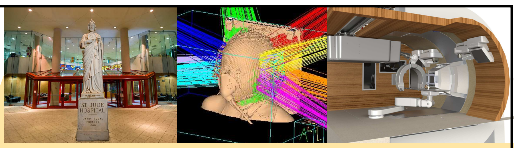

Pediatric Radiation Therapy: Simulation, Planning Guidelines, Image Guidance, and Proton Therapy

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AAPM SAM Therapy Educational Course MOC-BRF-1, July 21, 2014

Disclosure

No conflict of interest

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

Pediatric Simulation

Anesthesia, CT Sim, MR Sim

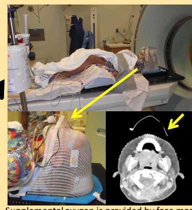
Pediatric Simulation: Anesthesia

- General anesthesia with intravenous propofol to <7 years old and uncooperative older children at St. Jude (40% of 25 treated children a day).
- Longer room time for simulation (1-1.5 hr) and treatment (30 min-1 hr) even anesthetized outside.

Anesthesia induction room

with parents/guardians present

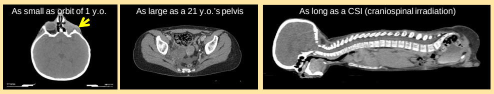
CT sim



Supplemental oxygen is provided by face mask. Oxygen tubing is used instead for patients in prone position. In case of rare upper airway obstruction, oral airway or laryngeal mask airway are used, affecting neck curvature.

Central anesthesia recovery

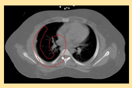
Pediatric Simulation: CT Sim



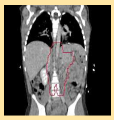
- **Methods to reduce radiation exposure from CT scans for pediatric patients**
  - Select an appropriate scan protocol based on anatomical sites
  - Limit the body scanned to the smallest necessary area but cover enough to allow the use of non-coplanar beams
  - Use automatic exposure control such as tube current modulation (e.g. Siemens CARE Dose4D and Philips Dose-Right)
  - Statistical iterative reconstruction already commercially available
  - Be careful with changing kVp – affecting energy spectrum and calibration curve
- Consider tradeoff between radiation exposure and image quality for treatment planning. Having to repeat scans due to insufficient quality defeats the purpose.
- **Image gently** by The Alliance for Radiation Safety in Pediatric Imaging: What can I do as a physicist? http://www.imagegently.org/WhatcanIdoasa/Physicist.aspx
- AAPM SAM imaging course – Best practice in pediatric imaging MO-E-18A-1

Pediatric Simulation: Respiratory Motion

- Relevant to neuroblastoma, thoracic tumors and pulmonary mets
- Unlike high image contrast of adult pulmonary lesions, pediatric tumors often need surrogates (fiducials, OARs) to determine target motion.
- Adults 8-16 breaths/min, younger children 15-20 breaths/min, and infants much higher. Teenagers approach adult respiration rates and motion extent.
- Example: Adolescents showed a larger kidney motion in S/I than children but in general <10 mm.



chest wall tumor



neuroblastoma

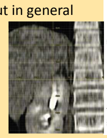


Table 1. Descriptive statistics of renal motion in pediatric patients grouped by age

Patient group	n	Variable	Mean	SD	Med	Min	Max	Lower 95% CI*	Upper 95% CI*
Young (2–8 years)	11	Age (years)	4.08	2.11	3.00	2.00	8.00	2.74	5.42
		Height (cm)	101.91	20.52	97.00	79.00	152.10	88.87	114.94
		Movement (mm)							
		Diaphragm	5.08	1.88	4.50	3.00	10.00	3.89	6.28
		R kidney ML	0.69	0.23	0.70	0.40	1.20	0.54	0.85
		L kidney ML	0.67	0.30	0.60	0.30	1.40	0.47	0.87
		R kidney AP	0.70	0.39	0.50	0.30	1.70	0.44	0.96
		L kidney AP	0.92	0.30	0.80	0.50	1.40	0.72	1.12
		R kidney SI	1.91	0.93	2.00	0.60	3.70	1.28	2.54
		L kidney SI	1.72	0.81	1.60	0.70	3.40	1.17	2.26
Old (9–18 years)	9	Age (years)	12.33	3.35	12.00	9.00	18.00	9.76	14.91
		Height (cm)	151.20	14.11	149.00	132.10	175.50	140.36	162.04
		Movement (mm)							
		Diaphragm	9.56	3.57	8.00	7.00	17.00	6.81	12.30
		R kidney ML	1.14	0.52	1.10	0.60	2.20	0.74	1.55
		L kidney ML	0.86	0.48	0.70	0.50	2.10	0.49	1.22
		R kidney AP	1.36	0.44	1.40	0.90	2.30	1.02	1.69
		L kidney AP	0.94	0.43	0.90	0.40	1.70	0.62	1.27
		R kidney SI	3.90	1.71	3.60	1.50	6.30	2.59	5.21
		L kidney SI	3.07	1.24	3.40	0.80	4.60	2.11	4.02

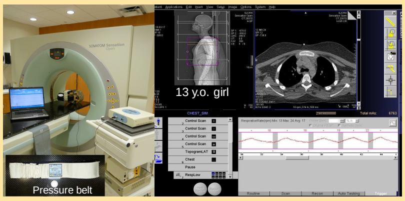
Abbreviations: AP = anteroposterior; CI = confidence interval; L = left; ML = mediolateral; Max = maximum; Med = median; Min = minimum; R = right; SD = standard deviation; SI = superoinferior.
* Lower and upper limits of the 95% confidence interval are shown.

