MCsquare can be used as a fast secondary dose calculation engine for intensity modulated proton therapy using synchrotron-based narrow and mini beams.

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INTRODUCTION

The Monte Carlo (MC) simulation of radiation transport is considered to be the most accurate method in dose calculations. General-purpose MC transport codes contain a highly accurate description of the physical processes of radiation transport. However, the use of general-purpose codes requires significant computational time and, therefore, is not efficient for clinical practice. Fast Monte Carlo (MC) codes leverage modern computational hardware architecture and shortcuts in particle transport modelling to reduce computation time. A recently designed MC transport code MCsquare [1] uses multi-core processor architecture.

Synchrotron-based proton therapy systems can produce Gaussian beams with standard deviations less than 1 mm, known as mini beams. The accurate simulation of a small proton beam is a challenging job for many algorithms.

PURPOSE

The purpose of this study is to explore the applicability of the MCsquare fast MC code for standard and mini proton beams as a secondary dose computation engine.

METHOD

We commissioned MCsquare for a spot-scanning proton therapy system (PROBEAT-V, Hitachi) at energies ranging from 69.4 MeV to 221.3 MeV with standard- and mini-beam options.

Commissioning data were generated by a benchmarked TOPAS model and were previously used to commission the clinical treatment planning system (Eclipse, Varian Medical Systems) [2-4]. The large scoring bin of 20 cm was used to collect the integrated depth doses (IDDs).

The provided MCsquare automated commissioning tool was used for commissioning calculations.

The absorbed dose was calculated from treatment plans comprising standard or mini beams with the MCsquare and TOPAS models and measured in a water-box phantom according to the TRS 398 protocol for reference fields.

The computational time for the various settings of MCsquare was collected and the time of the calculations to reach the required accuracy of 2, 2.5 and 3% was determined.

MCsquare was tested for potential use at a high-performance computing facility via Amdahl's Law.

RESULTS

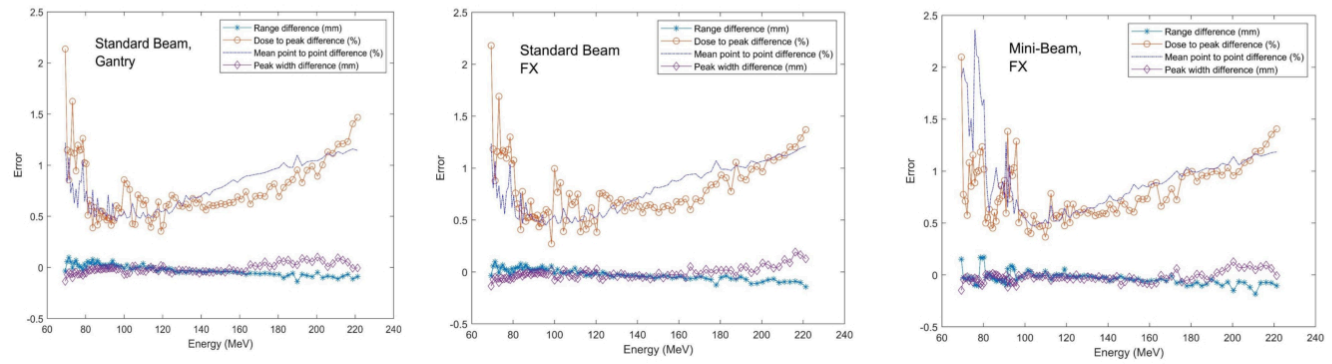

Figure 1. Comparison of the MCsquare source model output with the reference data produced by TOPAS for a spot beam at all 96 energy levels of the Probeat-V, Hitachi proton therapy system with gantry, fixed beam (FX) and mini-beam options.

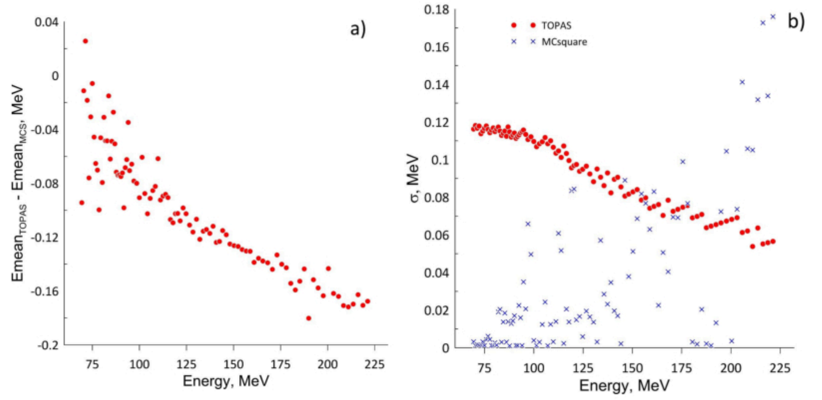

Figure 2. The difference in mean energy (a) and Gaussian sigma (standard deviation) (b) calculated from TOPAS generated phase spaces at the output of the nozzle and commissioned MCsquare model.

