Treatment Planning System (TPS) Commissioning and QA
Practical Medical Physics SAM
Challenges and Opportunities
Greg Salomons

Outline

- Why a Session on Treatment Planning Systems?
- Brief History of Treatment Planning Systems
- A Few Lessons Learned First Hand
- Key Consideration When Using Gamma Analysis

Reason for the Session

- Serious Incidents Involving TPS
  - Need to learn from incidents
- An Increasing Level of Complexity
  - More complex delivery system
  - More complex planning system
- TPS a Key Component of Radiation Therapy
  - Role of TPS fits in entire treatment process
- New Recommendations
  - MPPG #5 Published July 1
- Sharing our Experiences
  - Panel Discussion
Incidents Involving TPS

- Almost 1/3 of serious incidents in radiation therapy involve TPS

Table 3. Causes and frequencies of accidental exposure in radiotherapy

<table>
<thead>
<tr>
<th>Accidental exposure in external beam therapy</th>
<th>No. of cases</th>
<th>Percentage of cases (rounded)</th>
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<tr>
<td>Equipment problems</td>
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<td>6.5</td>
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<td>Maintenance</td>
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<td>Calibration of the beams</td>
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<td>Treatment planning and dose calculation</td>
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<td>28</td>
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<td>Simulation</td>
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<td>9</td>
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<tr>
<td>Treatment set-up and delivery</td>
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<td>20 (*)</td>
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<tr>
<td>Total</td>
<td>46 (*)</td>
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Table #3 from ICRP 86

An Increasing Level of Complexity

- More Sophisticated Treatments
  - Increased data requirements
- Require More Complex Plans
  - More difficult to identify errors
- Using More Advanced Software
  - Better model fitting required

Brief History of TPS

In 3 stages
1. Early Computer Based Planning
   - Computers and Medical Physics
   - Where it all began

2. CT Based Planning
   - A new level of complexity
   - Everybody’s planning now

3. Dynamic Treatments
   - The solution is no longer obvious
   - Everything is moving now

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Early Computer Based Planning

Where it all Began

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Development of Computer Based Planning

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<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tr>
<td>1947</td>
<td>First Computer Bug</td>
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<tr>
<td>1954</td>
<td>First program for calculating external beams</td>
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<tr>
<td>1970</td>
<td>First commercial TPS</td>
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</table>
• Initially most patients treated with SSD 100
  – For non SSD 100 fields Inverse Square Correction applied by therapists
• 1982 TPS acquired
  – Isocentric treatments
  – Inverse Square Correction continued to be applied by therapists
  – TPS already incorporated distance correction
  – Under dose by up to 30%

Source: ICRP 86 2.2

• Problem continued till 1991
• Discovered during commissioning of new TPS
• Contributing Factors
  – Shortage of medical physicists
  – No systematic quality assurance program
  – No written procedure for Correction calculations

Source: ICRP 86 2.2

CT Based Planning
A new level of complexity
Development of CT Based Planning

- 1971 First CT Scanner
- 1974 First "whole body" CT system
- 1978 First CT based TPS
- 1990 First 3D Planning System

Incident USA 2007 (Image Orientation)

- MRI imaging for Gamma Knife treatment
- The patient was positioned “head first”, but “feet first” scan technique selected
- The axial images reversed left-to-right
- Resulted in an 18 mm shift of isocentre
- 18 Gy single fraction given to wrong location

Dynamic Treatments

The Solution is no Longer Obvious
Development of Dynamic Treatments

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<td>Inverse planning proposed</td>
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<td>First experimental step-and-shoot delivery</td>
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<td>1994</td>
<td>VMAT first Proposed</td>
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<td>2002</td>
<td>First Commercial tomotherapy unit</td>
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<td>2007</td>
<td>VMAT available on conventional linac</td>
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QA Challenges with Dynamic Planning

- MLC dosimetry challenges
  - Tongue in groove
  - Leaf Gap
  - Measurement and modeling of small fields
- IMRT (complex motion)
- VMAT (coordinated motion)
- Gating – Synchronized delivery

Incident USA 2005 (Missing MLC Data)

- IMRT Patient re-planned mid treatment
- Computer hung due to network problem during saving of the plan
- Saved plan contains:
  - Actual fluence data
  - Partial DRR,
  - No MLC control point data

Source: IAEA Training Course Prevention of Accidental Exposure in Radiotherapy Module 2.10 Accident Update (2010)
Incident USA 2005 (Missing MLC Data) cont.

- Plan allowed to be used prior to physics check due to tight timelines for re-plan
- The patient is treated without MLCs for three fractions
- Discovered when verification plan is created and run on the treatment machine.
- Patient received about 39 Gy in 3 fractions

Source: IAEA Training Course Prevention of Accidental Exposure in Radiotherapy Module 2.10 Accident Update (2010)

Question

How common are incidents involving TPS?

- 0% 1. 10% of reported incidents
- 0% 2. 1/3 of all reported incidents
- 0% 3. 1/2 of all reported incidents
- 0% 4. 2/3 of all reported incidents
- 0% 5. 3/4 of all reported incidents
How common are incidents involving TPS?

