Current State of Volumetric Image Guidance for Proton Therapy

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AAPM SAM Therapy Educational Course WE-D-BRB-0, August 3, 2016

Disclosure

No conflict of interest.

No financial support from vendors mentioned in this presentation.

Manufacturers and product names mentioned in this presentation are for illustration purpose only, not an endorsement of the products.

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

→

Courtesy of Varian Medical Systems, USA

Available clinical solutions for volumetric image guidance in particle therapy

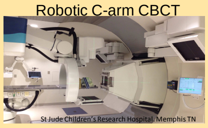
Gantry-mounted CBCT

Courtesy of Varian Medical Systems, USA

Nozzle-mounted CBCT

Courtesy of IBA group, Belgium

Robotic C-arm CBCT



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In-room CT-on-rails

Courtesy of IBA group, Belgium

State-of-the-art gantry-mounted CBCT

IBA CBCT system on Proteus Plus

Courtesy of IBA group, Belgium

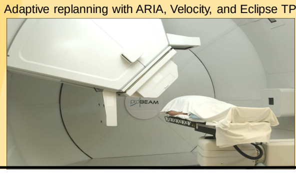
AdaPT Insight software

- 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 and 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



Courtesy of Varian Medical Systems, Palo Alto, CA, USA and Scripps Proton Therapy Center, San Diego, CA, USA

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(radial): 20cm (Full), 40cm (Half)
- Scan angle: 200deg (Full), 360deg (Half)

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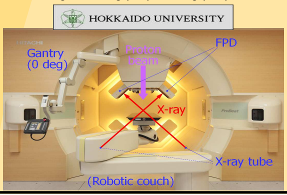
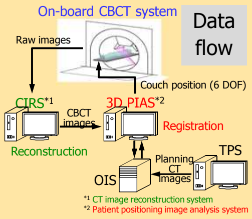




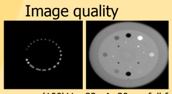
Courtesy of Drs. Kikuo Umegaki and Seishin Takao, Hokkaido University Proton Beam Therapy Center, Hokkaido, Japan

State-of-the-art gantry-mounted CBCT

Hitachi CBCT system at Hokkaido University Proton Beam Therapy Center

Commissioning

Image quality



(100kVp, 22mA, 20ms, full fan)

Spatial resolution: 7-8lp/cm

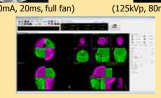
Spatial linearity: 0.6%

HU accuracy: ±40HU

Low contrast visibility: 15mm circle of 1%

Clinical application (from Oct. 2015)

(100kVp, 30mA, 20ms, full fan) (125kVp, 80mA, 20ms, half fan)



Accurate setup via 3D-3D image registration

Evaluation of anatomical changes

Assessment of need for plan adaptation

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Courtesy of Drs. Kikuo Umegaki and Seishin Takao, Hokkaido University Proton Beam Therapy Center, Japan

State-of-the-art nozzle-mounted CBCT

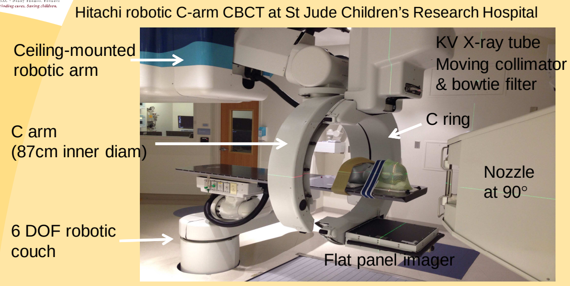
IBA CBCT system on compact Proteus One (220° gantry)

- 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

Courtesy of IBA group, Belgium

State-of-the-art robotic CBCT

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



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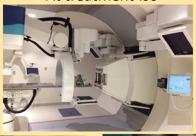
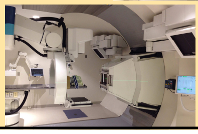
State-of-the-art robotic CBCT

3 imaging locations at each room of St Jude proton therapy center

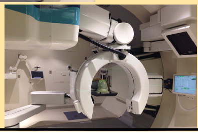
At treatment iso



27 cm from treatment iso



100 cm from treatment iso



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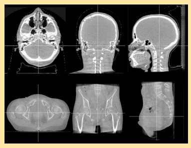
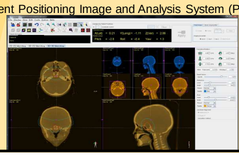
State-of-the-art robotic CBCT

St Jude robotic CBCT system

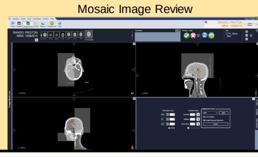
- ❑ In clinical use since November 2015
- ❑ SAD/SID = 100/150 cm
- ❑ On and off-treatment iso imaging
- ❑ Independent movable collimators
- ❑ Half fan (28cm diameter, 28cm long)
  Full fan (53cm diameter, 28cm long)
- ❑ 200° arc for brain and 360° for body



Patient Positioning Image and Analysis System (PIAS)



Mosaic Image Review



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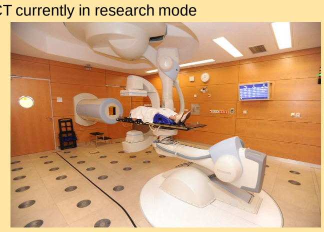
State-of-the-art robotic CBCT

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



Courtesy of Siemens Healthcare GmbH and Heidelberg Ion-beam Therapy Center, Heidelberg, Germany

