Dosimetricvalidation of the Monte Carlo dose engine in the treatment planning system RayStation for scanned proton fields including apertures

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Introduction

This poster presents the results of a comprehensive study aimed at validating the dosimetric accuracy of the Monte Carlo dose engine in the treatment planning system RayStation version 6 for scanned proton beams including an aperture. The study comprises of 312 measurements of 92 different beam configurations.

Treatment Plans

Beam configuration

92 individual scanned proton plans including a block aperture are created for this study. The plans are either single energy layers or multi energy layers with spot patterns optimized to yield uniform doses in box shaped targets of a water phantom. Plans are created iterating combinations of:

- Proton distal range R and target width M (box plans)
  - R: 6 to 30 cm
  - M: 5 to 20 cm
- Proton beam energy (single energy layer plans)
  - 101.6, 128.6, 160.9, 190.8, 218.2 MeV
- Aperture dimensions
  - $4x4^2$, $6x6^2$, $10x10^2$ and $15x15\ cm^2$
  - $4x10^2$, $10x4\ cm^2$
- Aperture/range shifter to phantom surface airgap
  - 5 to 30 cm
- Use of range shifter
  - ~Half of the plans includes a range shifter

The plans are created in RayStation 5 without inclusion of the apertures, which are subsequently included at the tie of delivery. The apertures are then added to the treatment plans and dose is calculated in RayStation 6, which does support both planning for, and dose calculation with apertures.

Monte Carlo dose algorithm

The MC dose engine in RayStation is fully developed by RaySearch and makes no use of any external software packages. The algorithms and their implementation are specialized to meet the accuracy requirements of radiotherapy dose calculation for treatment planning. The design goal is to realize an implementation that does not significantly prolong the planning process, while carefully maintaining a sufficiently faithful modeling of the relevant physics processes. The various algorithms may be summarized as:

- Bethe Block stopping power and Bohr straggling
- Multiple coulomb scattering (MCS) following Goudsmit-Saunderson theory
- Data driven non-elastic reactions with cross sections per ICRU63 tables
- Class II code
- Voxel steps for electronic energy loss and non-elastic reactions
- Large random-hinge steps for MCS and energy straggling
- Transport of protons, deuterons, and alpha particles
- No transport of delta electrons, neutrons, photons, and heavier secondaries (A>4)
- Phase space modeled at nozzle exit
- Range shifters and apertures modeled as geometrical beam line objects

Experimental

Delivery system

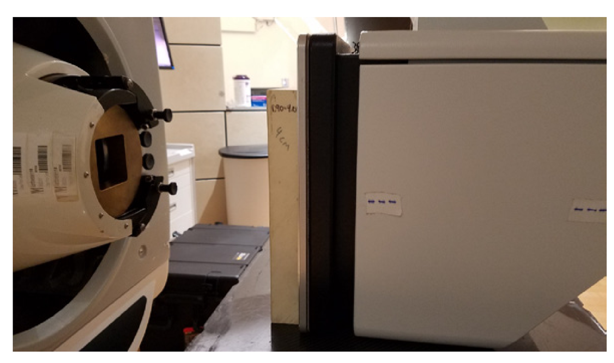
The treatment plans were delivered in the fixed beamline treatment room 1 at the Northwestern Medicine Chicago Proton Center, which is equipped with an IBA universal nozzle. The range shifter used for this study is made of Lucite with a physical thickness of 6.5 cm (7.5 cm WET).

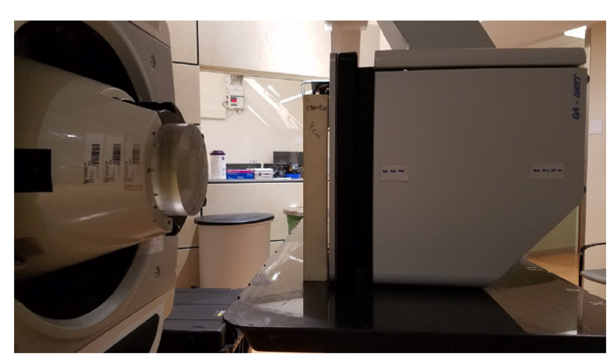
Measurements

The plans were delivered to a solid water phantom with a relative stopping power of 1.00. Three types of measurements are performed:

- Central axis depth doses
  - MLIC Zebra detector from IBA dosimetry
  - Total of 54 measurements
- Lateral profiles in X and Y at various depths
  - Lynx detector from IBA Dosimetry
  - Depths from near surface to end of range
  - Total of 224 measurements (X, Y pairs)
- Absolute dose at center of target
  - MatriXX detector from IBA Dosimetry
  - Total of 34 measurements

A total of 312 individual measurements are thus performed for this study.





Data analysis

To quantify the agreement between measured and calculated doses the following analysis is made:

- Depth doses
  - 1D Gamma(3%, 3mm)
  - Range (distal 90%)
  - Distal fall off (80-20%) (DFO)
- Profiles
  - 1D Gamma(3%, 3mm)
  - Full Width at Half Maximum (FWHM)
  - Left and right Penumbra width (80-20%)
- Absolute doses
  - Dose difference

Results

Figures 1 and 2 shows the differences in penumbra width, and absolute dose as a function of depth, airgap, and field (aperture) size. Tables 1 to 4 summarizes a statistical analysis of the results. Examples of measured and calculated profiles and depth doses are depicted in the graphs to the right

Depth Doses

Overall excellent agreement with no apparent systematic dependence of differences on the use of range shifter

- Range: MeanΔ=0.11 mm, MaxΔ=0.7 mm
- DFO: MeanΔ=0.16 mm, MaxΔ=0.95 mm
- Gamma(3%, 3mm): Mean=100%, Min=0%