1. 10% of reported incidents
2. 1/3 of all reported incidents
3. 1/2 of all reported incidents
4. 2/3 of all reported incidents
5. 3/4 of all reported incidents

Reference ICRP 86 Table 3

Learning from Experience

Some lessons are learned the hard way

- Critical Assessment of QA
- Personal Lessons
  - The Value of the Physics Chart Check
  - Test the Extremes
  - Be clear on What is Being Tested
**Critical Assessment of QA**


- Uses incident reporting system to identify types of errors and severity
- Identifies what measures could have caught the incident
- Uses this to assess effectiveness of different Quality Assurance checks

- Critical assessment of QA techniques Needed
- QA of TPS extends beyond physics

**The Value of the Physics Chart Check**

Irregular field Output Calculations
- Options for use with CT data were available even when no CT data present
- Selection of ‘surface correction’ tick box resulted in incorrect dose calculations when necessary CT data was not present
- Caught at physics plan check. Output values did not make sense
- Physics judgment is Vital

Output Factor given as 1.03
Instead of 0.97

**Test the Extremes**

- A published review of TPS accuracy reported < 2% discrepancy.
  - Only tested one dynamic wedge output factor at one field size (10x10 cm²) and one depth (10 cm).
- Comparisons made under a wider range of conditions.
  - Found discrepancies of up to 6% for some asymmetric field sizes

- Check the extremes
  - The accuracy of MU calculations for dynamic wedge with the Varian’s Anisotropic Analytical Algorithm (AAN+), Salomons, G. J., Kerr, A. T., Mei, X., & Patel, D. Medical Physics, 35 (2008), 4289–4291.
  - Evaluating IMRT and VMAT dose accuracy: practical examples of failure to detect systematic errors when applying a commonly used metric and action levels, Nelms, B. E., Chan, M. F., Jarry, G., Lemire, M., Lowden, J., Hampton, C., & Feygelman, V. I. Medical Physics, 40(2013).
Be clear on What is Being Tested

- Large fields split into multiple fields due to MLC travel limits.
- TPS performs field splitting automatically at plan approval and copies original plan dose to split field plan, no recalculating.
- Calculation uses incorrect jaw position for second sub fields underestimates dose.
- Verification plans correctly recalculated the already split fields: did not catch the error.
- Caught when patient re-scanned in middle of treatment.
- Be aware of what your QA is measuring.

Question

One of the principals for Testing a TPS is:

- 0% 1. Only test what you can measure
- 0% 2. Test the extremes
- 0% 3. Test all field sizes and depths
- 0% 4. Only test clinically relevant field shapes
- 0% 5. Repeat same dose calculation on a regular basis to catch changes
One of the principals for Testing a TPS is:

1. **Only test what you can measure**
   - Apply Physics judgment to such cases
2. **Test the extremes**
   - Calculations near boundaries are more likely to reveal errors or ambiguities
3. **Test all field sizes and depths**
   - Multiple tests under similar conditions are not likely to reveal new problems
4. **Only test clinically relevant field shapes**
   - Know the limits of the planning system
5. **Repeat same dose calculation on a regular basis to catch changes**
   - Software does not break. The same test under the same conditions gives the same results


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Gamma Analysis

**Common Issues**

- Has become a preferred comparison method in the delivery validation of radiotherapy treatment plans
- Can easily be misused
- References:
  - Tolerance Levels and Methodologies for IMRT Verification QA (2012), Daniel Low, AAPM Virtual Library
The Gamma Test

• Gamma indicates level of agreement between two data sets relative to some dose and distance criteria.
• Gamma test is a comparison between two dose maps:
  – ‘Reference’ and ‘Evaluated’
  – For each points on the Reference a closet point is found on the Evaluated
  • Reference point applies circular acceptance region (γ=1)
  • Evaluated data searched for nearest point to Reference point.
  • Gamma is “distance” to Evaluated point

Effect of Resolution

• If Reference data has higher resolution than Evaluated some points that should pass might fail
  – E.g. If no evaluated data point exists in the circle around Reference point C then it will generate a Gamma value based on Evaluated Point B and will fail, though it should have passed
  • Distance-to-Agreement criteria must be larger than Evaluated resolution

Effect of Noise

• Noise in Evaluated can artificially increase pass rates
  – Evaluated data given dose offset and Gaussian noise
  – Should fail Gamma test
  • Due to noise Evaluated is passing Gamma test in places where is should fail
Effect of Noise

- Noise in Reference data translates into noise in Gamma values.
- Noise shifts Reference data closer to or further from Evaluated data

![Graph showing the effect of noise on Reference and Evaluated data]

- Reference Point A shifted closer to Evaluated data
- Reference Point B shifted away from Evaluated data

Question

2D Evaluated data used for a Gamma test should:

0% 1. be obtained from measurements
0% 2. be obtained from the planning system
0% 3. match the resolution of the Reference data
0% 4. be higher resolution than the DTA criteria
0% 5. not be smoothed or interpolated
2D Evaluated data used for a Gamma test should:

1. **be obtained from measurements**
   - Noisy measurement data may reduce gamma values

2. **be obtained from the planning system**
   - The usual standard but not always necessary

