Commissioning and Quality Assurance for Proton Therapy

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Scope and Goals

- To learn about basic requirements for commissioning
  - Not to talk about how to perform commissioning

- To share machine QA experience and rationales in designing QA procedures

- To discuss risk-based vs. the best practice based approaches towards Machine QA
  - Not to give a list of tests to do for your center
General Definition of Clinical Commissioning

– Preparation to treat the first patient

• Workflow
  – Procedures, treatment protocol development, documentation

• Equipment commissioning

• TPS commissioning

• Quality assurance procedures

• Training
Commissioning Measurements for Passive Scatter Beams

- Pristine Bragg peaks IDDs
- Snout sizes (small, medium, large)
- Modulation depths (for combinations of energies/range shifter settings and width of the modulation wheels)
- Modulation ranges (for combinations of energies/range shifter settings and width of the modulation wheels)
- Relative output factors (for establishing dosimetric relationship among field size and modulation width)
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PBS Commissioning Measurements

• Measurements
  • Pencil beam IDD in water (all energies)
  • Pencil beam in-air fluence profiles at a few distances (at least three)
  • Normalization factor (output) at a fixed depth (all energies)
  • Pencil beam in-air profile at a few distances for each range shifter
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General Principle for Machine QA Program

- Consistency tests (nothing changed since commissioning)
  - QA program is **not** designed to repeat commissioning but to ensure commissioning results
  - Most involved in baseline comparisons

- Functionality tests

- Safety tests
What is risk-based thinking?  - ISO 9001

- It is a new international standard: ISO 9001 – 2015 revision
  - A systematic approach to risk, rather than treating it as a single component of a quality management system
  - “By taking a risk-based approach, an organization becomes proactive rather than purely reactive, promoting continual improvement.
  - Requiring more knowledge about the system, instead of relying on best practices
    - A “best practice” is a well-established/accepted method, superior to other alternatives
    - Question: how we perform the best practice for a new technology without established methods?
Why the best practice is still valid?

- Risks are difficult to assess

- The assumption is that a new technology will not be fundamentally different from the existing approach
  - For example, PBS has a similar process for therapists as in IMRT (for example, in simulation, image guidance, position-correction, etc.)

- Consistency!

- Examples of Best Practice QA Guidelines:
  - AAPM TG-142; TG-40, IAEA TecDoc 1040
More about Risk-based Approach

- New ISO 9001:2015 promotes risk-based thinking in a quality management systems due to the need for balancing operational efficiency and comprehensive quality management
  - Can we become smarter in our efforts while maintaining quality?
  - Risk-based ≠ Taking risks (without thinking consequences)
  - Act based on “calculated” risks
- Knowledge is needed to estimate risks
Assessing Risks Requires Knowledge

- Areas of Concerns
  - Beam delivery systems
    - Double-scatter (DS)
    - Uniform Scanning (US)
    - Pencil Beam Scanning (PBS)
  - Beam shaping devices
    - Collimator, compensator, range shifter, ridge filter etc.
  - Mechanical movement
    - Full and half-Gantry, (robotic) couch etc.
  - Image guidance system
    - kV x-rays; CBCT
  - Safety
    - Audio, video, interlocks, etc.

TG-179
TG-142
TG-40, IAEA TecDoc 1040
How do we apply this to PBS QA?
Assessing Risks Requires Knowledge

- Relative risks for pencil beam delivery
  - Spot Position (high risk)
  - Spot Intensity/dose (high risk/impact)
  - Spot Shape (intermediate risk)
  - Spot Energy (low risk)
Assessing Risks Requires Knowledge

- **Beam Control System**
  - Ion source and accelerator (**energy, dose rate**)
  - Energy selection system (**energy, shape**)
  - Beam transportation system (**shape, energy**)
  - Beam delivery system (**dose, spot position, shape**)
    - Scanning magnets, dose monitor, position monitor
Assessing Risks Requires Knowledge

Beam Exit

2/3 speed of light

Cyclotron: beam stability, beam switching, dark current
Beamline Components

Energy Selection System (ESS): Determine beam energy, beam divergence, energy spectrum, transmission efficiency, beam optics
Scanning Nozzle

