Potential Efficacy of Monte Carlo Dose Calculations of 6MV FFF Photon Beam of M6™ CyberKnife® using the EGSnrc Program

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INTRODUCTION

M6™ CyberKnife®

- The M6™ CyberKnife® (M6CK) is an advanced Robotic Radiosurgery System (Accuray Inc., Sunnyvale. CA), equipped with Incise™ 2 Multi-Leaf Collimator (IMLC) system (26 pairs of Tungsten leaf). It is preferred in Stereotactic Radiosurgery/Therapy (SRS/SBRT) cancer treatments.
- Each leaf in the IMLC has features like tip design- three flat and focused edges, side design – flat and focused with tilt angle of 0.5 degree, 90 mm height, and 3.85 mm width at 800 mm SAD.
- M6CK enables the delivery of 6MV Flattening Filter Free (FFF) radiation beam from multiple directions with stereotactic precision provided by image guidance, thereby providing a few mm accuracy for both static, as well as dynamic targets.
- M6CK has a potential to improve the efficiency of SRS and SBRT cancer treatments in which accurate measurement of dose gradients is of the highest importance, as the treatment plans often contain collections of small beamlets with steep dose gradients.

Monte Carlo Simulation

- Monte Carlo (MC) simulation is a stochastic method for numerical integration.
- MC simulation in radiation therapy uses the probability distributions governing the interactions of electrons/photons in materials to simulate the random trajectories of particles for a large number of histories to provide the required information on the average physical quantities.
- The interaction probabilities depend on the energy of the beam, atomic number, density, etc. of the materials.
- MC dose prediction model is proven to be the most accurate dose calculation method. It is recommended as an independent tool to validate the used dose calculation modalities, specifically in heterogeneous media and complex geometries, although it is a time consuming process.

PURPOSE

- To create an efficient MC module for the dose calculation in heterogeneous media and the complex geometry of the M6CK for SRS/SBRT treatment.
- To compare and validate this new module within the treatment planning system using different dose measurement methodologies.
- To calculate the field specific-correction factors or output factors and investigate the implementation in patient specific quality assurance.

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MATERIALS AND METHODS

BEAMnrc: BEAM Modeling

- The M6CK head including an IMLC was modeled, based on detailed diagrams provided by Accuray Inc. (Sunnyvale, CA) using the BEAMnrc simulation with millions of primary charged particles (histories) striking the target.
- The linac head was modeled using a mono-energetic electron beam with 2D Gaussian beam profile as a primary source and optimized with measurements at 800 mm SAD in water phantom.
- A new module (input file) for the IMLC was created upon the pre-existing regular MLC modules.

Target

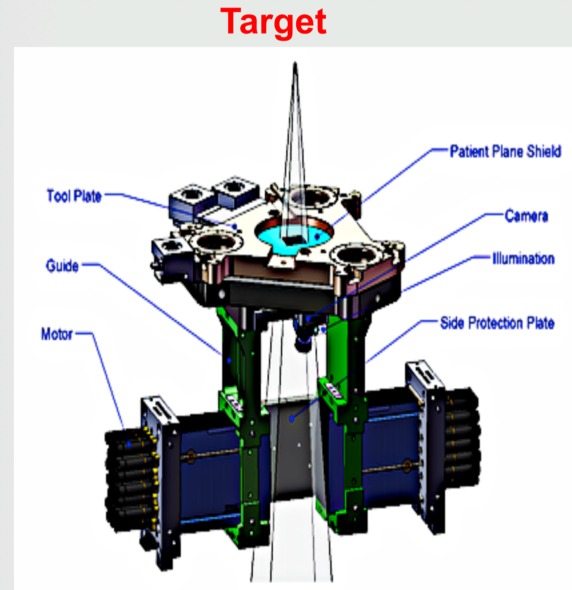
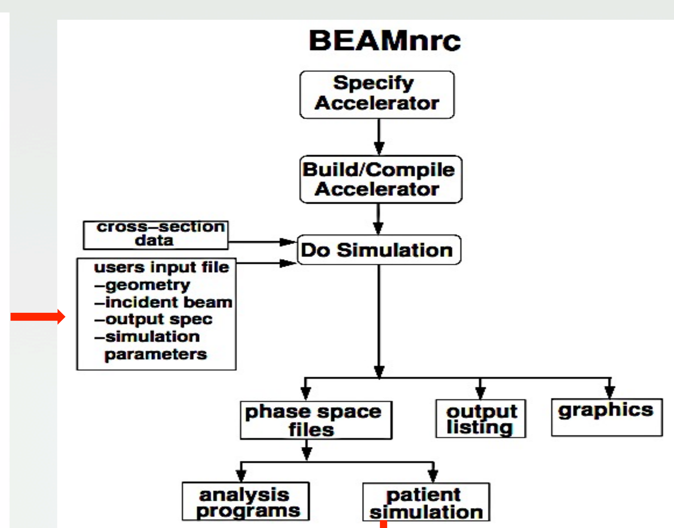


