Bottleneck Issues in Proton Monte Carlo Clinical Implementation and Companion Imaging Techniques – Report of NRG Survey Results

Liyong Lin, PhD, DABR, FAAPM, Associate Professor
Department of Radiation Oncology, Emory University

@Session

“Bottleneck Issues in the Clinic Implementation of Monte Carlo Method in Proton Therapy”
Virtual AAPM 2021
07/25/2021
Two Following Talks in Session

• Jan Schumann “Proton Monte Carlo Platforms – The way towards treatment planning and latest developments”

• Shuai Leng “Dual Energy CT and Metal Artifact Reduction - Fundamentals and Recent Development”
Why NRG survey?

• No publication about how proton therapy centers implement Monte Carlo (MC) and complimentary imaging

• Current practice pattern assessment is required to determine the feasibility of including them in clinical trials.

Lin et al “NRG Oncology Survey of Monte Carlo Dose Calculation Use in US Proton Therapy Centers” IJPT In Press
Goals of NRG survey

• Scope of MC utilization

• Validation methods in heterogeneous phantoms

• Clinical site-specific imaging guidance and proton range uncertainties

• How metal implants are handled in MC
1. 25/28 centers responded to the survey distributed on 5/13/19
2. Commercial Monte Carlo are in the super majority
Discussion of survey results 1a

\[
LET_d(v) = \frac{\sum_{\text{events}} dE \cdot (dE/dx)_p^{1/3}}{\sum_{\text{events}} dE}
\]

\[
LET_d(v) = \frac{\sum_F LET_d^F(v) \times D_F(v)}{\sum_F D_F(v)}
\]

3D modulation IMPT (3D-IMPT) vs. Distal Edge Tracking IMPT (DET-IMPT).
(a) In DET-IMPT the optimization routine assigns weights only to the distal beam spots, fewer # of spots.
(b) In 3D-IMPT, Bragg peaks are selected that cover the whole target volume.

1. Dose-averaged LET (LETd) should be considered for central serial OAR (brainstem as shown; optic chiasm, rectum and bladder Not shown)

2. LET feature is not available at current clinical commercial MC but they are available at in house and research versions.


Grassberger et al “Variations in linear energy transfer within clinical proton therapy fields and the potential for biological treatment planning” IJROBP 2011
LET distributions can be detected by pixelated proton counting detectors by characterizing simultaneous events extracting multi parameters at micron and nano second levels.

NRG survey result 2 - Heterogenous validation

Stoichiometric calibration

Electron density phantom (84%)

Heterogeneous validation

IROC phantom (92%)

Animal tissues (40%)

Animal tissues (28%)
NRG survey result 3

1. 17/25 centers primary dose calculation while 15/17 primary dose optimization
2. More heterogenous sites used MC more often.
3. Some centers don’t have MC optimization capability yet.
Discussion of survey result 3

Two main issues of analytical dose calculations:

1. Absolute output due to modelling of variable air gaps and large angle scattering of range shifters
2. Multi Coulomb scattering over heterogenous tissues (shown too sharp in analytical method)

Huang et al “Validation and application of a fast Monte Carlo algorithm for assessing the clinical impact of approximations in analytical dose calculations for pencil beam scanning proton therapy” Med Phys 2018
NRG survey result 4

1. 19/25 centers used MAR but only 3/25 centers used DECT
2. 11/25 centers used MRI and 7/25 centers used other proton imaging methods
Discussion of survey result-4a

Issues for virtual mono energy images of 79 keV from DECT to replace SECT: (1) not optimal for implant (2) 140 keV images sub optimal INR and BHR

Wolfhart P “Clinical Implementation of Dual-energy CT for Proton Treatment Planning on Pseudo-monoenergetic CT scans” IJROBP 2017
Discussion of survey result - 4b

1. Compared Metal Artifact Reduction (MAR) images to images without MAR
2. Compared Analytical dose calculation to Monte Carlo method
3. Concluded that extra 10 mm treatment margins are needed
4. Limited to titanium implant & did NOT consider complex implant structure that contain materials beyond titanium
5. Did not consider residual artifacts in MAR images
6. Most clinics overwrite implant & surrounding tissues without consensus on how to overwrite (NRG surveys)

Vurberg et al “Dosimetric accuracy of proton therapy for chordoma patients with titanium implants” Med Phys 2013
Acknowledgement

• NRG Proton Monte Carlo workgroup members
• AAPM TG-349 members
• Emory radiation oncology colleagues and trainees

Thank you for your attention! Questions...