Monte Carlo Validation of the EYEPLAN Treatment Planning System for ocular proton therapy

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on behalf of
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Outline

1. Radiotherapy with protons and ions
   CATANA: The only Italian protontherapy center
   MC and Potontherapy
   EYEPLAN Validation procedure
      Step1: MC vs Exp
      Step2: TPS vs MC
Outline

1. Radiotherapy with protons and ions
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3. MC and Protontherapy
4. EYEPLAN Validation procedure
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   2. Step2: TPS vs MC
Why PROTON and ADRON BEAMS in RADIOTHERAPY?

By Dr. Oliver Jakel (dkfz) Germany
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1. Radiotherapy with protons and ions

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5. And about Ion beams?
The Monte Carlo methods in radiotherapy with protons and carbon ions

- Beam line Design and Optimization
- Dose distributions benchmarking in clinical cases
- Analytic TPS Commissioning
- Monte Carlo planning
- Verify of the transport model beam for inelastic process (especially for carbon ions)
- Verify of radiobiological models
The Monte Carlo methods in radiotherapy with protons and carbon ions

Is the Monte Carlo method quite accurate for:
The TPS proton-therapy validation?
A design dedicated TPS based on Monte Carlo method?

A Monte Carlo (MC) code can be used to commission and validate a proton therapy treatment planning system:

1. MC validation versus experimental data is a fundamental step
2. The computation time for the entire virtual commissioning process is enough long for clinical routine
MONTE CARLO CODES IN PROTON-THERAPY

MCNP
MCNPX
GEANT4
FLUKA
PETRA
LAHET

MC systems actually adopted in the clinical case

**VMCP** M. Fippel et al – A Monte Carlo dose calculation algorithm for proton therapy – Med. Phys. 31 (8), August 2004

**PEREGRINE** L.J. Cox et al. – Proc. Int’l. Conf. NDST-94, p730,


**XiO by CMS** Next future
TPS COMMISSIONING FOR OCULAR PROTON-TRERAPY USING A MONTE CARLO METHOD
OUR EXPERIENCE

We replace the Newhauser’s* work using a SOBP for TPS commissioning in a real clinical case

The output TPS informations are compared to Monte Carlo Geant4 simulation code of a 60 MeV proton beam

We also design and perform a particular new eye-phantoms to compare the TPS output dose distribution to experimental measurement and Monte Carlo results

The composite analysis proposed by Low** is applied for the 3D dose distribution comparison. In this study, the possible accepted criteria for proton therapy are analyzed and discussed


1. Eyeplan analytical ocular proton treatment planning
   - Feature
   - Algorithm
   - Output

2. MC code to verify dose distribution
   - Validation Procedure
   - Beam Line
   - Analysis

3. Dosimetric TPS validation: Measured and Monte Carlo data
   - Experimental Setup
   - Measured Data
   - Dose distribution Comparison

4. Results
   - Discussion
   - Computation Time
   - Outlook
Entire Beam Line Simulation

Modify source parameters

Phantom and Detector Simulation

Measure benchmark data

MC output agree with measured data?

NO

YES

Verify TPS results vs Measured data (when possible)

Calculate dose distribution when we haven't measured data (MC vs TPS)

Verify agreement among TPS vs MC

STEP 1

STEP 2
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Application developed using GEANT4 libraries: *Hadrontherapy*

*Hadrontherapy* is an advanced example inside the GEANT4 toolkit distribution:

geant4_installDir/examples/advanced/hadrontherapy

- General geometric proton beam line configuration
- 3D dose distribution calculation using a sensitive detector with cubic voxel in different materials
- More physics model implementations


CATANA beam line simulation

Final Nozzle in treatment room
CATANA

Time – dependent geometry
The differences between nuclear interaction models are not observable as long as we consider dose distributions”*.