FIG 1: M6CK Robotic Radiosurgery Linac (Accuray Inc., Sunnyvale, CA).



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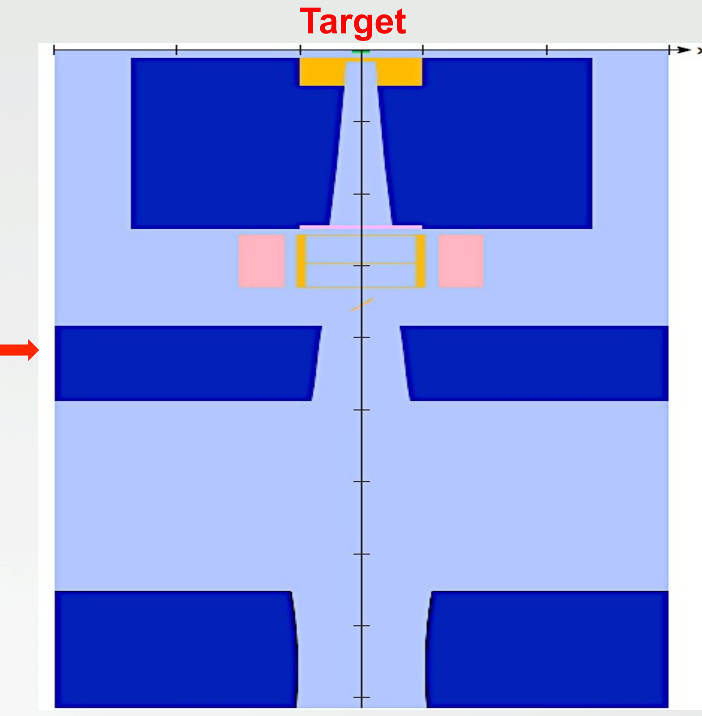
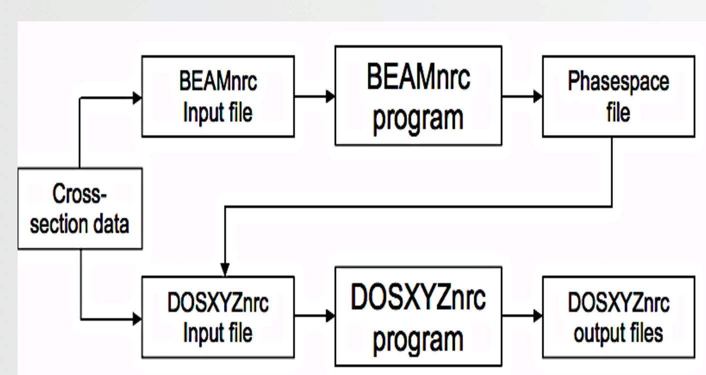


