Evolution of Radiation Treatment Planning

Radhe Mohan, PhD, Professor
Department of Radiation Physics

History Symposium

Intelligent Design of Radiation Treatment Planning

Radhe Mohan, PhD, Professor
Department of Radiation Physics

History Symposium

Treatment Planning is the Most Important Component of Radiotherapy

Plan quality determines the outcome

Accuracy  Optimality
Goals of Treatment Planning

To model / simulate a treatment ("virtual treatment")

To produce a treatment plan that shows the dose distribution expected to be delivered over the course of therapy

To take uncertainties into account

To optimize dose distributions to achieve an appropriate balance between tumor coverage and normal tissue sparing

Basic Process

- Imaging
- Anatomy Delineation
- Beam Configuration Definition
- Dose Distribution Calculations
- Generation of Displays, etc.
- Plan Evaluation

Evolution Over the Years

- Imaging: 3D, 4D, 5D Biological & Functional
- Anatomy Delineation Automation
- Beam Configuration Optimization
- Dose Calculations: Accuracy & Speed
- Generation of Displays & DVHs, TCP, NTCPs, etc.
- Plan Evaluation
- Multi-Criteria Optimization
Evolution Over the Years - Management of Uncertainties

- Reduction
  - More accurate dose computations
  - Imaging
  - Image guidance
- Incorporation
  - Margins
  - Robust optimization

Personal Perspective – Starting in the “Flat-Earth” Era

- Junior faculty at MSKCC hired to develop 2D TPS
- Time-shared computers
- Character maps, hand drawn contours on films, teletypes
- Pen plotters, digitizers, sophisticated terminals
- “Memorial Dose Distribution Computation Service”
  - ~200 institutions served
- In-house PDP 11’s in mid 1970’s and VAX in the early 1980’s

First Ever to be Hacked (1982)

Time Magazine Photo

Helped FBI Find and Apprehend the 414 Gang
3D Treatment Planning – 1980’s

- Rhode Island
- MGH - Goitein (Particles)
- University of Michigan –Fraass, et al
- NCI Contract for the “evaluation” of 3D Treatment Planning (NCI Project Leader: Al Smith)

3D RTP at MSKCC – Propelled by NCI Contract

Monte Carlo Revolution (~1980 → ...)

\[ \frac{\partial \phi}{\partial t} + \nabla \cdot (\vec{v} \phi) + \alpha \nabla^2 \phi = -\langle f - f_0 \rangle / \tau \]
IMRT, Dynamic Multi-Leaf Collimation, Tomotherapy and VMAT (1990's)

The Photon “Bragg Peak”  Sliding Window Delivery With DMLC

Tomotherapy  VMAT

The Intensity Map

4D CT, Respiratory Motion Management and 4D Planning (Late 1990’s and 2000’s)

Deformable Registration, Auto-Segmentation, Dose Accumulation, Adaptive Planning – 2000’s
Particle Therapy
A New Frontier

Drivers of Evolution of Treatment Planning

- Computers
- Imaging
- Technologies (e.g., MLC, Tomo, VMAT, ...)
- Monte Carlo Techniques

Amazing progress made

History of RTP is still being made

Lesson – It never ends

Thanks
Jake Van Dyke

Summary

History to be Made
Challenge of Uncertainties

In day-to-day practice, the dose distribution seen on a treatment plan is accepted as the gospel truth.

It is assumed that WYSIWYG.

However, there are uncertainties:

- Inter- and intra-fractional variations
  - Motion
  - Anatomy changes
  - Set up variations
- Approximations in dose computation methods
- Delineation of targets and normal tissues
- Tumor heterogeneity
- Dose response of tumors and normal tissues

Understanding uncertainties and their impact and minimizing and accounting for them is critical.

Improving the Effectiveness of Treatment Plans

- Functional and biological imaging
- Optimization and intensity-modulation
- Improving our knowledge of dose response of therapy (including in combination with chemical and biological agents)
- Automation
  - For efficiency
  - To reduced inconsistencies
  - Overcome obstacles caused by complexities
- Planning for Particle Therapy