Profiles

Overall excellent agreement with no apparent systematic dependence of differences on the use of range shifter, airgap, depth, and field size

- FWHM: MeanΔ=0.15 mm, MaxΔ=1.3 mm
- Penumbra: MeanΔ=0.13 mm, MaxΔ=-2.3 mm

Absolute Doses

Overall excellent agreement with no apparent systematic dependence of differences on the use of range shifter, airgap, depth or field size

- Dose: MeanΔ=0.3%, MaxΔ=1.8%

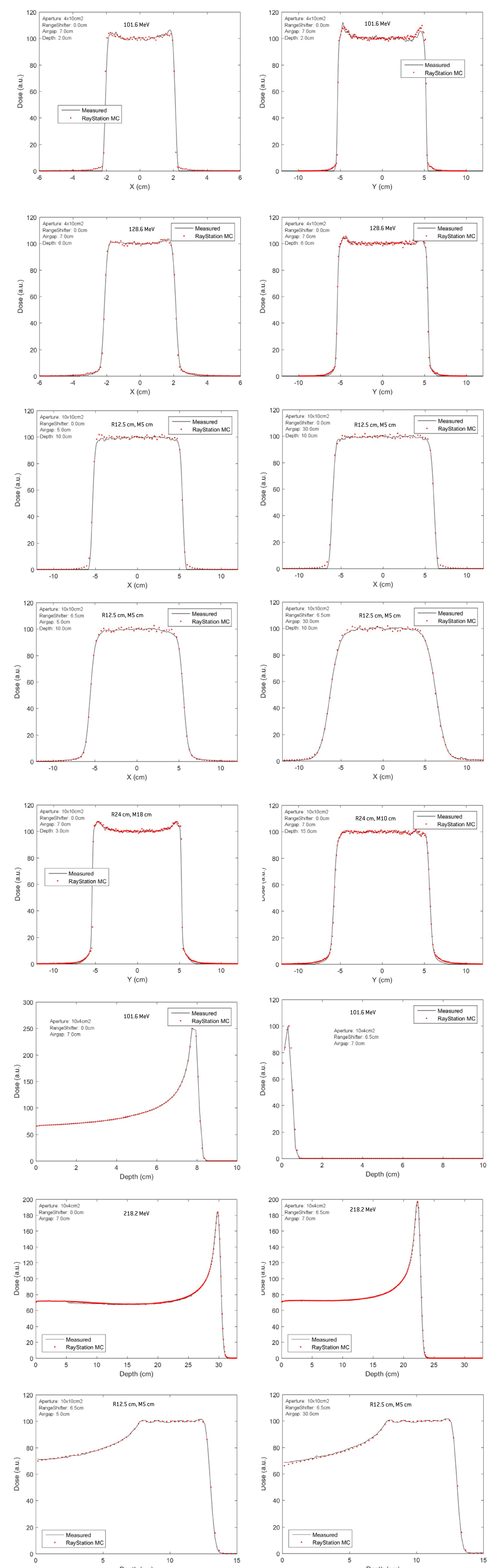


Table 1 Statistical analysis of Range and DFO differences of all depth doses

DEPTH DOSE	#	MEAN (MM)	STD (MM)	MIN (MM)	MAX(MM)
OPEN BEAM					
RANGE	26	-0.03	0.29	-0.53	0.66
DFO	26	0.20	0.40	-0.25	0.95
GAMMA3	26	100.00	0.00	100.00	100.00
RANGE SHIFTER					
RANGE	28	0.19	0.27	-0.36	0.68
DFO	28	0.12	0.26	-0.36	0.56
GAMMA3	28	100.00	0.00	100.00	100.00

Table 2 Statistical analysis of FWHM differences of all profiles

FWHM	#	MEAN (MM)	STD (MM)	MIN (MM)	MAX(MM)
OPEN BEAM					
Δ X FWHM	110	-0.13	0.23	-0.59	1.32
Δ Y FWHM	110	-0.14	0.26	-0.68	1.06
RANGE SHIFTER					
Δ X FWHM	114	-0.10	0.27	-0.82	0.54
Δ Y FWHM	114	-0.15	0.29	-1.08	0.64

Table 4 Statistical analysis of absolute dose differences

ABSOLUTE DOSE	#	MEAN (%)	STD (%)	MIN (%)	MAX(%)
OPEN BEAM					
ΔDOSE	16	0.46	0.58	-0.63	1.23
RANGE SHIFTER					
ΔDOSE	18	0.18	0.75	-0.86	1.76

Table 3 Statistical analysis of Penumbra width differences of all profiles.

PENUMBRA	#	MEAN (MM)	STD (MM)	MIN (MM)	MAX(MM)
OPEN BEAM					
Δ X PEN-L	110	0.01	0.60	-0.89	1.74
Δ X PEN-R	110	0.00	0.65	-0.99	1.79
Δ Y PEN-L	110	0.15	0.69	-1.00	1.93
Δ Y PEN-R	110	0.18	0.71	-0.90	1.88
RANGE SHIFTER					
Δ X PEN-L	114	0.05	0.42	-1.83	1.02
Δ X PEN-R	114	0.09	0.42	-1.82	1.00
Δ Y PEN-L	114	0.32	0.47	-2.18	1.22
Δ Y PEN-R	114	0.25	0.46	-1.56	1.13
TOT	896	0.13	0.56	-2.28	1.93

Figure 1 (Top) Penumbra width differences as a function of depth (right), airgap (mid) and field size (right)

Figure 2 (Bottom) Dose differences as a function of depth (right), airgap (mid) and field size (right)