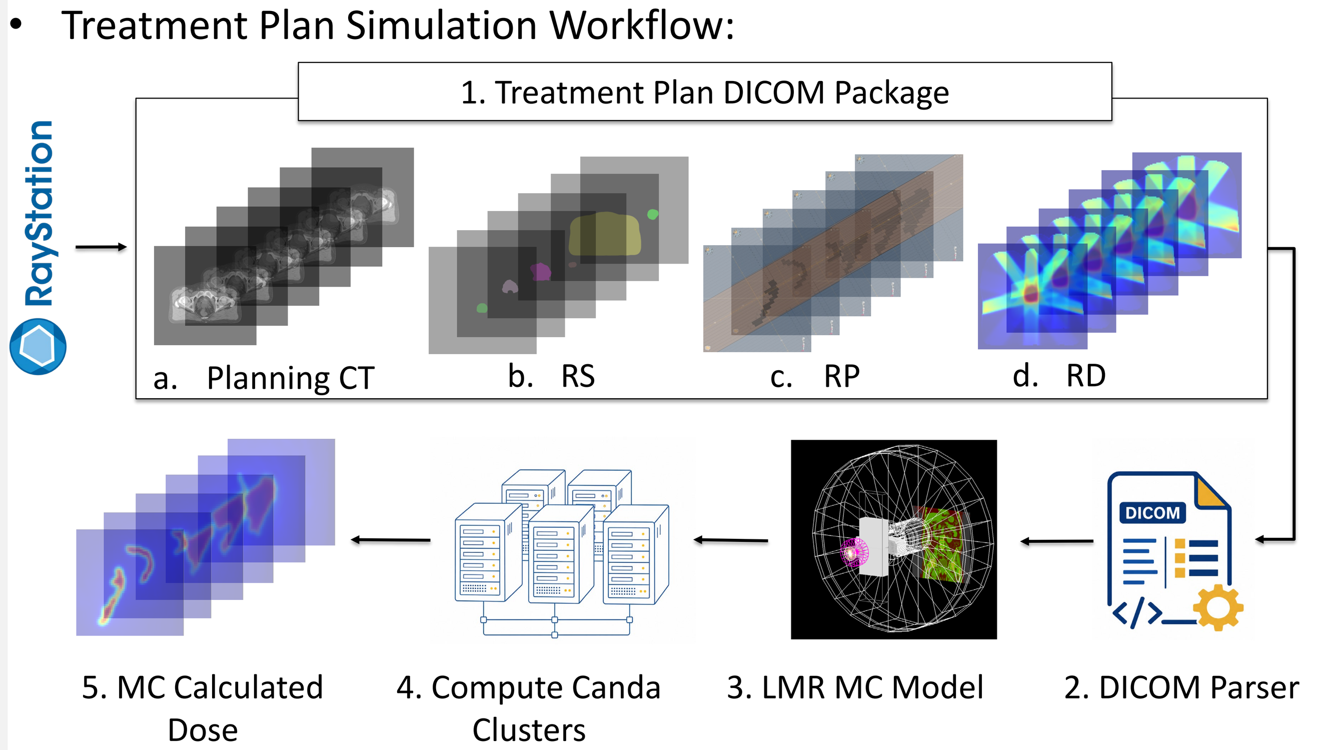
