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. Classes and frequencies of accidental exposure in radiotherapy

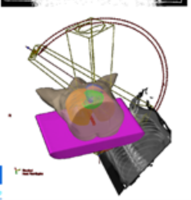
Accidental exposures in external beam therapy	No. of cases	Percentage of cases (rounded)
Equipment problems	3	6.5
Maintenance	3	6.5
Calibration of the beams	14	30
Treatment planning and dose calculation	13	28
Simulation	4	9
Treatment set-up and delivery	9	20 (**)
Total	46 (*)	100

Table #3 from ICRP 86

An Increasing Level of Complexity

From

To



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

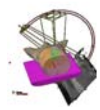
Brief History of TPS

In 3 stages

Brief history of TPS

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

Events
Incidents
Documents

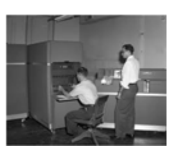


Early Computer Based Planning

Where it all Began

Development of Computer Based Planning

1947	First Computer Bug
1954	First program for calculating external beams
1970	First commercial TPS



Incident UK 1982-1990 (Correction Factor)

- 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

Incident UK 1982-1990 (Correction Factor) cont.

- 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

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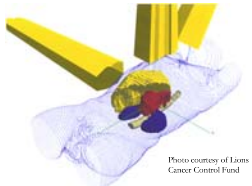
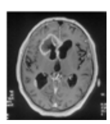


Photo courtesy of Lions Cancer Control Fund

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



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Source: IAEA Training Course Prevention of Accidental Exposure in Radiotherapy Module 2.10 (2010), NRC Medical Event Report

Dynamic Treatments

The Solution is no Longer Obvious

Development of Dynamic Treatments

1988	Inverse planning proposed
1993	First experimental step-and-shoot delivery
1994	VMAT first Proposed
2002	First Commercial tomotherapy unit
2007	VMAT available on conventional linac

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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**

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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)

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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

1

How common are incidents involving TPS?

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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

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Reference ICRP 86 Table 3

Learning from Experience

Some lessons are learned
the hard way

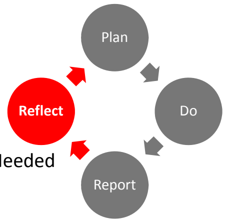
Learning from Experience

- 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

2012 Ford, E. C. *et al.* Quality control quantification (QCQ): A tool to measure the value of quality control checks in radiation oncology. *Int. J. Radiat. Oncol. Biol. Phys.* **84** (2012)**,** e263–e269.

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

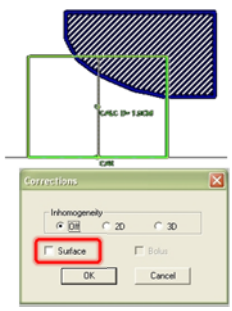


- Critical assessment of QA techniques Needed
- QA of TPS extends beyond physics

The Value of the Physics Chart Check

Irregular field Output Calculations

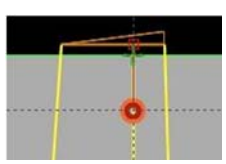
- Options for use with CT data were available even when no CT data present
- Selection of 'surface correction' tick box resulted in incorrect dose calculations when necessary CT data was not present
- Caught at physics plan check. Output values did not make sense
- Physics Judgment is Vital



Output Factor given as 1.03 Instead of 0.97

Test the Extremes

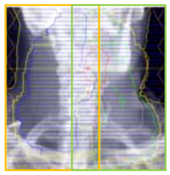
- A published review of TPS accuracy reported < 2% discrepancy.
  - Only tested one dynamic wedge output factor at one field size (10x10 cm^2) and one depth (10 cm).
- Comparisons made under a wider range of conditions.
  - Found discrepancies of up to 6% for some asymmetric field sizes



- Check the extremes
  - **The accuracy of MU calculations for dynamic wedge with the Varian's Anisotropic Analytical Algorithm**. 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. (). *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 re-calculating
- 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

2

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

Reference: Scientific Software Testing: Analysis with Four Dimensions Kelly, D., Thorsteinson, S., & Hook, D. (2011).. IEEE Software, 8(3), 84–90.

Gamma Analysis

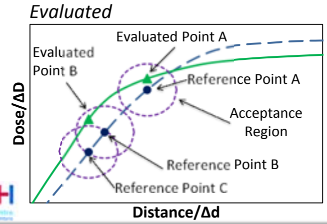
Common Issues

Gamma Analysis

- 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
  - Analysis and evaluation of planned and delivered dose distributions: Practical concerns with gamma and chi evaluations. *J. Phys.: Conf. Ser., 444* (2013) Schreiner, L. J., Holmes, O. E., Salomons, G., & Jechel, C.