• No change in beam energy, there is no WET variation in the nozzle
• Control the lateral position of spot (position)
• Monitor dose
• Monitor ~shape
Double-Scatter Beam Shaping Devices

- High speed rotation
- Beam gated for different SOBP width
- Intensity varied to produce a flat top SOBP

Source size variation: change proximal dose shoulder
- Paganetti Book Ch5
Dose Monitor and Spot Position Monitor

Dose and position monitoring for scanned beams

Diagram showing dose signal electrode, ground plane, dose signal electrode, strip electrode (x and y), window, HV electrodes, and scanned beam.
Single Spot Position Error

How likely can it happen? What is the impact?

Spot size: \( \sigma_{\text{Spot}} = 3 \text{ mm} \)
Motion error: \( \Delta x = 1.5 \text{ mm} \)
Dose error: \( e = \pm 19.8\% \)
Off-axis Distal Range Uniformity

Double-Scatter vs. Pencil Beam Scanning

Range uniformity check using picket fence.
Assessing Risks Requires Knowledge

- Relative risks for pencil beam delivery
  - Spot Position (high risk)
  - Spot Intensity (high risk)
  - Spot Shape (intermediate risk)
  - Spot Energy (low risk)
Daily QA

- End-to-end test for the end user (therapists)
  - From Oncology Information System (OIS) to dose delivery
  - Safety checks
Daily QA

- End-to-end test run by therapists in the morning
- QA Phantom
- Imaging the block to verify:
  - Laser
  - couch position
- Dose pattern
  - Uniform spot pattern
  - 4 electron chambers to measure energy (~1mm resolution)
  - Central chamber for output
  - It can detect beam shape changes to some degrees
Monthly QA

Output measurement

• Repeat at machine calibration condition
  – Parallel plate chamber
  – Depth: 1.5 cm
  – Single layer
  – 160 MeV
  – Spot spacing 2.5mm
  – Electrometer bias -400v
Energy Check

- **Two-depth Technique**
  - Ratio of ion chamber readings
  - Base: 1.5cm build-up
  - Deeper depth: 16.5cm build-up
Monthly QA

Spot Position Accuracy across the field

• Coarse Pattern
  – Geometric distortion
  – FWHM in all positions
    • Shape of spots
Monthly QA

Spot Position Accuracy

• IBA Lynx™
  – CCD camera
  – 27cm x 27cm
  – Measures fluence
  – Export in DICOM format
Monthly QA – Spot Off-Axis Position

X Spatial Distortion

Spot Distance Map

Δx (mm)
0.8
0.4
0.0
-0.4
-120 -80 -40 0 40 80 120

y (mm)
120
80
40
0
-40
-80
-120
-120 -80 -40 0 40 80 120

Δx
2
1
0
-1
-2
Luis Perles
Monthly QA – Spot Off-Axis Position

Y Spatial Distortion

Spot Distance Map

Δy

Luis Perles
## Monthly QA – Spot Size

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
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<tbody>
<tr>
<td>FWHM Y</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>+/- 0.1 (mm)</td>
</tr>
<tr>
<td>FWHM X</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>+/- 0.2 (mm)</td>
</tr>
</tbody>
</table>

### 160 MeV

- FWHM X: 11 mm

### 90 MeV

- FWHM X: 12 mm

5% Margin
10% Margin
15% Margin

Luis Perles
Monthly QA

• Center Spot Accuracy and agreement with imaging (kV or CBCT) and lasers
Scripps Proton Therapy Center Monthly Quality Assurance

Month: February  
Year: 2016  
Physicist Name: Lei Dong  
Completion Date: 2/5/2016

Review & sign off on month
- Review DailyQA log
- Sign off

Perform DailyQA imaging test
- Perform DailyQA imaging test
- Lasers within phantom crosshair

Daily QA / Imaging

Device: Sun Nuclear DailyQA3
Tolerances:
- Dose = 2%
- e-check = 3.5%

<table>
<thead>
<tr>
<th>Date</th>
<th>Gantry</th>
<th>Dose (Gy)</th>
<th>e-check</th>
<th>Dose (Gy)</th>
<th>e-check</th>
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</thead>
<tbody>
<tr>
<td>2/12/2016</td>
<td>0</td>
<td>100.0</td>
<td>0.0%</td>
<td>101.9</td>
<td>1.9%</td>
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</table>