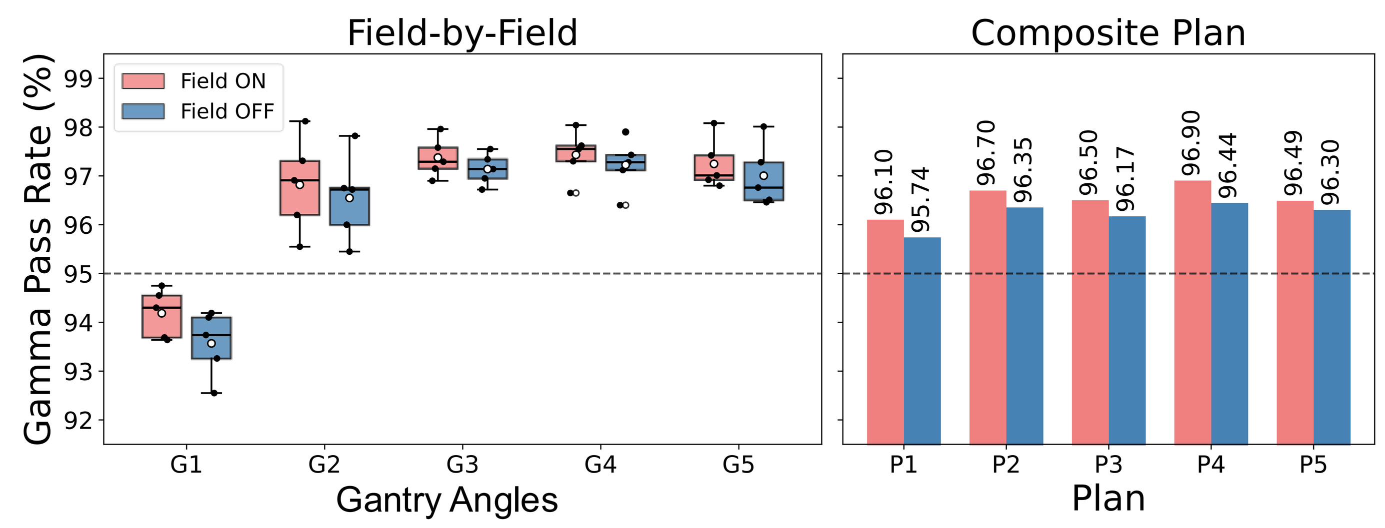


