Buyer Beware – Third party products
Linac and TPS commissioning
Treatment planning &
Brachytherapy sources

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Objectives

• Why a session on buyer beware of third party services and products?
  ➢ Increased use of third party services and products

• An increasing level of complexity
  ➢ More complex treatment planning systems (TPS), delivery systems and treatment techniques

• Serious incidents involving TPS, treatment delivery systems, treatment planning and brachytherapy

• Many AAPM TG/MPPG recommendations available for qualified medical physicist (QMP) to use
Motivation

- Therapist makes a mistake
  - Affected – One Fraction
- Physician makes a mistake
  - Affected – One Patient
- Physicist makes a mistake
  - Affected – All patients treated through the duration of the mistake
- Linac or Treatment Planning System (TPS) mistake
  - Affected – All patients planned or treated until the mistake is caught
Qualified Medical Physicist (QMP) Responsibilities

• The QMP is responsible for acceptance testing, commissioning, calibration, and periodic QA of therapy equipment

• In particular, the QMP must certify that the therapy units and planning systems are performing according to specifications, generate beam data, and outline written QA procedures which include tests to be performed, tolerances, and frequency of the tests
TPS Linac Commissioning Timetable

Third-Party vs. TG 106/MPPG 5a

<table>
<thead>
<tr>
<th>Agenda</th>
<th>Third Party Website</th>
<th>Estimation (TG-106)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance Testing</td>
<td>Pre</td>
<td>Pre</td>
</tr>
<tr>
<td>Linac Commissioning</td>
<td>2 Days</td>
<td>30 Days</td>
</tr>
<tr>
<td>Data Processing for TPS</td>
<td>1 Day</td>
<td>6 Days</td>
</tr>
<tr>
<td>TPS Beam Modeling</td>
<td>2 Days</td>
<td>9 Days</td>
</tr>
<tr>
<td>TPS Validation</td>
<td>1 Day</td>
<td>5 Days</td>
</tr>
<tr>
<td>Data Review and Data Book Generation</td>
<td>Post</td>
<td>Post</td>
</tr>
<tr>
<td><strong>TOTAL DAYS</strong></td>
<td><strong>6</strong></td>
<td><strong>50</strong></td>
</tr>
</tbody>
</table>

TG-106 states approximately 4 – 6 weeks plus additional time for validation, baselines, etc.
MPPG5a states approximately 6-8 weeks for 2 photon and 5 electron energy linac, assuming 1.5 to 2 FTE working 12 to 16 hours per day!!!
Beam Matching & Golden Beam Data

- Some vendors provide beam matching services or provide a reference dosimetry dataset called “golden beam data”
- Issues that could arise from vendor provided services:
  - Consistent reproducibility of manufacturing procedures for all linear accelerators
  - On-site changes to the beams (energy and/or profiles) will not be reflected in the golden beam data
  - Individual machine variation of non-physical wedges (EDW)
  - Commissioning process may uncover potential problems that may not otherwise be discovered
- Golden beam data could be useful as a reference to verify site’s commissioning results
Linac and TPS Commissioning – QMP Responsibility

• If a linac or TPS has been commissioned by a third-party, it is the duty of the site’s QMP to ensure that all work has been performed appropriately and correctly.

• The QMP should verify commissioning and validate accuracy of dose calculation through machine specific QA, compute and compare plans on old and new TPS, IMRT/VMAT QA on numerous test cases, IROC end-to-end phantoms, OSLD services to verify linac output and if possible inter-institutional comparisons.