FIG 2: M6CK BEAM model

DOSXYZnrc: MC Dose



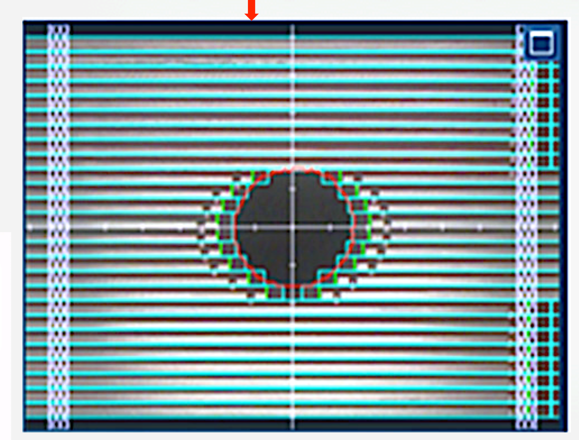


FIG 3: processed view of IMLC in CK

TMR Method:

- Set up 1
  - SAD - 80cm
  - SSD - 78.5 cm
  - Depth - 1.5 cm
- Set up 2 (MapCheck QA)
  - SAD - 80 cm
  - SSD - 73 cm
  - Depth - 7 cm

- TMR= D(d=7)/D(d=1.5)