Fig 2. Treatment-plan DICOM package, planning CT, structure set (RS), treatment plan (RP), and dose distribution (RD), is exported from The RS-11B . A DICOM parser is developed to convert treatment plans into the TOPAS MC simulation framework. Simulations are submitted to compute Canada clusters, and the resulting MC dose distributions are reconstructed for comparison with the planned dose.

- Post Processing:
  - 3D Gamma analysis for individual fields and composite plan
    - 3%|2mm, Reference: RS-11B, Evaluation: MC
  - Dose Volume Histogram
    - Mean Skin dose receiving >5% prescription

Results

Fig 3. Field-by-field and composite gamma analysis (3% |2 mm) for prostate plans. Individual gantry fields are labeled G1–G5 and the composite plans are labelled P1-P5. Results are shown for magnetic field ON and OFF conditions.



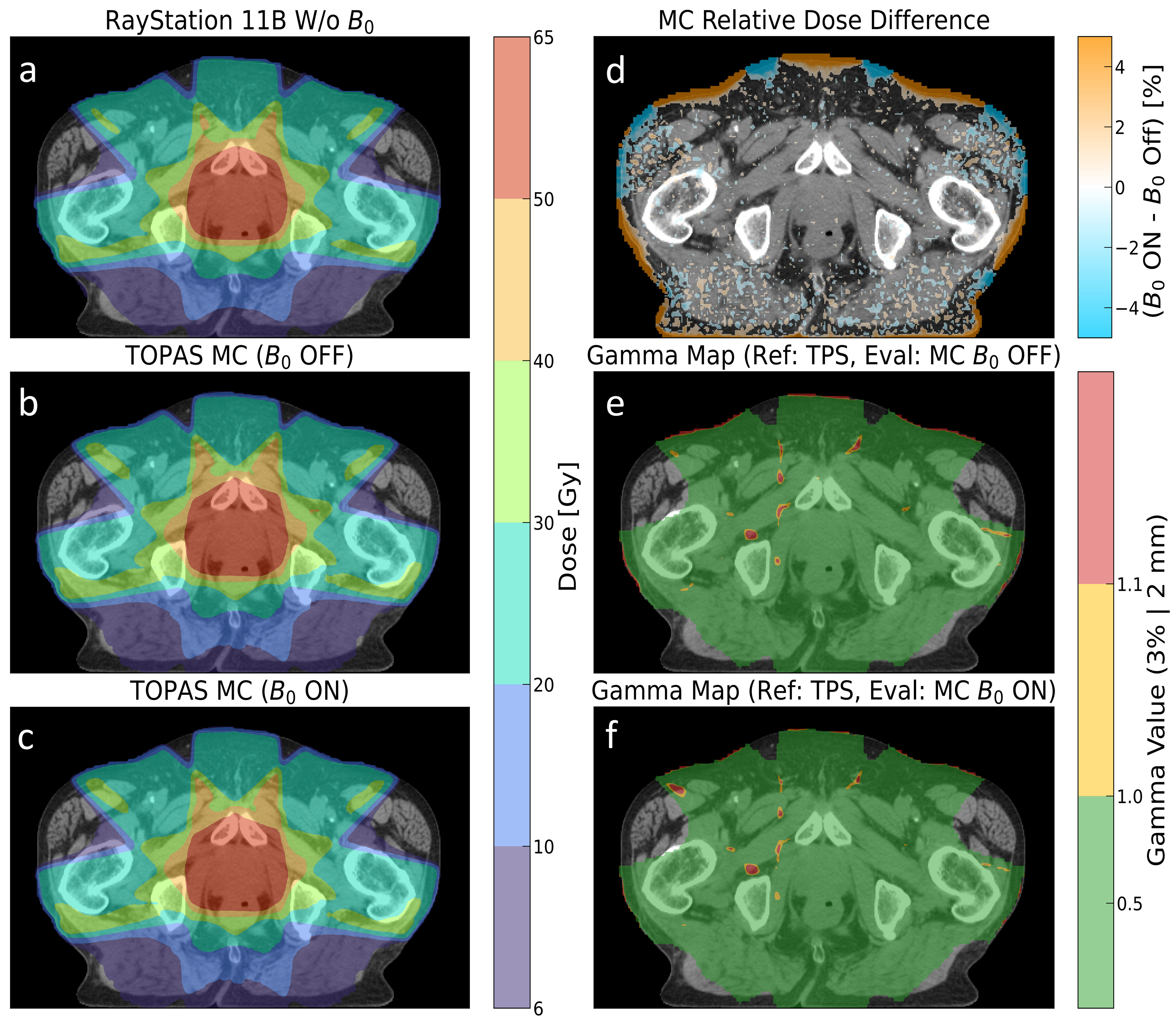


Fig 4. Comparison of RayStation and TOPAS Monte Carlo dose distributions for a prostate plan. Dose distributions are shown on the planning CT for RS-11B CC calculation (a), TOPAS MC with B_0 OFF (b), and TOPAS MC with B_0 ON (c). The relative MC dose difference $(B_0 \text{ ON} - B_0 \text{ OFF})/B_0 \text{ OFF}$ (d) highlights magnetic field-induced perturbations. Gamma maps are shown using RS-11B as the reference and TOPAS MC as the evaluated dose for both B_0 OFF (e) and B_0 ON (f) conditions using a 3%|2 mm TG-218 recommended criteria.