The Gamma Test

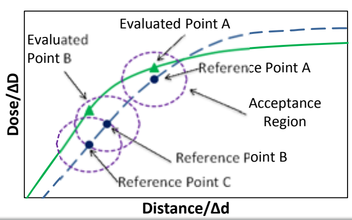
- Gamma indicates level of agreement between two data sets relative to some dose and distance criteria.
- Gamma test is a comparison between two dose maps:
  - *'Reference'* and *'Evaluated'*
  - *For each points on the Reference a closet point is found on the Evaluated*



- 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

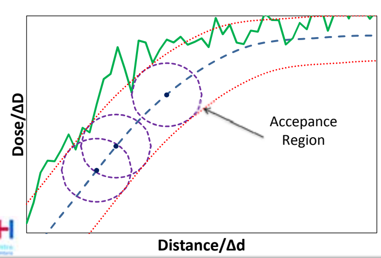
- If Reference data has higher resolution than Evaluated some points that should pass might fail
  - E.g. If no evaluated data point exists in The circle around Reference point C then it will generate a Gamma value based on Evaluated Point B and will fail, though it should have passed



- Distance-to-Agreement criteria must be larger than Evaluated resolution

Effect of Noise

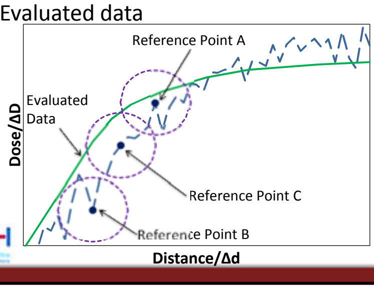
- Noise in Evaluated can artificially increase pass rates
  - Evaluated data given dose offset and Gaussian noise
  - Should fail Gamma test



- 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



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

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Question

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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

3

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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

Reference: Analysis and evaluation of planned and delivered dose distributions: Practical concerns with gamma and chi evaluations. Schreiner, L. J., Holmes, O. E., Salomons, G., & Jechel, C. (2013). J. Phys.: Conf. Ser., 444(1), 012016.

Selection of Key Documents on Treatment Planning System Commissioning and Quality Assurance

Year	Who	Nature of document	Title	Comments
1955	Tsien, K. C.	Br. J. Radiol. 28, 432–439 (1955).	The Application of Automatic Computing Machines to Radiation Treatment Planning.	• First use of computers for treatment planning
1980	McCullough et al	Int. J. Radiat. Oncol. Biol. Phys. 6, 1599 - 1605 (1980)	Performance Evaluation of Computerized Treatment Planning Systems for Radiotherapy: External Photon Beams	• 1st general article on TPS QA • list of recommended tests • Discussion of appropriate accuracy
1987	ICRU	Report 42	Use of computers in External beam Radiotherapy Procedures with High-Energy Photons and Electrons	• Very General Recommendations: • Repeat same calculation on a regular basis • Maintain manual calculation skills • In Vivo measurements in limited cases
1990	Jacky et al	Int. J. Radiat. Oncol. Biol. Phys. 18, 253 – 261 (1990)	Testing a 3-D Radiation Therapy Planning Program	• Compare against independent calculations • Testing based on program specifications • Performed hand calculations to match computer generated output using the same algorithm as computer
1993	Van Dyke et al	Int. J. Radiat. Oncol. Biol. Phys. 26, 261–273 (1993).	Commissioning and Quality Assurance of Treatment Planning Computers	• Comprehensive overview of TPS Commissioning and QA • Detailed tests for both commissioning and ongoing QA described • Recommended tolerances given • Recommends both manual point dose calculation check and in Vivo dosimetry
1995	AAPM	TG #23 Report 55 downloadable data	Radiation Treatment Planning Dosimetry Verification	• Data and measured/computed results to verify accuracy of TPS • Outdated IAEA 1540 replaces it
1998	**AAPM**	**TG #53 Report 63**	**Quality assurance for clinical radiotherapy treatment planning**	**• Covers acceptance, commissioning, ongoing QA, Personnel** **• Incudes tests of imaging, dose calculation, output, security** **• For Photon, Electron, Brachytherapy**