3. **match the resolution of the Reference data**
   - The resolution of the Reference data is not critical

4. **be higher resolution than the DTA criteria**

5. **not be smoothed or interpolated**
   - Noisy or low resolution Evaluated data will give incorrect Gamma values

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<th>Year</th>
<th>Who</th>
<th>Nature of document</th>
<th>Title</th>
<th>Comments</th>
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<tr>
<td>1987</td>
<td>ICRU</td>
<td>Report 42</td>
<td>Use of computers in External beam Radiotherapy Procedures with High-Energy Photons and Electrons</td>
<td>• Very General Recommendations: • Repeat same calculation on a regular basis • Maintain manual calculation skills • In Vivo measurements in limited cases</td>
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<tr>
<td>1995</td>
<td>AAPM</td>
<td>TG #23 Report 55 downloadable data</td>
<td>Radiation Treatment Planning Dosimetry Verification</td>
<td>• Data and measured/computed results to verify accuracy of TPS • Outdated IAEA 1540 replaces it</td>
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<tr>
<td>1998</td>
<td>AAPM</td>
<td>TG #53 Report 63</td>
<td>Quality assurance for clinical radiotherapy treatment planning</td>
<td>• Covers acceptance, commissioning, ongoing QA, Personnel • Includes tests of imaging, dose calculation, output, security • For Photon, Electron, Brachytherapy</td>
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<td>1999</td>
<td>Swiss Society of Radiobiology and Medical Physics</td>
<td>Published Report</td>
<td>Quality Control of Treatment Planning Systems for Teletherapy Recommendations No 7</td>
<td>Very practical guidelines</td>
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<td>2004</td>
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<td>Technical Report #430</td>
<td>Commissioning and Quality Assurance of Computerized Planning Systems for Radiation Treatment of Cancer</td>
<td>Includes purchase process, training, patient specific QA, recommendations after upgrades, 244 recommended tests, Emphasis on staffing and reporting structures</td>
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<td>2006</td>
<td>AAPM</td>
<td>TG #76</td>
<td>The management of respiratory motion in radiation oncology</td>
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| 2007 | IAEA         | TECDOC 1540   | Specification and Acceptance Testing of Radiotherapy Treatment Planning Systems | • Provides Data, Tests and Results for use in evaluating a TPS  
• Include functional tests, dose accuracy tests,  
• This IAEA report uses the description of the tests directly from the IEC 62083 Standard |
| 2007 | AAPM         | AAPM TG #105 Report (Medical Physics Article) | Issues associated with clinical implementation of Monte Carlo-based photon and electron external beam treatment planning | • Issues specific to Monte Carlo algorithms |
| 2007 | ACR          | American College of Radiology practice guideline | Practice Guideline for Intensity-Modulated Radiation Therapy (IMRT) | • High level document |
| 2008 | IAEA         | IAEA TECDOC 1583 | Commissioning of Radiotherapy Treatment Planning Systems: Testing for Typical External Beam Treatment Techniques | • Practical tests relevant to typical planning scenarios  
• Helps give a sense of accuracies in planning system |
| 2008 | ESTRO        | Booklet #9    | Guidelines for the Verification of IMRT | • Includes In Vivo dosimetry  
• Summarizes practices at different centers |
| 2008 | AAPM         | Med. Phys. 35, 4186–4215 (2008) TG #106 | Accelerator beam data commissioning equipment and procedures | • Include recommendations for pre-processing data prior to use with TPS commissioning |
| 2009 | AAPM         | Med. Phys. 36, 5359 - 5373 (2009). TG #119 | IMRT commissioning: Multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119 | • Clinically relevant set of tests  
• Reports plan results and measurements from 10 different institutions  
• Planning and QA test data available via aapm.org |
<table>
<thead>
<tr>
<th>Year</th>
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<tr>
<td></td>
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<td>• An expansion of ICRP 86 focusing on the risks in new technology</td>
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<td>• A critical evaluation of IMRTQA techniques</td>
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<td>• Critical analysis of the effectiveness of various QA techniques</td>
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<td>2013</td>
<td>Molineu et al</td>
<td>Med Phys, 40, 2013</td>
<td>Credentialing results from IMRT irradiations of an anthropomorphic head and neck phantom</td>
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<td>• Significant number of failures with RPC Credentialing</td>
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<td>Includes discussion of manual vs TPS MU calculations</td>
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<td>• Deliberately introduced errors into TPS parameters to determine dosimetric effect</td>
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<td>• Applied TG #119 and IROC TLD tests to evaluate their effectiveness at detecting the errors</td>
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<td>• A tool to check RT data transfer</td>
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<td>Canadian Partnership for Quality Radiotherapy Guidance Document</td>
<td>Technical Quality Control Guidelines for Canadian Radiation Treatment Centres Treatment Planning Systems</td>
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<td>Treatment Planning System Commissioning and QC/QA</td>
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<td>Method for Evaluating QA Needs in Radiation Therapy</td>
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<td>Commissioning of beam models in Monte Carlo-based clinical treatment planning</td>
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<td>Strategies for Effective Physics Plan and Chart Review in Radiation Therapy</td>
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