Learning Objectives

- Understand proton beam dosimetry characteristics and compare them to photon beams
- Familiarize with proton dosimetry QA tools
- Understand challenges in proton therapy QA

Clinically operating proton therapy facilities
Multi-room Facilities

In-room Design

Inclined Beam 1  Inclined Beam 2
Gantry  Fixed Beam

Inside Treatment Room

Three major elements of QA:
- Imaging System
- Positioning System
- Beam delivery
Beam Delivery Techniques

Beam Spreading Techniques

Passive Scattering vs Active Scanning

- Single Scattering
- Double Scattering (DS)
- Uniform Scanning (US)
- Pencil Beam Scanning (PB)

Beam Delivery Techniques
Beam Characteristics at Depth

Dosimetric Advantage of PT

Coverage at depth: Protons vs Photons
**Anatomy of a Spread-Out Bragg Peak (SOBP)**

![Graph showing depth, dose, and distal and lateral penumbra](image)

ICRU 78

**Tolerances**
- Flatness within 5%
- Symmetry within 3%
- Range within 1.5 mm
- Modulation within 5 mm

**Lateral penumbra at depth**

![Graph showing range vs lateral penumbra](image)

Uniform Scanning beam data, ProCure - OEC

**Distal penumbra at depth**

![Graph showing range vs distal penumbra](image)

Uniform Scanning beam data - ProCure - OEC
Proton vs. Photon PDDs in presence of heterogeneities

**Photons** → Loss in Fluence (attenuation)  
SAME ENERGY

**Protons** → Loss in Range (Energy)  
(degradation)  
SAME FLUENCE

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How to manipulate the SOBP beam?

\[ x + y = M \]

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What can you get from a SINGLE delivery?

- Get creative with compensator design
- Get creative with array housing (Ding et al., 2012)
Distal end shaping - no compensator

- Proton Beam
- Aperture
- Inhomogeneity (Air Pocket)

Target Inhomogeneity (Air Pocket)

Distal end shaping – with compensator

- Compensator
- Aperture
- Inhomogeneity (Air Pocket)

Patient Device QA

- Thick for tissue, thin for bone
Improving QA equipment

Output factor measurements

Output factor dependencies

Other factors:
Field size, snout position, phantom material, dose rate
Beam QA with 1D Arrays

1D Arrays – How do they compare for PDD measurements?

Zebra PDDs
Monthly Range Trend

Beam QA with 2D Arrays

Measurements of Flatness & Symmetry

| Flatness and Symmetry | Flatness | Symmetry | Field size (mm) | Flat
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Monthly QA Sheet, IBL2 – Jan 2012
Imaging QA: Comparing DRR with X-ray Image

Morning QA Procedure

One setup, One device, One beam

to get the following:

1. Output consistency check
2. Range consistency check
3. Symmetry consistency check
4. Imaging vs mechanical alignment check
5. In-room laser check

Morning QA Trends
Temporal tracking of PPS correction vector

Colinearity Test

- Purpose: to check that imaging isocenter coincides with radiation isocenter to within 1 millimeter.

Daily Checks  Monthly Checks  Annual Checks

- Imaging vs mechanical alignment
- Output
- Range
- Software Communication
- Proton-imaging isocentricity
- Flatness & Symmetry
- Ranges and Modulations
- Mechanical
- PPDs + Modulations
- Combinations of field sizes and gantry angles
- X-ray source & detector image characteristics
- Dose rate dependencies
QA Challenges in PT

• Proton delivery modes & control systems are complex — more things to check

• Lack of methodology or forum to exchange ideas that improves QA processes — very few clinical proton physicists

• PT systems are not robust yet — few years of operations, many bugs to resolve (software & hardware)

• QA programs highly depend on vendor’s system specs

QA challenges in PT – cont.

• There are currently no task group recommendations for proton beam QA. Where relevant we follow guidelines from the following sources:
  – IAEA TRS 398
  – ICRU 59
  – ICRU 78
  – TG 40
  – TG 142
  – Journal publications

• Lack of dedicated commercial QA devices for PT — adaptation of photon QA devices is necessary
QA Challenges in PT – cont.

- It takes time to switch, tune, and deliver beam in every room
  - QA tasks take longer compared to linac systems
- Current PT centers have 3-5 rooms with sequentially beam delivery – beam sharing is necessary
- Cost of proton specific QA equipment
- Multi vendor software/hardware – lack of true integration

Anatomy of a linac head

- Carousel (scatterers)
- Magnets
- Jaws (primary)
- Jaws (tertiary)
- Ion chamber
- MLCs
- Light field
- **OUTPUT**
  - Electrons (4-6 energies)
  - Photons (1-3 energies)

Anatomy of a Nozzle

- Compensator
- Aperture(s)
- Snout with variable positions
- Lollipops
- Modulator wheels (multiple tracks)
- Multiple ion chambers
- Collimators (X-Y)
- X-Y magnets (3 scanning fields)
- Range verifier
- X-ray source
- Scatterers
- Light field
- **OUTPUT**
  - Modulation (very large combinations)
  - Range (very large combination)
Summary

- Proton Therapy Systems are complex and requires specialized equipment to measure various beam parameters
- It is imperative to make use of commercially available 1D & 2D arrays and adapt them to PT to check routinely for:
  - Beam parameters (R.M, Symmetry, Flatness, Output)
  - Imaging System
  - Robotic positioning System
- Standardization of QA procedures for PT is essential in establishing tolerance limits

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Thank you