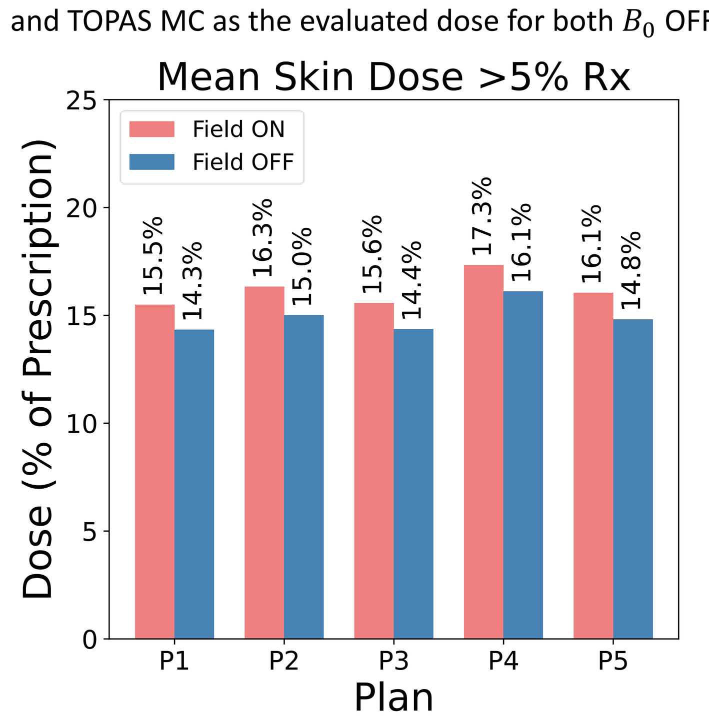


Fig 6. Comparison of skin dose metrics with magnetic field ON and OFF. Mean skin dose is shown for five prostate plans as a percentage of the prescription dose.

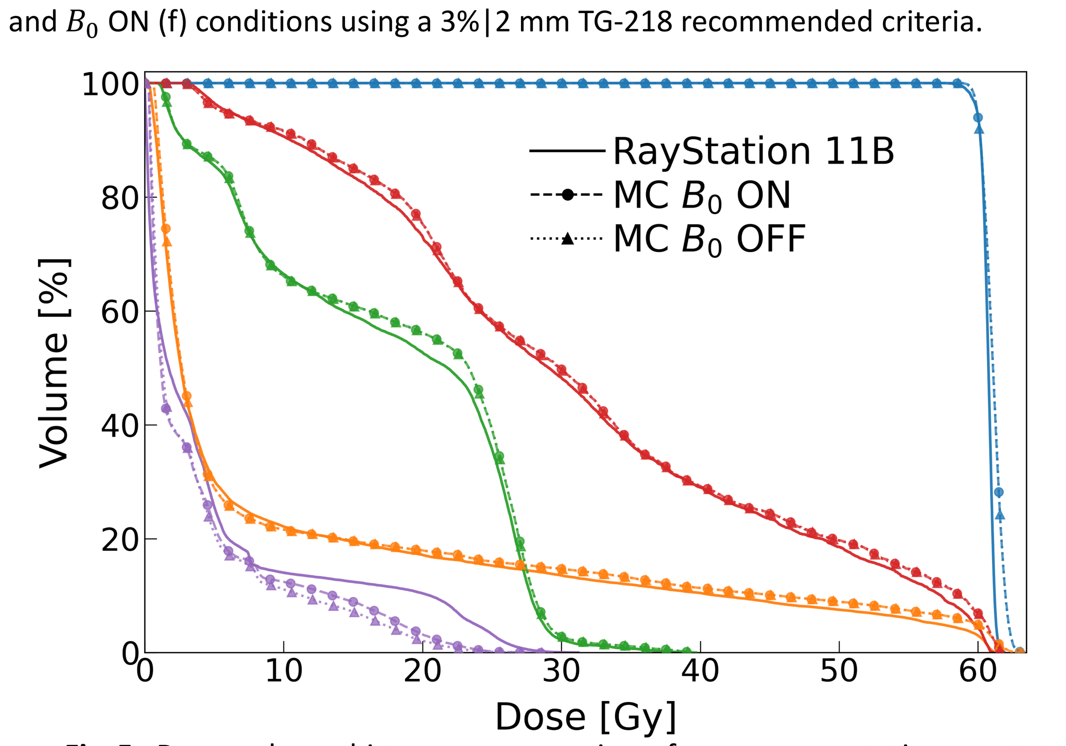


Fig 5. Dose volume histogram comparison for a representative prostate plan. DVHs are shown for RS-11B and MC calculations with B_0ON and OFF. PTV, Bladder, Femur, Rectum and Skin are evaluated structures.