• The QMP should consolidate all tests, data and results performed by third-party vendors and generate linac and TPS commissioning reports and data-books.
MPPG 5a: TPS Commissioning & QA

- QMP understand TPS algorithms and has received proper training
- Appropriate CT calibration data acquired
- Review of raw beam data collected
- Beam modeling completed per vendor recommendation
- Photon and electron beam models including heterogeneities evaluated qualitatively and quantitatively
- IMRT/VMAT validation and end-to-end phantom tests
- Baseline QA and routine QA established
- Commissioning report generation

MPPG5a: Recommendations for Small Field Dosimetry Validation

- Since small field dosimetry is often extrapolated by TPS, verification measurements for small fields and MLC are recommended.
- Intra-leaf and inter-leaf transmission/leakage and leaf gap should be measured with appropriate detectors.
- Leaf-end penumbra and small field PDD’s should be obtained with a small detector to avoid volume averaging effects.
- Small field output factors should be measured for beam modeling/verification.

# VMAT/IMRT Validation Tolerances

<table>
<thead>
<tr>
<th>Measurement Method</th>
<th>Region</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Chamber</td>
<td>Low gradient target region</td>
<td>2% of prescribed dose</td>
</tr>
<tr>
<td></td>
<td>OAR region</td>
<td>3% of prescribed dose</td>
</tr>
<tr>
<td>Planar/Volumetric Array</td>
<td>All regions</td>
<td>2%/2mm*, no pass rate tolerance, but areas that do not pass need to be investigated</td>
</tr>
<tr>
<td>End-to-End</td>
<td>Low gradient target region</td>
<td>5% of prescribed dose</td>
</tr>
</tbody>
</table>

*Application of a 2%/2 mm gamma criterion can result in the discovery of easily correctable problems with IMRT commissioning that may be hidden in the higher (and ubiquitous) 3%/3 mm passing rates

*Smilowitz et al, AAPM MPPG5a, JACMP 16 (5): 14-34 (2015)*
# Gamma Criteria Tolerance and Passing

<table>
<thead>
<tr>
<th>Clinical Site</th>
<th>$\Gamma$ (5%/3mm)</th>
<th>$\Gamma$ (3%/3mm)</th>
<th>$\Gamma$ (2%/2mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prostate Fossa</td>
<td>99.1</td>
<td>98.4</td>
<td>91.0</td>
</tr>
<tr>
<td>Bottom of Tongue</td>
<td>99.9</td>
<td>98.5</td>
<td>82.1</td>
</tr>
<tr>
<td>Throat</td>
<td>99.3</td>
<td>98.0</td>
<td>89.9</td>
</tr>
<tr>
<td>Esophagus</td>
<td>99.7</td>
<td>97.9</td>
<td>79.6</td>
</tr>
<tr>
<td>Parietal Brain</td>
<td>99.6</td>
<td>98.1</td>
<td>92.8</td>
</tr>
</tbody>
</table>

## Esophagus Case

- **Gamma 3%/3mm**
- **Gamma 2%/2mm**
IROC Anthropomorphic Head & Neck
IMRT Phantom End to End Test
IROC H&N Phantom TLD & Film Results
MDACC Varian Truebeam

Summary of TLD and film results:

<table>
<thead>
<tr>
<th>Location</th>
<th>IROC-H vs. Inst.</th>
<th>Criteria</th>
<th>Acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary PTV sup. ant.</td>
<td>0.99</td>
<td>0.93 – 1.07</td>
<td>Yes</td>
</tr>
<tr>
<td>Primary PTV inf. ant.</td>
<td>0.98</td>
<td>0.93 – 1.07</td>
<td>Yes</td>
</tr>
<tr>
<td>Primary PTV sup. post.</td>
<td>0.96</td>
<td>0.93 – 1.07</td>
<td>Yes</td>
</tr>
<tr>
<td>Primary PTV inf. post.</td>
<td>0.95</td>
<td>0.93 – 1.07</td>
<td>Yes</td>
</tr>
<tr>
<td>Secondary PTV sup.</td>
<td>0.97</td>
<td>0.93 – 1.07</td>
<td>Yes</td>
</tr>
<tr>
<td>Secondary PTV inf.</td>
<td>0.97</td>
<td>0.93 – 1.07</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Film Plane | Gamma Index* | Criteria | Acceptable |
------------------------|--------------|----------|------------|
Axial                   | 100%         | ≥85%     | Yes        |
Sagittal                | 100%         | ≥85%     | Yes        |

*Percentage of points meeting gamma-index criteria of 7% and 4 mm.