1999	Swiss Society of Radiobiology and Medical Physics	Published Report	Quality Control of Treatment Planning Systems for Teletherapy Recommendations No 7	• Very practical guidelines
2001	ICRP	Publication 86 Ann. ICRP 30, 1–70 (2001).	Prevention of accidental exposures to patients undergoing radiation therapy	• Summary and analysis of accidents in RT
2002	Kilby W. et al	PMB 47 1485–1492 (2002)	Tolerance levels for quality assurance of electron density values generated from CT in radiotherapy treatment planning.	• An 8% error in estimating tissue density will cause a 1% dose error
2003	AAPM	Med. Phys. 30, 2089–2115 (2003).	Guidance document on delivery, treatment planning, and clinical implementation of IMRT	• 1st Guidance document on IMRT • Inverse planning • Leaf sequencing algorithms • MLC leaf gap • Modeling small fields • Discusses individual patient QA
2003	AAPM	Med. Phys. 30, 2762-2792 TG #66	Quality assurance for computed-tomography simulators and the computed tomography-simulation process	• Includes RED curve tests and DRR tests
2004	AAPM	TG #65 REPORT NO. 85	Tissue Inhomogeneity Corrections for Megavoltage Photon Beams	• Highlights increased complexity of TPS calculations with CT based planning
2004	ESTRO	Booklet #7	Quality Assurance of Treatment Planning Systems Practical Examples for Non-IMRT Photon Beams	• Include block cutter and Data Transfer checks
2004	IAEA	Technical Report #430	Commissioning and Quality Assurance of Computerized Planning Systems for Radiation Treatment of Cancer	• Includes purchase process, training, patient specific QA, recommendations after upgrades • 244 recommended tests • Emphasis on staffing and reporting structures
2006	Netherlands Commission on Radiation Dosimetry	Published Report	Quality assurance of 3-D treatment planning systems for external photon and electron beams	

2006	AAPM	TG #76	The management of respiratory motion in radiation oncology	
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
2008	Breen S, et al	Med. Phys. 35, 4417–4425 (2008)	Statistical process control for IMRT dosimetric verification	• Process Control charts applied to IMRT QA
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
2009	AAPM	JACMP 10(4):16-35 (2009) TG #201 Initial Report	Information technology resource management in radiation oncology	• Tasks and personnel required for radiation oncology IT infrastructure

2009	ICRP	Publication112 Annals of the ICRP 39, (2009).	Preventing Accidental Exposures from New External Beam Radiation Therapy Technologies.	• An expansion of ICRP 86 focusing on the risks in new technology
2011	Nelms et al	Med. Phys. 38, 1037–1044 (2011).	Per-beam, planar IMRT QA passing rates do not predict clinically relevant patient dose errors.	• A critical evaluation of IMRTQA techniques
2012	Ford et. al.	Int. J. Radiat. Oncol. Biol. Phys., 84(3), 263-269, (2012)	Quality Control Quantification (QCQ): A tool to measure the value of quality control checks in radiation oncology	• Critical analysis of the effectiveness of various QA techniques
2013	Molineu et al	Med Phys, 40, 2013	Credentialing results from IMRT irradiations of an anthropomorphic head and neck phantom	• Significant number of failures with RPC Credentialing
2014	AAPM	Med. Phys. 41, 031501 (2014). TG #71	Monitor unit calculations for external photon and electron beams	Includes discussion of manual vs TPS MU calculations
2014	AAPM	AAPM TG #176 Report (Medical Physics Article)	Dosimetric effects caused by couch tops and immobilization devices: Report of AAPM Task Group 176	
2014	Mcvicker, A. T., et al.	Master's Thesis from Duke University	Clinical Implications of AAA Commissioning Errors and Ability of Common Commissioning & Credentialing Procedures to Detect Them.	• Deliberately introduced errors into TPS parameters to determine dosimetric effect • Applied TG #119 and IROC TLD tests to evaluate their effectiveness at detecting the errors
2014	Noel et al	Int J Radiation Oncol Biol Phys., 88, 1161-1166 (2014)	Quality assurance with plan veto: Reincarnation of a record and verify system and its potential value	• A tool to check RT data transfer
2015	CPQR	Canadian Partnership for Quality Radiotherapy Guidance Document	Technical Quality Control Guidelines for Canadian Radiation Treatment Centres Treatment Planning Systems	• Some things not covered by other documents e.g.: • Backup restore test, • Checking error logs, • Detailed end-to end test, • Review by second medical physicist

2015	AAPM	AAPM Practice Guidelines TG #244 (MPPG #5) (JACMP Article to be published Sept 2105)	Treatment Planning System Commissioning and QC/QA	
Not Published	AAPM	TG #100	Method for Evaluating QA Needs in Radiation Therapy	
Not Published	AAPM	TG #132	Use of Image Registration and Data Fusion Algorithms and Techniques in Radiotherapy Treatment Planning	
Not Published	AAPM	TG #157	Commissioning of beam models in Monte Carlo-based clinical treatment planning	
Not Published	AAPM	TG #201	Quality Assurance of External Beam Treatment Data Transfer	
Not Published	AAPM	TG #218	Tolerance Levels and Methodologies for IMRT Verification QA	
Not Published	AAPM	TG #219	Independent Dose and MU Verification for IMRT Patient Specific Quality Assurance	
Not Published	AAPM	TG #262	Electronic Charting	
Not Published	AAPM	TG #262	Strategies for Effective Physics Plan and Chart Review in Radiation Therapy	