Daily QA Baseline

Device: Adv. Markus
Electrometer: Unidos E
Serial Number: 1340  
Serial Number: 1165
Date: 2/12/2016
Tolerance: ± 2%

Ion Chamber: Adv. Markus
Electrometer: Unidos E
Serial Number: 1340  
Serial Number: 1165
Date: 2/12/2016
Tolerance: ± 2%

Note:

Absolute Dose

Ion Chamber: Adv. Markus
Electrometer: Unidos E
Serial Number: 1340  
Serial Number: 1165
Date: 2/12/2016
Tolerance: ± 2%

Note:

Energy Baselines

Device: Adv. Markus + HDPE

<table>
<thead>
<tr>
<th>Date</th>
<th>MeV</th>
<th>Energy</th>
<th>Δ Range</th>
<th>Energy</th>
<th>Δ Range (mm)</th>
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</thead>
<tbody>
<tr>
<td>1/18/2016</td>
<td>90</td>
<td>160.0</td>
<td>0.0</td>
<td>159.86</td>
<td>-0.29</td>
</tr>
</tbody>
</table>

Note:

Absolute Dose

Ion Chamber: Adv. Markus
Electrometer: Unidos E
Serial Number: 1340  
Serial Number: 1165
Date: 2/12/2016
Tolerance: ± 2%

Note:

Energy Baselines

Device: Adv. Markus + HDPE

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Note:

Lynx - Sparse Spots Pattern

Device: IBA Lynx
Date: 1/18/2016
Iris = 70
Time = 25s (Sparse)
Lynx at isocenter

Notes:

X-ray / Laser Congruence

Device: Logos XRV100
QA Patient ID: zzzXRV100, LOGOS
Date: 1/23/2016
Tolerance = 1.5 mm

<table>
<thead>
<tr>
<th>Lateral</th>
<th>IN</th>
<th>OUT</th>
<th>Vertical</th>
<th>L</th>
<th>R</th>
<th>Horizontal</th>
<th>L</th>
<th>R</th>
</tr>
</thead>
</table>
| Laser within tolerance of holes/marks

X-ray / Proton Congruence:

Tolerance = 1.5 mm

<table>
<thead>
<tr>
<th>x (mm)</th>
<th>Expected</th>
<th>Actual</th>
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</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>-0.09</td>
</tr>
<tr>
<td>y (mm)</td>
<td>0.00</td>
<td>-0.25</td>
</tr>
<tr>
<td>z (mm)</td>
<td>79.45</td>
<td>80.39</td>
</tr>
<tr>
<td>xyz (mm)</td>
<td>0.00</td>
<td>0.973</td>
</tr>
</tbody>
</table>

Safety / Interlocks

- Console emergency stop
- Door interlock during irradiation
- Audio-visual functionality
- Beam-on, red flashing light and light box sign

Completion

- Print and sign Monthly QA summary sheet
- Insert signed summary into room logbook

Raw data on shared drive in folder
Annual QA – Repeat Commissioning

▪ What if the QA baseline was wrong or changed?

▪ Repeat selected commissioning measurements
  ▪ Measure IDD in water tank for selected energies
  ▪ Measure spot shape and size for selected energies
  ▪ Measure the relative energy dependence factor
  ▪ Confirm range shifter thickness, integrity, and snout position accuracies
Summary: Establishing Machine QA Program

- Design tests to track changes from the TPS commissioning conditions (Risk-based; continuous improvement)
- Define Tolerances for each test
- Define Actions if out of tolerance
  - Treat options
  - Alternative validations
  - Additional tests for trouble-shooting
  - Standard Operating Protocol (SOP)
    - Contact List
    - Decision making

References:
- TG-224 (work-in-progress)
- Previous PTCOG presentations
- Books (books, AAPM summer school proceeding etc.)
- Standard Practice Guidelines (AAPM TG-40; TG-179, TG-142, IAEA TecDoc 1040 etc.)
Knowledge is Power!