Right Left Profile

Anterior Posterior Profile
IROC Phantom 2001-2011 results

- Irradiated 1139 times by 763 institutions
- Only 82% of institutions passed the end-to-end test with the Head and Neck phantom on the first irradiation (Passing criteria was 7% for TLD in PTV and DTA of 4 mm in high dose gradient area (≥85% pixels pass) between PTV and OAR)

Cumulative and Passing Rate Over Time

TLD/Institution ratio for all PTV TLD Results

Distance to Agreement Values for All Irradiations

Global (non-systematic) & Systematic Error

Causes of Failure

- Some linac TPS combinations performed better than other combinations
- Most detectable errors are systematic and dosimetric (60%)
- Causes of failure include:
  - Incorrect data entry into the TPS - output factors, pdd’s, etc.
  - Inexact beam modelling
  - MLC leaf modeling
  - Software and hardware failures
  - Inexperienced QMP’s and dosimetrists
  - IMRT implementation incorrect
  - Gross setup errors
  - Systematic and nonsystematic errors

**Improvement** – Carson et al predict that if IROC tightened criteria to 5%/4 mm, 77% of institutions would meet criteria today

Treatment Planning - Third Party Products and Services

- Treatment intent, disease stage, previous treatments
- Patient positioning and immobilization
- Image acquisition, registration and input into TPS
- Anatomy delineation & image fusion (if necessary)
- Beam setup, technique (IMRT/VMAT/3DCRT, etc.) and dose calculation
- Dose constraints/goals
- Plan evaluation and quality

Ideally the patient should be simulated, planned and treated in one location by the same team. If not, “third party” could be Radiation Oncologist, Physicist, Dosimetrist or Therapist
Treatment Intent, Disease Stage & Previous Treatments

• Radiation oncologist, physicist, dosimetrist and therapist must have clear communication regarding the patient treatment site, intent and disease staging
• Any previous radiation treatment records for the patient should be obtained and documented
• If patient has a pacemaker, prosthesis, is pregnant, need anesthesia, etc. this information should be documented upfront and included during the entire process
• If patient has health issues, is claustrophobic, etc. this needs to also be taken into consideration
• Communication between all involved parties is key!!!!!
Patient Positioning and Immobilization

- Patient positioning and immobilization is extremely important to provide reproducible daily patient setup and minimize motion during treatment (simulation directives).
- This becomes more important if the patient is simulated, planned or treated in different locations.
- The treatment site and adjacent normal tissues that need to be avoided need to be stated upfront (planning directives).
- The intended treatment technique – 3DCRT, IMRT, VMAT, SBRT, etc. needs to be defined.
- Appropriate immobilization devices for the treatment site and treatment technique need to be utilized (transfer of devices, etc.).
- If bolus is needed this should be stated.
- Take into account patient weight and couch weight limitations.
Image acquisition, registration and input into TPS

- CT is the primary imaging modality in radiation therapy
- Adequate bore size for the patient and immobilization devices
- Ensure patient CT scan extent is sufficient
- Does the patient have metal prosthesis that could lead to severe CT artifacts? If so, is Metal Artifact Reduction reconstruction needed?
- Is 4D CT imaging needed for motion management?
- Appropriate patient isocenter marking
- Ensure connectivity between CT simulation software and TPS
- Ensure appropriate CT electron density match between scanner and treatment planning system
Anatomy Delineation & Image Fusion

