Current and future of independent dose calculation using Monte Carlo in Nagoya Proton Therapy Center

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Outline

• Introduction
• Development of MC system
• Independent dose calculation
• Speeding up by GPU
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PBA vs. MC

TPS (TPS): Pencil beam algorithm (PBA)
Large uncertainty in inhomogeneous structure

Figure 1: Axial views of three proton therapy treatment fields planned for a paraspinal tumor.

The calculated dose distributions using the Monte Carlo system are shown in the left column. The treatment plan was executed using X0 (middle column). The right column shows the dose difference (Monte Carlo minus X0).

Paganetti PMB 53 4825 2008
MGH, US
Range uncertainty
Dose to OAR

Yamashita PMB 57 7673 2012
HIBMC, Japan

Schuemann IJROBP 92 1157 2015
MGH, US
Max. error in dose to target: 5%
TCP: 11%

• “The most accurate, and hence desirable, dose-estimation algorithm are Monte Carlo models.”
— ICRU 78, 2007

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Figure 2: Comparisons of dose distributions in the example of a head/neck case. (a-b) Dose distribution on the source-center plane calculated by PBA and MC. MC is represented as the same color in yellow around the origin. (c-d) Dose distribution between two calculation methods. (e-f) Comparison along the y-axis, where the x-axis is sat along the beam axis with positive beam direction and the y-axis perpendicular to the y-axis on the transverse plane. While the y-axis is less to avoid dose distribution by MC (pencil beam) is represented by the black horizontal (dashed) line. y distribution is represented by the blue dashed line with circles.

Figure 3: Head and neck patient with the lowest 5-year overall survival rates. The prescription dose for the clinical target volume was 66 Gy(RBE). (a, b) Dose distributions for ADC and MC, respectively. (c) Difference (MC – ADC). (d) Dose-volume histograms for the clinical target volume (CTV) and the selected organs at risk. (e) Beam angles and aperture sizes for each treatment field. ADC = analytical dose calculation; MC = Monte Carlo simulation.
NPTC - Nagoya Proton Therapy Center

Spot scanning
Gantry 1
for head and neck, etc.

Broad-beam
Gantry 2 Double scatt.
for lung and liver

Fixed Beam
Double scatt.
for prostate

250 MeV synchrotron

7 MeV Linac RFQ+DTL

Injector
Patients

2013-May 31, 2019

- Prostate: 45%
- Liver: 20%
- Lung: 13%
- H&N: 4%
- Pancreas: 2%
- Pediatric: 2%
- B&S: 1%
- Others: 13%

Total 2778
• Introduction
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Data flow

CT

MIM Maestro
contouring
dose evaluation

VQA (Hitachi)
TPS (PBA)

MOSAIQ (Elekta)
OIS

PTSIM
Monte Carlo
Linux PC cluster
Intel Xeon 364 cores

CT image, coordinate system,
Range shifter, energy absorber, aperture

Beam parameters
position($x_i$, $y_i$), Energy$_i$, MU$_i$

half a day for one patient
all patients for scanning $1.2 \times 10^8$ protons
some patients for double scatt.
Treatment Nozzles

Broad-beam

Double scatt.

Spot scanning

range modulation wheel

2nd scatt.

range compensator

MLC

scanning magnets

aperture

~ 3m
Software development

Geant4
1M lines
International collaboration 100 developers, 20 years

PTSIM
100k lines
10 developers mainly in Japan, since 2003

Dedicated for Nagoya Proton Therapy Center
10k lines
2 medical physicists, since 2012
Verification

PDD in water

OCR for single spot in water

139.3MeV Depth: 100mm

In

Cross

Measurement

MC

Measurement

MC

FWHM (mm)

FWHM (mm)

Depth (mm)

Energy (MeV)

139.3MeV

71.6MeV

221.4MeV

I=77eV

D25mm

D50mm

D100mm

D200mm
Verification and absolute dose normalization

10x10 field PDD

- R30 SOBP10 FS10 (mm)
- R20 SOBP10 FS10 (mm)
- R12 SOBP10 FS10 (mm)
- R8 SOBP10 FS10 (mm)
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Work flow for patient-specific QA

We have carried out MC dose calculation as independent dose calculation in patient-specific QA for more than 400 patients since 2013.
Clinical Case 1
70.2 GyE to the CTV in 26 fraction (2.7 GyE/fr)

MC

TPS (PBA)

3 fields
Clinical case 2
Paranasal sinus 70.2GyE/26frac SFUD
3 fields 30°, 80°, 120°

• Proton scanning for H&N: Overdose to optic nerve was revealed by MC in two cases out of 78 head and neck patients, and treatment plan was modified.

T. Toshito et al., The 30th Annual meeting of the Japanese Society for Radiation Oncology 2017
Clinical case 3

70.2 GyE/26frac IMPT
3 fields 195°, 80°, 110°

re-plan from 7th fraction

• IMPT for H&N: Intolerable dose to OAR was revealed by MC and treatment plan was modified in two cases out of 43 cases.

T. Toshito et al., The 116th Scientific meeting of the Japan Society of Medical Physics 2018
Clinical case 4

Artificial bone made by titanium

MC

TPS (PBA)

6 fields
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MPEXS [Massive Parallel Electro X-ray Simulator]: Geant4-based GPU Simulators

Developed in Stanford univ./SLAC/KEK  https://wiki.kek.jp/display/mpexs/MPEXS+Project

- NVIDIA CUDA computing platform
- Parallel tracking

- GeForce GTX 1080Ti 1480 MHz 3584 CUDA cores
- Tesla K40 745 MHz 2880 CUDA cores

MPEXS: Massive Parallel Electro X-ray Simulator
- Geant4 EM on CUDA for medical application
- Speedup factor: ∼440

References
- N. Henderson, et al. Joint International Conference on Supercomputing in Nuclear Applications and Monte Carlo 2013 (SNA + MIC 2013) DOI: https://dx.doi.org/10.1051/snamc/201404204

MPEXS-DNA
- Geant4-DNA on CUDA DNA-scale physics and chemical processes
- Speedup factor: ∼1000

References
Migration from PTSIM to MPEXS-h

**PTSIM**
- CPU-based Particle Therapy MC Simulation framework using Geant4
- Versatile
  - Dose calculation
  - Machine design
  - Commissioning
  - Neutron dose
- Since 2003

**MPEXS-h**
- GPU-based MC for hadron on MPEXS platform
- Standard EM and Binary Cascade model in Geant4 are transplanted to CUDA
- Dedicated to dose calculation
- Since 2017
Conclusion

• In Nagoya Proton Therapy Center, in-house Monte Carlo dose calculation system was developed.
• It has been used for independent dose calculation for patient specific QA.
• Treatment planning was modified for a few percent of clinical cases according to Monte Carlo dose calculation.
• We demonstrated that Monte Carlo dose calculation was clinically useful.
• Migration to GPU-based system is conducted to speed-up calculation.