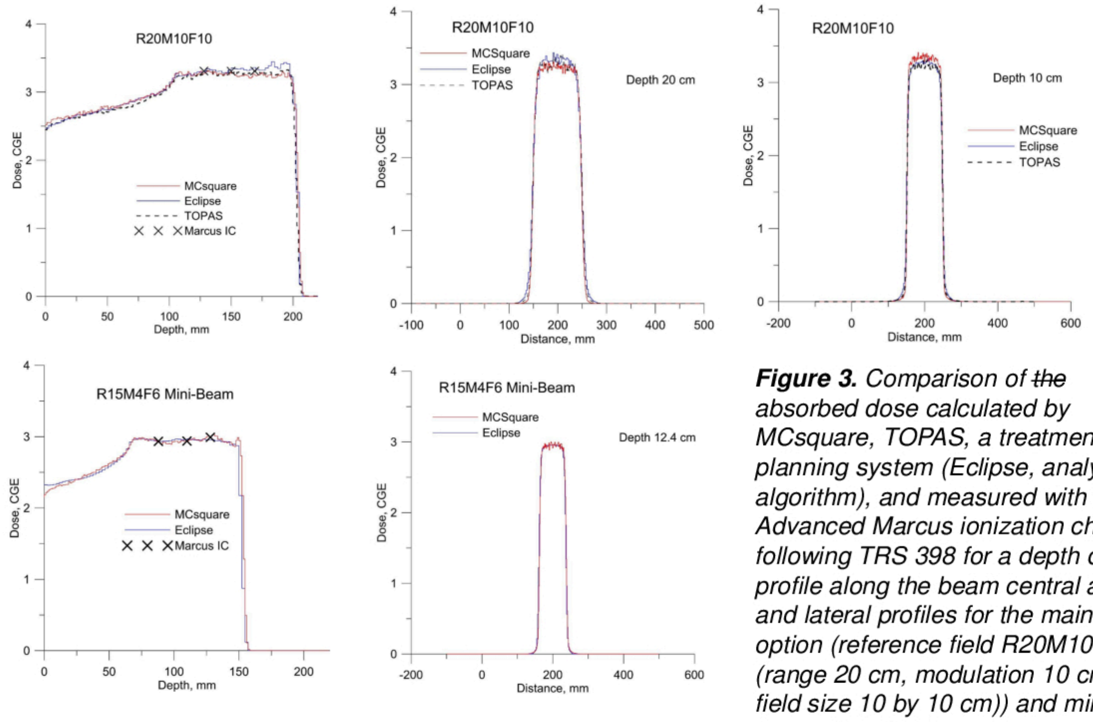

Figure 3. Comparison of ~~the~~ absorbed dose calculated by MCsquare, TOPAS, a treatment planning system (Eclipse, analytical algorithm), and measured with the Advanced Marcus ionization chamber following TRS 398 for a depth dose profile along the beam central axis and lateral profiles for the main beam option (reference field R20M10F10 (range 20 cm, modulation 10 cm and field size 10 by 10 cm)) and mini beam (R15M4F6).

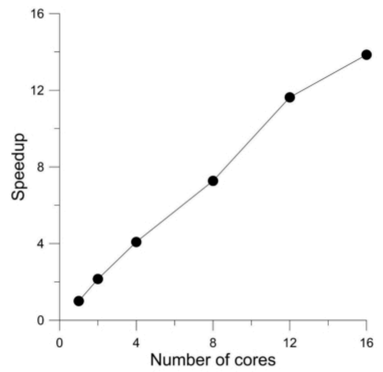

Figure 4. Amdahl's curve characterized the level of parallelization of MCsquare. The calculations were performed on a 16-core Intel Xeon CPU E5-2687W @3.1 GHz workstation. The curve did not reach saturation. The speedup for 16 cores is 14. MCsquare code has a great potential for usage with HPC facilities.

- Therapeutic ranges (R90) of individual spot beams computed with MCsquare and TOPAS agreed with measurements within 0.1 mm (Figure 1).
- The parameters of the MCsquare source physical model agreed with those from the TOPAS phase space files for the nozzle output simulation within 0.16 MeV for the mean energies and 0.17 MeV for the energy spread (Figure 2)
- The absorbed dose from reference fields agreed between two MC codes and with measurements for both standard and mini beams within 0.7%. (Figure 3)
- The test of MCsquare computation speed showed a high level of code parallelization and required 0.34% of the time of TOPAS computations.
- The computational time at 16 core dual CPU Intel Xeon E5-2687W workstation for 20 x10 cm field with range 20 cm, modulation 10 cm was 8 min for the 3% statistical error or 12.5 min for the 2.5% statistical error. The 2% statistical error will require 21 min. Lower energies and smaller beams require less computational time. Thus, a field with range 4 cm, modulation 3 cm, field size 10 cm, the range shifter requires 1.2 min for the 3% error and 3 min for 2.5% error. Typical therapeutic fields have a proton range of 12–16 cm and will require 4 to 10 min.
- The execution time at the HPC cluster appears to be about the same as for a single workstation and should be run on a single node (Figure 4).

DISCUSSION

We designed and validated MCsquare-based models for a synchrotron beam with the minibeam option. The results show that the MCsquare model agreed well with measured and general purpose MC–simulated data.

The results of model commissioning show that the error levels for the main and minibeam options are similar (see Figure 1). Thus MCsquare can properly handle the calculations for the proton minibeams.

The reasonable computation time of 4 to 10 min for typical therapeutic beams makes MCsquare suitable for a secondary dose check engine in treatment plan verification calculations and integration into the QA process.

Our results are in agreement with those recently published by another group for larger beam sizes [5].

CONCLUSIONS

MCsquare agreed with the output of a TOPAS-based secondary dose computation engine and with measurements. MCsquare is an attractive candidate for fast secondary dose calculations of proton therapy treatment plans using synchrotron-based standard and mini beams.

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