- Sometimes contours are drawn by third-party
- Have the proper gross tumor volume (GTV) and clinical target volume (CTV) been delineated?
- Have the appropriate internal target volume (ITV) and planning target volume (PTV) with appropriate margins been contoured?
- Have the appropriate organs at risk (OAR) and planning organ at risk volumes (PRV) with appropriate margins been contoured?
- If possible standardized nomenclature (ICRU 83, ASTRO 2009, AAPM TG 263, NRG/RTOG) recommendations should be used
- Override density of artifacts, etc.
- Correct CT/MRI/PET fusion techniques if required
Beam Setup, Technique & Dose Calculation

- The radiation oncologist should define the treatment technique (3D CRT, IMRT, VMAT, SBRT, etc.) that needs to be used
- Appropriate machine selection with capability, field naming, isocenter location, etc.
- Appropriate IMRT/VMAT parameter choice and optimization
- Optimal dose grid size selection for calculation
Dose Constraints/Goals

• Have appropriate dose constraints been used?
• Joint AAPM/ASTRO Quantitative Analysis of Normal Tissue Effects in the Clinic (QUANTEC) published in IJROBP March 2010 is a good starting point
• Fraction size, total dose, tissue volume, etc. can affect tolerance dose
## Quantec Tolerance Doses Example

### Table 1. QUANTEC Summary: Approximate Dose/Volume/Outcome Data for Several Organs Following Conventional Fractionation (Unless Otherwise Noted)* (Continued)

<table>
<thead>
<tr>
<th>Organ</th>
<th>Volume segmented</th>
<th>Irradiation type (partial organ unless otherwise stated)</th>
<th>Endpoint</th>
<th>Dose (Gy), or dose/volume parameters</th>
<th>Rate (%)</th>
<th>Notes on dose/volume parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectum</td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Grade ≥ 2 late rectal toxicity, Grade ≥ 3 late rectal toxicity</td>
<td>V50 &lt;50%</td>
<td>&lt;15</td>
<td>Prostate cancer treatment</td>
</tr>
<tr>
<td></td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Grade ≥ 2 late rectal toxicity, Grade ≥ 3 late rectal toxicity</td>
<td>V60 &lt;35%</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Grade ≥ 2 late rectal toxicity, Grade ≥ 3 late rectal toxicity</td>
<td>V65 &lt;25%</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Grade ≥ 2 late rectal toxicity, Grade ≥ 3 late rectal toxicity</td>
<td>V70 &lt;20%</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Grade ≥ 2 late rectal toxicity, Grade ≥ 3 late rectal toxicity</td>
<td>V75 &lt;15%</td>
<td>&lt;15</td>
<td></td>
</tr>
<tr>
<td>Bladder</td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Grade ≥ 3 late RTOG</td>
<td>Dmax &lt;65</td>
<td>&lt;6</td>
<td>Bladder cancer treatment.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Variations in bladder size/shape/ location during RT hamper ability to generate accurate data</td>
</tr>
<tr>
<td></td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Grade ≥3 late RTOG</td>
<td>V65 ≤50 %</td>
<td>&lt;15</td>
<td>Prostate cancer treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V70 ≤35 %</td>
<td>&lt;15</td>
<td>Based on current RTOG 0415</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V75 ≤25 %</td>
<td>&lt;15</td>
<td>recommendation</td>
</tr>
<tr>
<td>Penile bulb</td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Severe erectile dysfunction</td>
<td>Mean dose to 95% of gland &lt;50</td>
<td>&lt;35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Severe erectile dysfunction</td>
<td>D90&lt;50</td>
<td>≤35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Severe erectile dysfunction</td>
<td>D60-70 &lt;70</td>
<td>≤35</td>
<td></td>
</tr>
<tr>
<td>Small bowel</td>
<td>Individual small bowel loops</td>
<td>3D-CRT</td>
<td>Grade ≥ 3 acute toxicity⁵</td>
<td>V15 &lt;120 cc</td>
<td>≤10</td>
<td>Volume based on segmentation of the individual loops of bowel, not the entire potential peritoneal space</td>
</tr>
<tr>
<td></td>
<td>Entire potential space within peritoneal cavity</td>
<td>3D-CRT</td>
<td>Grade ≥ 3 acute toxicity⁵</td>
<td>V45 &lt;195 cc</td>
<td>≤10</td>
<td>Volume based on the entire potential space within the peritoneal cavity</td>
</tr>
</tbody>
</table>
Plan Check & Evaluation