* Paganetti et Al. “Accurate Monte Carlo simulations for nozzle design, commissioning and quality assurance for a proton radiation therapy facility” [Med. Phys. 31.7., July 2004]
Entire Beam Line Simulation

- Modify source parameters
  - NO
  - YES

Phantom and Detector Simulation

- Measure benchmark data
  - YES
  - NO

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STEP 1

STEP 2
STEP 1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS

DOSIMETRIC PARAMETERS USED TO COMPARE THE AGREEMENT BETWEEN SIMULATED AND EXPERIMENTAL DATA

- Full Energy
- Bragg peak
- and SOBP

- Peak – plateau Ratio
- Practical Range
- Distal dose fall-off (90%-10 %)
- FWHM
- Modulation Range

- Profile

- Beam Width 50%
- Penumbra (80% – 20%)
- Homogeneity
- Symmetry
STEP 1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS

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STEP 1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS

**LowEnergy + Precompound**

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STEP1: AGREEMENT BETWEEN SIMULATED AND MEASUR ED RESULTS

Experimental and Simulated Lateral dose distribution comparison

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<th>Penombra Laterale SX</th>
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Two different configurations planned

NON Clinic Case

Clinical Configuration

The Comparisons between dose distribution are along and perpendicular to beam direction at different PMMA depth
STEP 1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS
J. Van Dyk et al.
Commissioning and quality assurance of treatment planning computers

B. Fraass et al.
American Association of Physicists in Medicine Radiation Therapy Committee
Task Group 53: Quality assurance for clinical radiotherapy treatment planning

Any report, currently in literature related to the quality assurance of a TPS, NO introduces sections dedicated to proton beam radiotherapy

The guidelines traced by various authors are however of general nature, so we can extend the procedures to any treatment planning system in general
How compare Two dose distributions?

Analysis System used

**Composite Analysis: Dose Difference, DTA e Gamma function**

D. A. Low et al.

*A technique for the quantitative evaluation of dose distributions*


**NAT Distribution**

N. L. Childress et al.

*The design and testing of novel clinical parameters for dose comparison*


**NDD e MADD**

S. B. Jiang et al.

*On dose distribution comparison*

STEP1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS

NON Clinical case (Perpendicular to beam direction)

GOOD Agreement among TPS and Measured Data. Isodose level Maximum difference = 1 mm
**STEP 1: VALIDAZIONE DEL MC RISPETTO A DATI SPERIMENTALI**

**NON Clinical case (Perpendicular to beam direction)**

Gamma function distribution is not uniform, the values fail criteria are focused around 90% isodose level. This difference can be due to a non accurate phantom centering. In the same mode, local spot near to unit gamma value (inside 90% isodose level) are given by a non ideal detector homogeneity.
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Entire Beam Line Simulation

Modify source parameters

Phantom and Detector Simulation

Measure benchmark data

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Verify TPS results vs Measured data (when possible)

Calculate dose distribution when we haven’t measured data (MC vs TPS)

Verify agreement among TPS vs MC
Many of its features apply to treatment planning program in general:

- Three – dimensional definition of the tumor volume and normal structures
- Possibility of delivering the treatment beam from any direction in space
- Provision of arbitrary viewpoints including a beam’s eye point of view

**INPUT NEED (configuration of Environment file)**

- 2 geometric parameters
  - (Virtual source – isocenter, Final collimator – isocenter)
- 3 dosimetric parameters
  - (Later penumbra, dose distal fall-off (Range) and Proximal Bragg Peak Points)
Ultra Simplified Broad beam method using the dosimetric parameters (Environment file) to get out a non-divergent beam, large enough beam so that the relative depth-dose curve on the central axis does not depend on the field amplitude.

Eyeplan reconstructs eye dose distribution so that isodose 90% enclose totally PTV, with a security Margin of 2.5 mm.

Eyeplan uses a dose plane divided in voxels (Variable dimension) to perform all 3D dose distribution in entire eye.

