Application and Potential of Model-Based Planning in Proton Therapy

Anthony Mascia, PhD
Director of Medical Physics
Cincinnati Children’s Hospital
University of Cincinnati
anthony.mascia@cchmc.org

Disclosures
The Department of Radiation Oncology at Cincinnati Children’s Hospital and University of Cincinnati has a research agreement with Varian Medical Systems.

Last presentation. Last session. Last day

“We wanted to save the best for last.”
- Katja Langen

“You must think I was born yesterday.”
- Anthony Mascia
Outline

• Treatment planning
• Model-based treatment planning
  – Applications and utility
  – Results
• Future work

Treatment Planning

Current Practices

Unique Factors in Proton Treatment Planning

• Beam angle selection
• LET evaluation / optimization
• Emerging and evolving delivery modalities
  – Proton arc therapy, FLASH therapy, GRID therapy, PBS + MLC, etc.
• Range uncertainty
• Nozzle and beam modifiers (e.g. range shifters, collimators, apertures, etc)
• PTV optimization
• Robust evaluation / optimization
• And so forth…
Unique Factors in Proton Treatment Planning

- Beam angle selection
- LET evaluation / optimization
- New emerging or potential technologies, like proton arc therapy, FLASH therapy, GRID therapy, PBS+MLC, etc

Range Uncertainty

Gantry, Nozzle and Beam Modifiers
Robust Optimization

Example: Prostate + Nodes

Optimizations: PTV vs. Robust
Optimizations: PTV vs. Robust

Evaluated at uncertainties of 5mm / 3%

Looking at 95% dose cloud

Range Uncertainty Mitigation RO vs. PTV

Robust Opt - +3% uncertainty
PTV Opt - +3% uncertainty
AI in Radiation Oncology

- Image segmentation
- Dose optimization
- Clinical decision support and outcome prediction
  - Pre-planning outcome predictions
  - Cross-correlating radiation oncology with genomics, imaging, EMRs
- Quantitative imaging
- Quality assurance
Some comments and limitations

- Generally, Radiation Oncology datasets have been small relative to other professions
- Lack of access to high quality, standardized therapy and outcome data is an obstacle
- Specifically, on planning, knowledge-based planning has shown to:
  - Increase efficiency
  - Improve standardization
  - Provide a quality assurance tool
    - “The need is emerging for QA of AI-based processed and other clinically deployed algorithms”

Knowledge-based planning

Knowledge-based planning aspects

- Dosimetric predictions
- Patient selection
- Clinical decision support
- Quality assurance
- Improved plan quality and efficiency
- Knowledge sharing
Predicting potential dosimetric benefits

Using at least 20 patients, models for several OARs are created and validated against at least 20 other patients.

Model used to predict proton benefits for photon patients.

Model Prediction Correlated to Actual Planned Dose Distributions

Patient selection using knowledge base

Patient selection is high priority in proton therapy, particularly in regional or national healthcare systems.

Model created for photon and proton for H&N patients.
Methodology
• Compare predicted and actual plans
• Validate plan quality
• Devise a selection criteria for sorting patients potentially for photon and proton

Manual Doses and KBP Prediction Doses Correlate
• For photon, KBP OAR dose often better than manual (slope = 0.84)
• For proton, KBP OAR dose nearer to manual (slope = 0.96)
• NTCP models may be tied to such predictions, if desired

Step further in clinical decision support...
• Using plan classification and course feature definitions, a clinical decision support model constructed
• Model for H&N proton found at least 30 patients are needed for model
• Provide information prior to planning
Clinical Decision Support

Knowledge-based planning process

Standard planning process

Using plan classification, treatment plan outcome model process

Quality assurance

• Using institutional models to quality assurance patient on clinical trial
• Institutional model used to identify potential outliers, then also model possible improvements given a different optimization approach
Identifying cases for review

- Using a single institution’s model:
  - Patients on trial with outliers, in this case V20 > 37%, can be identified for review or additional planning optimization

Potential to improve plan quality on clinical trial setting

- On trial, based on this study, institutions often sacrificed coverage for OAR dose
- By using model, in many cases, these trade-offs can be rebalanced

University of Cincinnati Initial Collaboration on KBP

Cincinnati Children’s began pilot project with Varian and VUMC testing a RapidPlan model using our patient datasets
Initial Collaboration and Experience with VUMC

Improved efficiency, quality and sharing

General Observations
KBP vs. Clinical Plans

Some practical gaps in applying KBP

- Release of technology
- Enhance knowledge sharing
  - Particularly important in emerging technologies and/or in regions with limited experienced staff
- Generalization of models
  - Beam angle optimization or selection
  - PTV and robust optimization
  - Inter-facility differences in hardware and procedure (i.e. range shifters, range uncertainty quantification and management, etc)
- Incorporating additional patient information
  - For example, radiosensitivity, risk tolerances, re-irradiation setting, etc.

Knowledge Sharing – VUMC & Cincinnati
Moving Forward: University of Cincinnati H&N Model

- Build using clinical patients (H&N, oropharynx)
- Test model against clinical plans
- Assess model generalization for robust optimization
- Presented at AAPM 2018:
  - Manuscript in process

Build model

Case by Case Comparisons: Clinically Acceptable?
Case by Case Comparisons: Clinical Acceptable?

Nominal & Worst-Case Robustness Coverage?

Model Apply to Robustness Optimization?
Summary

- Proton planning has unique aspects (e.g., range uncertainty, beam angle selection, PTV and robust optimization methods, etc.) presenting challenges to model creation
- Knowledge-based models require more patient data (i.e., some studies showing 30 or more for a single model with a single purpose)
- Knowledge-based planning models may
  - Predict dosimetric advantages
  - Improve efficiency
  - Improve standardization
  - Provide quality assurance
  - Pair with clinical decision support models
- Knowledge-based planning is part of the AI future in Radiation Oncology

Acknowledgements

Cincinnati Children’s / University of Cincinnati, Medical Physics
Yongbin Zhang, MS
Eunjin Lee, PhD
Zhiyan Xiao, PhD
Chrysalis Jenkins, CMD
Dana Blasioigne, CMD
Sarah Johnson, CMD
Joseph Specht, BS
Anthony Masia, PhD

Cincinnati Children’s / University of Cincinnati, Physician
John Breneman, MD
Luke Pater, MD
Ralph Vater, MD, PhD
Kevin Radford, MD
Jordan Khafra, MD
Tessa Meyer, MD

Multi-institutional Collaborators
Wilko Verbakel, PhD (VUMC)
Alex Delaney, PhD (VUMC)
Tony Lomax, PhD (PSI)
Lei Dong, PhD (UPenn)

Vendor Collaborators
Christel Smith, PhD
Reynald Vanderstraeten

Institutional Support
University of Cincinnati Medical Center
Cincinnati Children’s Hospital
University of Cincinnati, SOM, Department of Radiation Oncology
Thank you