- Patient & Plan info (Patient name, MR, Radonc, Plan type)
- Setup & CT info (Immobilization, Orientation, Isocenter, CT-ED table)
- Dose Calculation Parameters (Linac properties, dose grid resolution, etc.)
- Prescription (Dose, time, fractionation, etc.)
- Contours (PTV and OAR, density overrides, DVH constraints, etc.)
- Beam Parameters (Beam info, isocenter, modality, energy, collimator, modifiers, control points, dose rate, MU Monitor unit (time) per field, etc.)
- Dose Calculation (DVH, isodose lines, hot spots, max dose, etc.)
- Plan deliverability (Plan inspector, Collision check, etc.)
- Record and Verify data import
- IMRT / VMRT quality assurance
- Other (pacemaker, prosthesis, etc.)
Evaluating & Quantifying Plan Quality

- Do IMRT planning goals & constrains ensure safe plans?
- Need system that can identify sub-optimal plans (mostly manifested by insufficient OAR sparing)
- In cases with minimal PTV/OAR overlap the planners might not push to provide a dose distribution that spares OAR more than the standard goal even if additional sparing was possible
- In cases with large PTV/OAR overlap the planners might expend time and effort to meet goals that are impossible to accomplish without unacceptable sacrifice of another goal

Moore et al, IJROBP 81 (2): 545-551 (2011)
Evaluating & Quantifying Plan Quality

- Analyzed previous plans, then developed and implemented a model to predict OAR doses in advance for new patients
- Reduced inter-clinician treatment plan variability

\[
\frac{D_{\text{pred}}}{D_{Rx}} = 0.2 + 0.8 \left( 1 - e^{-3 \frac{V_{\text{overlap}}}{V_{OAR}}} \right)
\]
Evaluating & Quantifying Plan Quality

- Metrics can be developed using previous plans to alert user that their current plan is suboptimal

Prostate Implant Brachytherapy - Third Party Products and Services

- American Cancer Society estimates approximately 180,890 new prostate cancer patients in the US in 2016
- Low dose rate prostate brachytherapy (prostate implant) is a treatment option depending upon the extent of the disease and approximately 40,000 men receive this treatment in the US annually
- Third party products (equipment, sources, etc.) and services (commissioning, QA, etc.) are available for performing prostate implants and qualified medical physicists should perform adequate QA to validate such products or services prior to clinical use
Ultrasound Commissioning and QA

- AAPM TG128 provides guidance on Trans Rectal Ultrasound QA

<table>
<thead>
<tr>
<th>Test</th>
<th>Minimum frequency</th>
<th>Action level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grayscale visibility</td>
<td>Annual</td>
<td>Change &gt;2 steps or 10% from baseline</td>
</tr>
<tr>
<td>Depth of penetration</td>
<td>Annual</td>
<td>Change &gt;1 cm from baseline</td>
</tr>
<tr>
<td>Axial and lateral resolution</td>
<td>Annual</td>
<td>Change &gt;1 mm from baseline</td>
</tr>
<tr>
<td>Axial distance measurement accuracy</td>
<td>Annual</td>
<td>Error &gt;2 mm or 2%</td>
</tr>
<tr>
<td>Lateral distance measurement accuracy</td>
<td>Annual</td>
<td>Error &gt;3 mm or 3%</td>
</tr>
<tr>
<td>Area measurement accuracy</td>
<td>Annual</td>
<td>Error &gt;5%</td>
</tr>
<tr>
<td>Volume measurement accuracy</td>
<td>Annual</td>
<td>Error &gt;5%</td>
</tr>
<tr>
<td>Needle template alignment</td>
<td>Annual</td>
<td>Error &gt;3 mm</td>
</tr>
<tr>
<td>Treatment planning</td>
<td>Acceptance testing</td>
<td>Error &gt;5%</td>
</tr>
<tr>
<td>computer volume accuracy</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pfeiffer et al., QA tests for prostate brachytherapy US systems. Med Phys 35,12, 5471-89 2008
Prostate Implant TPS QA