Pai-Panandiker et al, IJROBP 2012:82:1771-1776

Pediatric Simulation: Respiratory Motion

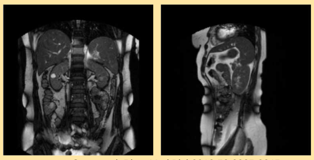
- Our 4DCT protocol: measured CTDI of 33 mGy (32cm diameter plastic body phantom).

  120 KV, 400 effective mAs,
  0.5-1s rotation
  0.1 pitch, 3mm slice,
  1.2 mm collimation



Hua et al, Med Phys 2009:36:2726

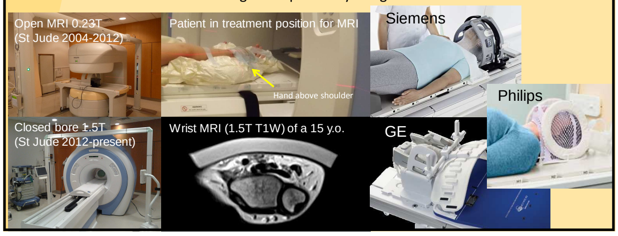
- 2D cine MRI or 4D MRI may be a good alternative for assessing the motion extent due to no radiation exposure to children and better soft tissue contrast. But motion could be out of 2D plane and pixel resolution is often lower than CT.



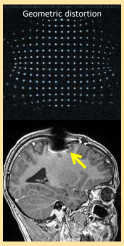
Stam et al, Phys Med Biol 2013:58:2235-2245

Pediatric Simulation: MR Sim

- MRI is essential for delineating CNS tumors and the majority of solid tumors.
- MRI is helpful for critical organ delineation in children (e.g., ovary, thyroid).
- MRI in treatment position is preferable for registration.
- More RO department now have dedicated MR scanners with lasers and flat table top.
- Vendors start to offer radiation oncology configurations with RF coils to accommodate immobilization devices although not specifically designed for children.



Pediatric Simulation: MR Sim



- **Watch out for spatial distortion**
  - ❑ Position target within the high homogeneity region of the magnet (important for tumors in extremity, shoulder, skin surface)
  - ❑ Paramagnetic objects causing local distortion (orthodontic braces, CSF shunts – common in children)
  - ❑ Focus on target region when registering MRI to CT
  - ❑ Monitor the spatial distortion regularly with QA
- **MRI pulse sequences for pediatric MR sim**
  - ❑ Perform important sequences first and keep them short in case unsedated children becoming agitated after a few minutes
  - ❑ Isotropic high resolution 3D imaging (e.g. 1mm T1W MPRAGE) good for reformatting
  - ❑ Fast sequences to minimize motion artifacts in thorax and abdomen (e.g. BLADE)
  - ❑ Sequences to reduce artifacts from blood vessel and CSF pulsations often seen in children (e.g. in posterior fossa region of the brain)
  - ❑ Close monitoring for increased heating from high SAR sequences in young children

Pediatric Planning Guidelines

RT Planning: Clinical Trial Guidelines

- Many pediatric patients are enrolled on clinical trials (COG, PBTC, other consortia, institutional trials) and treated per guidelines. The best resource is in the section of radiation therapy guidelines of the protocol.
- Different trials may have different RT guidelines (allowed treatment techniques, target definition and dose, OAR constraints, data reporting) due to principal investigator's preference and difference in treatment regimens.

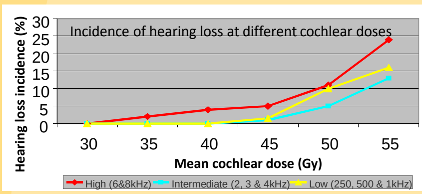
e.g. ARAR0331 for childhood nasopharyngeal carcinoma (61.2-66.6 Gy)

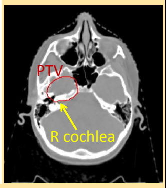
High priority	
Spinal cord	max dose 45 Gy or 1 cc can not exceed 50 Gy
Mandible/TM joint	no more than 1 cc exceeding 77 Gy
Temporal lobes	max dose 65 Gy, no more than 1 cc exceeding 60 Gy
Brainstem	max dose 60 Gy, no more than 1 cc exceeding 54 Gy
Optic nerve and chiasm	max dose 60 Gy, no more than 1 cc exceeding 54 Gy
Low priority	
Parotid	mean dose ≤ 26 Gy to at least one gland
Oral cavity	mean dose ≤ 40 Gy, no more than 1 cc exceeding 70 Gy
Cochlea	mean dose < 40 Gy
and glottic larynx, eyes, lens, pituitary, unspecified tissues	

RT Planning: Normal Tissue Sparing Vs. Tumor Coverage

Normal tissue sparing is important but don't over protect at the expense of tumor coverage.

