Current State of Volumetric Image Guidance for Proton Therapy

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Outline

1. Importance of volumetric image guidance for proton therapy
2. Challenges of translating photon experience
3. State of the art IG solutions for proton therapy
4. System integration
5. Challenges of retrofitting image guidance systems
6. New developments on the horizon
7. Summary

Importance of volumetric image guidance for proton therapy
- Proton dose distributions are sensitive to patient set up, tissue inhomogeneity, and anatomical changes along the beam paths.
- Volumetric image guidance can help mitigate the degradation in delivered dose.

Challenges of translating photon experience of image guidance to proton
- Image guidance with orthogonal radiographs implemented in 1970s
- Protons lag behind photons in volumetric image guidance
- Photon IGRT solutions cannot be easily translated to protons due to difference in gantry design, hardware and control software, and room layout.
- Half fan mode (large FOV) CBCT is more challenging with offset detector panel
- Fixed beam rooms (no gantry) and partial gantry (180-220°) require a novel design

Available clinical solutions for volumetric image guidance in particle therapy
- Gantry-mounted CBCT
- Nozzle-mounted CBCT
- Robotic C-arm CBCT
- In-room CT-on-rails
**State-of-the-art gantry-mounted CBCT**

IBA CBCT system on Proteus Plus

- **Adapt Insight software**
- SAD/SID = 288.4/347 cm (59cm iso to imager)
- 192° full fan and 360° half fan (available soon)
- FOV: 34cm radial, 34cm longitudinal
- CBCT for proton therapy at U Penn since Sept 2014

**State-of-the-art gantry-mounted CBCT**

Varian CBCT system at Scripps Proton Therapy Center

- SAD/SID = 200/300 cm (100cm iso to imager)
- 192° full fan and 360° half fan (near future upgrade)
- FOV (full fan): 26cm radial, 19cm longitudinal
- Bowtie and anti-scatter grid currently not used
- Integrated imaging and treatment on one console
- Offline review on ARIA OIS
- Adaptive replanning with ARIA, Velocity, and Eclipse TPS

**State-of-the-art gantry-mounted CBCT**

Hitachi CBCT system at Hokkaido University Proton Beam Therapy Center

- Single room compact 360° gantry (internal diameter 250cm)
- SAD/SID = 160/220 cm
- Rotation speed: 0.5 and 1.0rpm
- FOV (full fan): 20cm, 40cm (half)
- Scan angle: 200° (full), 360° (half)

**State-of-the-art gantry-mounted CBCT**

Hitachi CBCT system at Hokkaido University Proton Beam Therapy Center

- Commissioning
  - Image quality
    - Spatial resolution: 7-8lp/cm
    - Spatial linearity: 0.6%
    - HU accuracy: ±40HU
    - Low contrast visibility: 15mm circle of 1%
  - Evaluation of anatomical changes
  - Assessment of need for plan adaptation

**State-of-the-art gantry-mounted CBCT**

IBA CBCT system on compact Proteus One (220° gantry)

- X-ray tube and detector panel are mounted on nozzle
- CBCT full fan acquisition of ~187° (180° + fan angle)
- Half fan acquisition will be available by offsetting detectors

**State-of-the-art robotic CBCT**

Hitachi robotic C-arm CBCT at St Jude Children’s Research Hospital

- Ceiling-mounted robotic arm
- KV X-ray tube
- Moving collimator & bowtie filter
- C ring
- Nozzle at 90°
- 6 DOF robotic couch
- Flat panel imager
State-of-the-art robotic CBCT

- 3 imaging locations at each room of St. Jude proton therapy center
  - At treatment iso
    - 27 cm from treatment iso
    - 100 cm from treatment iso

State-of-the-art robotic CBCT

- Siemens Artis Zeego in HIT and Shanghai Proton Heavy Ion Center
  - Ceiling mounted; multi-axis; adapted from interventional imaging system
  - CBCT currently in research mode

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State-of-the-art rail-on in-room CT

- CT sliding gantry (Siemens SOMATOM Definition AS Open) for particle therapy
  - Directly facing the proton gantry, in-room CTs-on-rails in Fukui Prefecture Hospital and National Cancer Center Hospital East in Japan are examples that volumetric image guidance is feasible with traditional non-robotic couches.
Integration of in-room CT to proton system

- Challenging multi-vendor integration with PT and OIS systems. Either use PT or CT vendor’s image registration software. Each center has a unique workflow.
- Collision avoidance is critical.

Challenges of retrofitting in-room CT/CBCT to an existing proton facility

The majority of proton therapy centers are currently equipped with only 2D X-ray imaging.

Challenges:
1. Limited available options (upgrade by PT vendor or 3rd party in-room CT)
2. Space limit (room size), electricity, water supply, supporting structures
3. Financial burden
4. Shutting down the treatment room for an extended period of time
5. Opportunity for new products – ceiling-, floor-, or couch-mounted robotic CBCT?

Image registration

- For institutions with volumetric image guidance capabilities (CBCT/in-room CT), the majority perform 3D-3D registration with 6 DOF (3 translation, 3 rotation) correction.
- In addition, many also do 3D-2D registration for certain anatomical sites with 6 DOF correction – searching the optimal shifts so automatically generated DRRs from planning CT would match the acquired 2D orthogonal images.

New development on the horizon

Proton CT

- Proposed in 1960s; Currently only preclinical prototypes
- More accurate stopping power estimation; range verification; image guidance
- Different detector technologies (proton integrating to proton tracking)
- <=10 min reconstruction through parallelization and hardware acceleration
- Imaging dose comparable to or lower than x-ray CT
- Challenges: Multiple scattering (nonlinear path -> lower spatial resolution)
- Challenges: Difficult to access >230 MeV (33cm range) for body transmission
- Challenges: May have to rotate patient for fixed-beam ports
New development on the horizon
Integrating MRI with proton therapy

- Commercial products of integrated MRI and linac/colbalt systems are available.
- Protons are deflected by magnetic field of MRI. Correction strategies needed.
- Magnetic field interactions between beam MRI, beam steering magnets, and monitoring systems need careful investigation.
- Issues of image distortion due to field inhomogeneity, treating through surface coils, and neutron damages (can’t easily turn off like CT-on-rails).

Summary

- New proton centers are now equipped with volumetric image guidance capabilities.
- Available solutions:
  - gantry-, nozzle-, and couch-mounted CBCT
  - robotic C-arm CBCT
  - in-room CT on rails
- Proton CT and MR-guidance are two areas under research investigation.

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