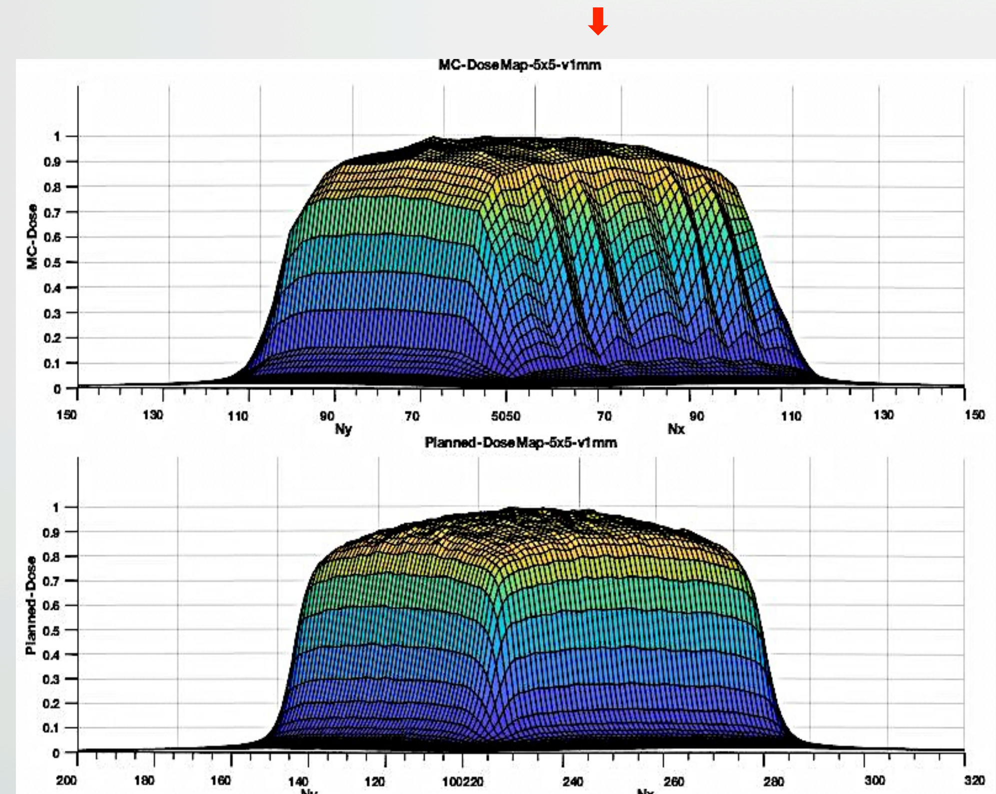


FIG 4: MC vs planned dose profiles

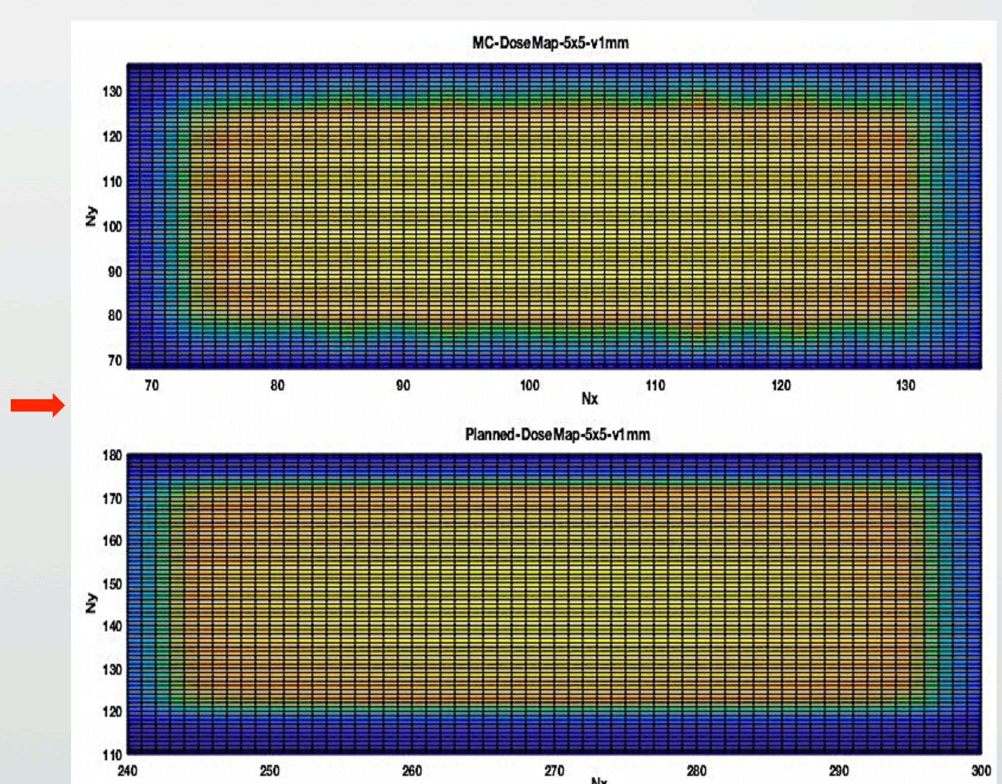


FIG 5: MC vs planned 2D dosemaps

MC Simulation Process

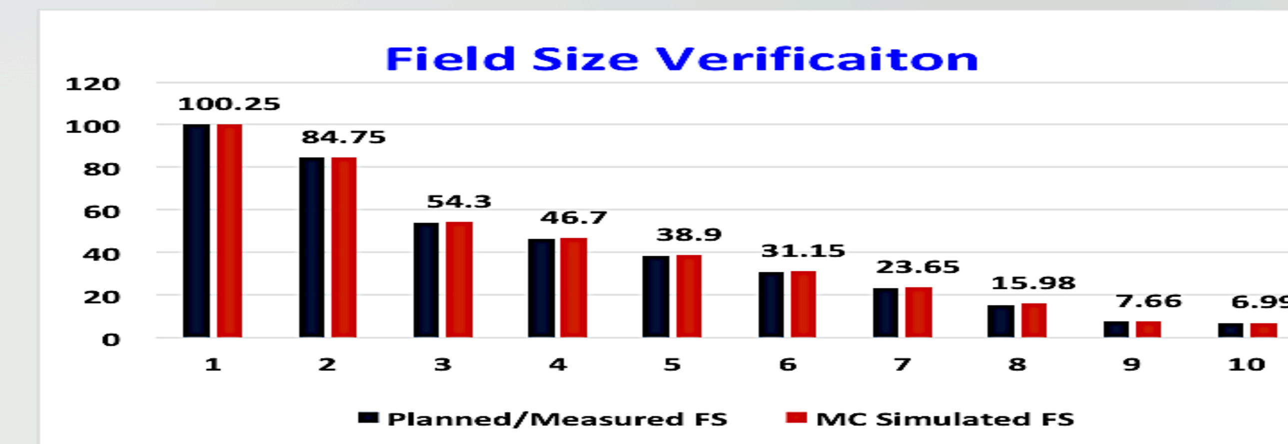
- The phase space files in the BEAMnrc are stored before and after IMLC for every particle crossing a scoring plane, and then fed into the DOSXYZnrc for MC dose calculations in a phantom.
- Several simulations were run by varying parameters like the number of initial histories, energy (6.5-7MeV) and FWHM (1.8-2.4mm) of primary beam, voxel size (1-5mm) of the phantom. The dose profiles and depth dose curves were plotted for multiple field sizes, including 10 small IMLC segments.
- The MC simulated dose maps were compared with those generated by Accuray Precision tools (measurements) to validate the new MC model.
- During the simulation, various variance reduction techniques were applied to minimize the statistical uncertainties and optimize the simulation efficiency.