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

CT sliding gantry (Siemens SOMATOM Definition AS Open) for particle therapy

Courtesy of Gerald Reinig, Siemens Healthcare GmbH and Radiation Therapy Department, Carl Gustav Carus University; Oncoray, Dresden, Germany

Courtesy of Gerald Reinig, Siemens Healthcare GmbH and Fudan University Shanghai, PRC

- ❑ Large CT bore opening (80cm)
- ❑ Integrated with different proton system vendors
- ❑ Installed 90° to proton gantry and turned off during beam on to avoid neutron damage
- ❑ Dose saving features, 4D/gated scans, and metal artifact reduction available

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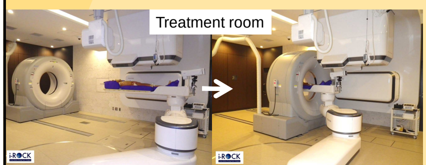
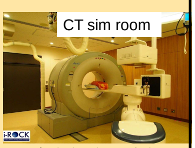
State-of-the-art rail-on in-room CT

CT sliding gantry (Toshiba Aquilion LB CT) for particle therapy



Courtesy of Dr. Shinichi Minohara, iROCK (ion-beam Radiation Oncology Center in Kanagawa), Kanagawa, Japan



Courtesy of Dr. Shinichi Minohara, iROCK (ion-beam Radiation Oncology Center in Kanagawa), Kanagawa, Japan

- ❑ iROCK is a carbon ion facility in Kanagawa Japan with fixed beam ports.
- ❑ Large-bore CT on rails (90cm opening, 70cm FOV) and robotic couch in both CT sim and treatment rooms

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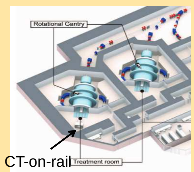
State-of-the-art rail-on in-room CT

CT sliding gantry (Toshiba Aquilion LB CT) for particle therapy

Courtesy of Fukui Prefecture Hospital Proton Therapy Center, Fukui, Japan



Satoh D et al, Journal of Nuclear Science Technology 2012

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.

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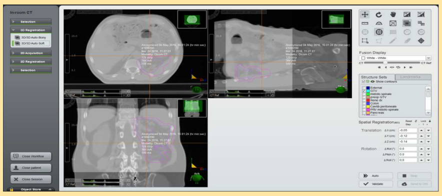
Integration of in-room CT to proton system

- ❑ Challenging multi-vdenor 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.



Courtesy of Frederic Dessy, IBA group

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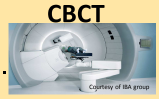
In-room CT vs. CBCT



Benefits of in-room CT:

1. Low contrast image quality
2. CT number accuracy for replanning with in-room CT scans
3. Faster scan (no 1 rpm restriction)
4. Larger axial and longitudinal FOV
5. Feasibility of 4D/gated scans
6. Can directly calculate WET and dose
7. Viable solutions for fixed beam rooms

Considerations:

1. Only imaged at off treatment isocenter; couch and CT movement takes time
2. 2D imaging not available at isocenter for verification or tumor tracking
3. Requirements on room size; occupy floor space in proton rooms
4. Accuracy of robotic couch and CT gantry sliding is critical
5. Lower-dose IG scans may not be suitable for replanning?
6. Challenges of integration with proton and OIS vendors

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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?

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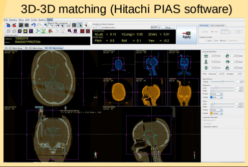
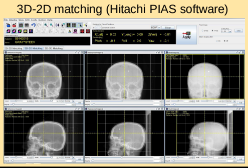
Image registration

- ❑ 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.

3D-3D matching (Hitachi PIAS software)



3D-2D matching (Hitachi PIAS software)



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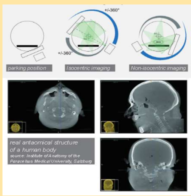
New development on the horizon

Sliding imaging ring (medPhoton GmbH)

- ❑ Directly mounted to the robotic couch; slide along the table top
- ❑ X-ray source and flat panel can independently rotate
- ❑ Independently movable jaw and dynamic filter for dual energy scans
- ❑ LFOV CBCT with large clearance

Courtesy of medAustron, Austria



Courtesy of medPhoton GmbH, Austria

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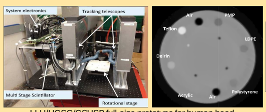
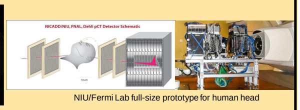
New development on the horizon

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



LLU/UCSC/CSUSB full-size prototype for human head
IEEE Nuclear Science Symposium and Medical Imaging Conference. NY, NY: IEEE; 2014.

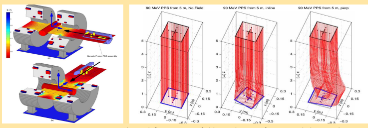


NIU/Fermi Lab full-size prototype for human head
23rd Conference on Application of Accelerators in Research and Industry, CAARI 2014, San Antonio, TX

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).



Proton beam deflection in MRI field s: Implications for MRI-guided proton therapy.
Oborn B et al, Medical Physics vol 42, 2015

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.

Acknowledgement for contributions

St. Jude Children's Research Hospital: Weiguang Yao, Marian Axente
HITACHI: Kazuo Tomida, Takao Kidani
Penn: Kevin Teo
Scripps: Lei Dong
LMU: Guillaume Landry
北海道大学: Kikuo Umegaki, Seishin Takao
i-ROCK: Shinich Minohara, Yousuke Kusano
福井県立病院: Makoto Sasaki
iba: Frederic Dessy
VARIAN: Heidi Seitz
SIEMENS: Gerald Reinig, Nora Huenemohr

END