There is no density measurement in Eyeplan, as it gives range and modulation in millimeters of whatever the eye material is. The density only makes a difference when you convert the measured range from the material you use to measure it. Eyeplan only uses one model of the beam penumbra and depth dose for all combinations of range and modulation.
STEP2: EYEPLAN COMMISSIONING

3D EYEPLAN dose distribution (Transversal plan)

Calculation and Visualization of isodose curve in more eye section plane

Mean Spatial Resolution = 0.8 mm

Dose-Volume histogram (HDV) for more important eye structure and PTV
Entire Beam Line Simulation

Modify source parameters

NO

Measure benchmark data

Phantom and Detector Simulation

MC output agree with measured data?

YES

Verify TPS results vs Measured data (when possible)

Calculate dose distribution when we haven’t measured data (MC vs TPS)

STEP 2

Verify agreement among TPS vs MC

STEP 1

Modify source parameters

NO

Measure benchmark data

Phantom and Detector Simulation

MC output agree with measured data?

YES

Verify TPS results vs Measured data (when possible)
STEP 2: TPS vs Monte Carlo

NON Clinical case (Perpendicular to beam direction)

The gamma voxel distribution, when the test fails, is uniform on the whole gamma function distribution inside the 90% dose level (Statistic fluctuations in the MC simulation).

Geant confirms the initial perception about positioning error and film inhomogeneity.

5% - 1 mm
94% voxel pass
Differences between 20% Isodose levels along beam direction = 0.6 mm

Good agreement TPS versus MC
Maximum difference = 0.6 mm

Range Difference (90% idodose) < 0.2 mm

Direct Comparison between Isodoses levels

5% - 1 mm
95% voxel pass

NON Clinical case (Along beam direction)

Why these differences???
STEP 2: TPS vs Monte Carlo

NON Clinical case (Along beam direction)

Only along beam direction there is experimental data (SOBP as input in Enviroment file configuration)

The accuracy of Monte Carlo simulations is superior to that of EYEPLAN

Eyeplan is not able to reproduce the distal dose fall-off as an input data in the TPS configuration file

Eyeplan makes an approximation the treatment modulation region to a constant value
Range Difference (90% Isodose level) < 0.2 mm

Difference in lateral penumbras < 0.2 mm

Eye structure complexity, in a real clinical case, can modify the results found?!

Eye structure emphasizes the maximum differences in dose distal fall-off calculation
STEP 3: VERIFY TPS and MC RESULTS
Summary of the results for the clinical configuration (along beam)

2D gamma function distribution

The discordances appear also in gamma distribution
DISCUSSION

Our results suggest that the GEANT4 Monte Carlo code is suitable to validation procedure

THE COMPARISON DEMONSTRATE SOME DIFFERENCES AMONG MC RESULTS AND TPS OUTPUT. THESE DIFFERENCES ARE DUE TO TPS LIMITS:

- LOW SPATIAL RESOLUTION
- ESTIMATE MAXIMUM DOSE TO CONSTANT VALUE
- NO MULTIPLE SCATTERING

THESE MAXIMUM DISCREPANCIES ARE EQUAL TO THOSE REPORTED IN LITERATURE BY NEWHAUSER’S WORK (NON CLINICAL CONFIGURATION)

THE EYE STRUCTURE IN EYEPLAN INVOLVES A MORE INACCURACY. HOWEVER THE DIFFERENCES REVEALED ARE VERY CONTAINED AND CLINICALLY ACCEPTABLE
WE EXPECT THAT THESE TECHNIQUES WILL BE USED FOR NOZZLE DESIGN WORK, DOSE-PER-MONITOR-UNIT PREDICTIONS AND, EVENTUALLY, ROUTINE TREATMENT PLANNING

TO RAISE TPS ACCURACY (Analytic and Monte Carlo):

- Study of Multiple scattering effect (especially in more high energy beams)
- Imagines DICOM (anatomical more accurate than mathematical reconstruction)
- pCT e no xCT for DICOM images

TO REDUCE COMPUTATION TIME

- Optimization of the simulation processes
- To use a “more and more-node” cluster system
Supported by

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