• AAPM TG43 and TG43 updates provide dose calculation recommendations
• AAPM TG53 provides TPS QA guidelines

Dose Verification

Contour Verification

Isodose Verification
Source/Seed Location QA Film

Treatment Plan
Needle Loading Pattern

Loaded Needles
Source Assay

- Variety of options are available for sources and applicators
- The physicist must be aware of the different assay requirements for sources that are loose, stranded, or ones that are preloaded into needles
- Third party vendors provide assay services, although mistakes can still occur, thus the qualified medical physicist should independently verify the assay
- AAPM TG56 recommends a random sample of 10% of the sources in a shipment be checked
Source Assay

Needles, strand and source holder

Calibrated Well Chamber & Electrometer

Vendor 100% source assay

Independent institution assay
Quantity of brachytherapy sources to be assayed by the end-user physicist

<table>
<thead>
<tr>
<th>Source Form</th>
<th>Number to be Assayed</th>
</tr>
</thead>
<tbody>
<tr>
<td>All loose sources, non-sterile</td>
<td>≥10% of total or 10 seeds, whichever is larger</td>
</tr>
<tr>
<td>Non-sterile cartridges</td>
<td>≥10% of total via whole cartridge assay or via single sources</td>
</tr>
<tr>
<td>Mixture of non-sterile loose sources and sterile assemblies</td>
<td>Loose sources amounting to ≥10% of the total order or ten seeds, whichever is larger</td>
</tr>
<tr>
<td>Sterile source assemblies</td>
<td>≥10% of assemblies via sterile well chamber inserts or quantitative image analysis Alternatively, order and assay non-sterile loose seeds equal to 5% of the total or five seeds, whichever is fewer</td>
</tr>
<tr>
<td>Strands</td>
<td>≥10% of total of two strands, whichever is larger, using single-seed calibration coefficient Alternatively, order and assay non-stranded loose seeds equal to 5% of the total or five seeds, whichever is fewer</td>
</tr>
</tbody>
</table>
### Action to be taken based on sample size and relative difference $\Delta S_K$

<table>
<thead>
<tr>
<th>Sample size for assay of sources by end-user medical physicist</th>
<th>Relative difference vendor and physicist assay ($\Delta S_K$)</th>
<th>Action by end-user medical physicist</th>
</tr>
</thead>
</table>
| Individual source as part of an order of $\geq 10$ sources    | $\Delta S_K \leq 6\%$  
$\Delta S_K > 6\%$                                           | Nothing further  
Consult with radiation oncologist regarding use of the outlier source |
| $\geq 10\%$ but $<100\%$ of order, or batch measurements of individual sterile strands, cartridges or preloaded needles | $\Delta S_K \leq 3\%$  
$5\% \geq \Delta S_K > 3\%$  
$\Delta S_K > 5\%$                                           | Nothing further  
Investigate source of discrepancy or increase no.  
Consult with vendor to resolve difference & Radonc |
| 100% of order, or batch measurement of each sterile strand, cartridge or preloaded needle | $\Delta S_K \leq 3\%$  
$5\% \geq \Delta S_K > 3\%$  
$\Delta S_K > 5\%$                                           | Nothing further  
Investigate source of discrepancy or increase no.  
Consult with vendor to resolve difference & Radonc |

*Butler et al. Med Phys 35,9, 3860-65 2008*
Conclusions

• There is an increased use of third party radiation therapy products and services
• These products and services play an important role by filling a need due to lack of well qualified physicists in certain regions
• It is alright to use third-party products and services, however, these products and services should be thoroughly validated prior to clinical use