Discussion

- The developed patient-specific MC workflow showed good agreement with RS-11B for 5-field sIMRT prostate plans, despite RS-11B not explicitly accounting for magnetic field (**Fig 3.**)
- DVH analysis showed near-overlapping MC curves with and without magnetic field for the PTV and most deeper OARs, suggesting that the inline magnetic field had limited impact on target coverage and deep-tissue dose for prostate sIMRT (**Fig 5.**)
- The mean dose to skin receiving more than 5% of the prescription, $\bar{D}_{>5\%}$, increased with magnetic field (**Fig 6.**)
  - These results are consistent with previous LMR surface-dose work by Oliver et al., who reported surface-dose enhancement for a five-field LMR irradiation geometry in an anthropomorphic phantom [4]
  - The magnitude of the observed skin-dose increase was smaller than expected for a single-field geometry, likely because the prostate plans use multi-field delivery, distributing the electron-focusing contribution over multiple beam angles
- The next step is to investigate dose perturbations in low-density regions, such as the head and neck (where air cavities are present) and the lung.
  - The magnetic field are perturbations are prominent in heterogenous tissues such as lung or in air cavities in (**Fig 7.**)

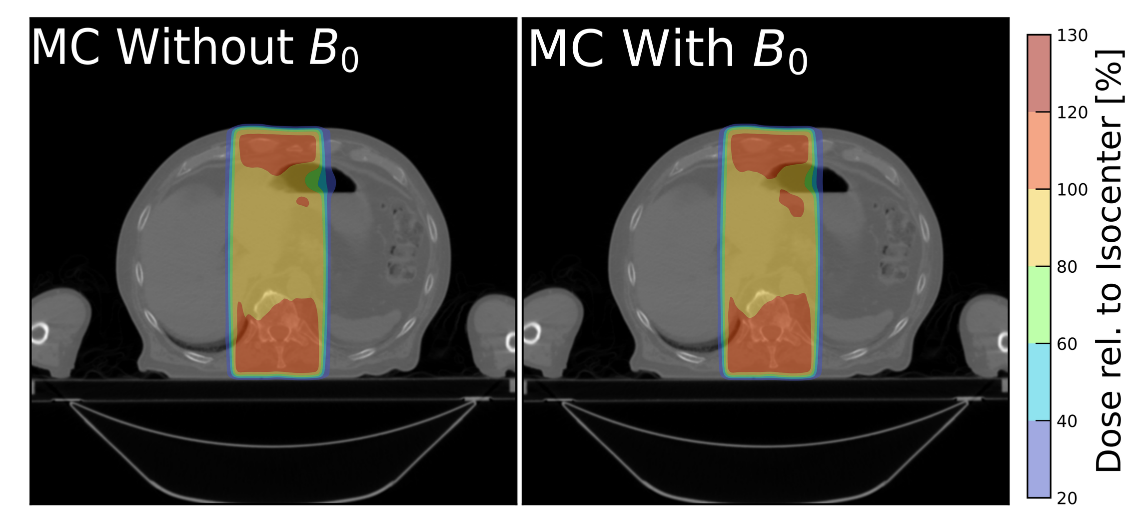


Fig 7. MC simulated 3D dose calculation comparison for a parallel opposed treatment plan with and without magnetic field [8].

Conclusion

- A patient-specific workflow was established to MC simulate RS-11B sIMRT prostate plans using the validated LMR TOPAS MC model
- MC simulations with and without magnetic field showed strong agreement with RS-11B, with all composite **3%|2 mm** gamma pass rates exceeding **95%**.
- The primary magnetic field-induced effect observed in prostate plans was elevated skin dose rather than changes in target or deep-OAR dose
- The $\bar{D}_{>5\%}$increased by approximately **1.23% Rx** with magnetic field
- This framework provides a foundation for systematic patient-specific evaluation of magnetic field induced dose effects in the LMR system and future TPS validation.

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Acknowledgments

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