RESULTS AND DISCUSSIONS

MC Model Validation Process: The new MC model verification involves Following steps:

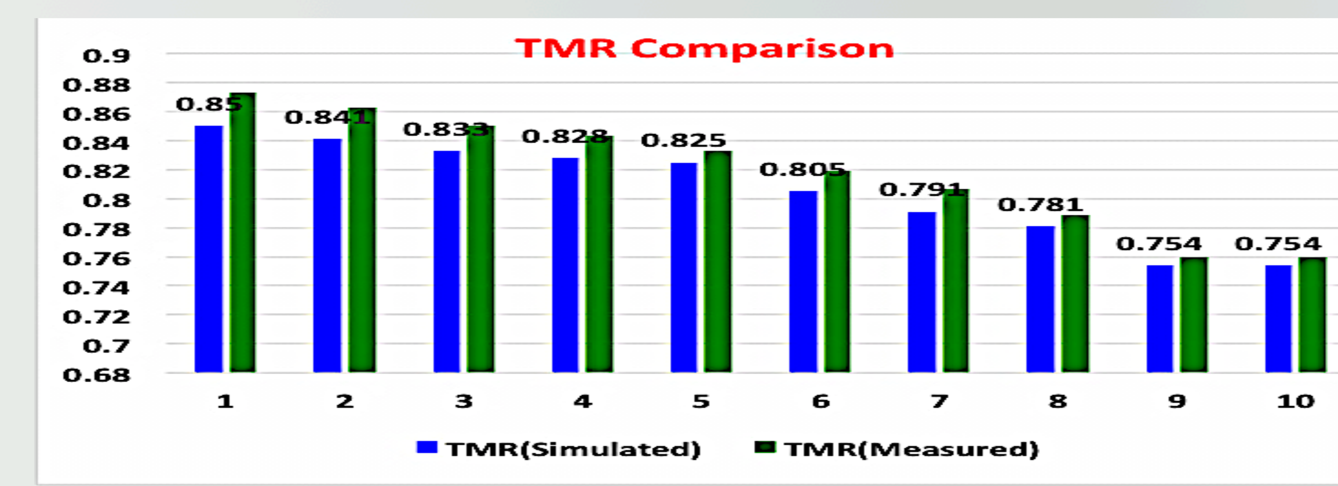
1. Field Size Verification (Dose Profiles):

- Field sizes (at 800 mm SAD in water phantom) for open fields (100x100.1 to 7.6x7.7 mm²) were compared between treatment plans and MC plans by defining the Full Width-Half Maximum (FWHM) and found within ± 2mm margin of error.



2. Depth Dose Comparison: TMR Method

- Depth dose curves for open fields (100x100.1 to 7.6x7.7 mm²) between the treatment plans and MC plans were compared (using TMR method) and found within 3% dose (output) agreement .



3. Gamma Evaluation:

Currently, we are working on Gamma analysis with 3%/ 3mm and 2%/2mm criterion for the dose evaluation between the treatment plans (measurements) and MC plans.

CONCLUSIONS AND FUTURE WORK

- Our preliminary results (with 2 millions incident histories in BEAMnrc and 20 millions in DOSXYZnrc) have shown that the new MC model can be applied in the M6CK system to customize its components.
- A reasonable accuracy of dose calculations (2% dose uncertainties for open fields and 5% for 10 small segments) was found with the new MC model for both static and step-shoot modes.
- We are working on simulations for higher numbers of initial particles/histories by using parallel processing to further reduce the dose uncertainty, as well as to optimize the efficiency for potential clinical implementation.
- We calculate the field-specific correction factors (CAX and Off axis), which have potential implications in patient specific quality assurance (PSQA).

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