Example: Currently a conservative planning constraint of Dmean to cochlea <35Gy is often recommended for preserving hearing after RT.





Hua et al, IJROBP vol 72, p892-899, 2008

RT Planning: PENTEC Reports

Adults

QUANTEC (QUantitative Analysis of Normal Tissue Effects in the Clinic) reports, published in 2010, reviewed dose-volume-outcome data of normal tissues in adults and recommended dose/volume constraints for treatment planning.

Children and Adolescents

PENTEC (PEdiatric Normal Tissue Effects in the Clinic) group has been formed to achieve the same goals for pediatric cancer patients receiving radiation therapy. Treatment planning guidelines will be provided for a variety of pediatric organs. (AAPM presentation MO-D-BRF-1)

Image Guidance for Pediatric Radiation Therapy

Image Guidance: Approaches and Imaging Frequency

- Pediatric IGRT approaches – implanted fiducials, EPID/2D orthogonal X-rays, CBCT, CT on rail, optical tracking/surface imaging, and MRI.
- **IGRT practice for children**
  - Survey of 80 COG member institutions in 2004 – 88% performed portal imaging once per week (Olch et al IJROBP 2004).
  - Survey of 9 international institutions with dedicated pediatric expertise – IGRT was used daily in 45% and weekly in 35% of pediatric patients. >50% CNS patients had daily IGRT. All photon institutions equip kV CBCT (Alcorn et al PROS 2014).
  - St. Jude performs daily CBCT for all patients except TBI, TLI and CSI (3mm PTV margin for brain cases, 3-5 mm for body). Higher imaging dose than weekly but allow tighter margins and occasionally detect anatomy changes.

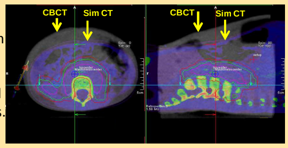


Image Guidance: Variation in Target Volume and Location

St. Jude example CBCT cases

As large as whole abdomen

As small as a finger

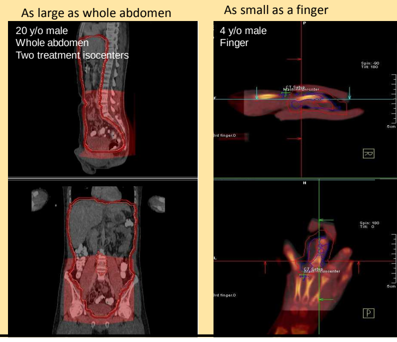


Image Guidance: CBCT Dose Reduction

KV CBCT dose has been reported to be as low as 2-3 mGy for pediatric head in recent versions. Bones and surface doses are higher.

Dose Reduction Strategies

- Increasing beam hardening by adding the copper/aluminum filter at the source side
- Reducing the length of the patient being irradiated by adjusting the collimator blades for each individual patient
- Using the X-ray technique that best matches the clinical task – reducing beam current and exposure time per projection for smaller patients
- Selecting the direction of the KV beam to avoid sensitive structures – partial arc acquisition
- Using bow-tie filters to reduce skin dose in large patients
- Low-dose protocols may be sufficient for verification purposes

Image Guidance: Collimation to Reduce Scan Length and Dose

Longitudinal asymmetric collimation is needed for pediatric CBCT

- To minimize exposure to thyroid, lens, testes, heart, and previously irradiated spinal cord
- To include additional anatomic landmarks (orbit, vertebral body) for improved image registration
- To cover two neighboring targets with one CBCT while using one treatment isocenter as the imaging isocenter

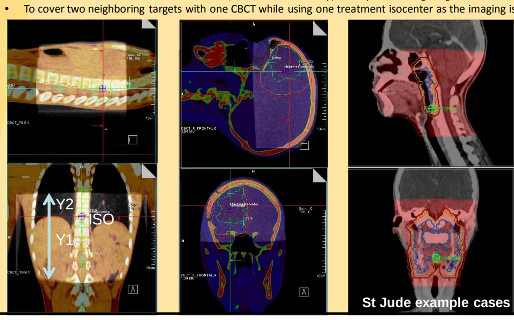


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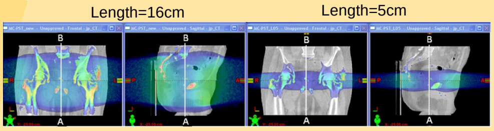
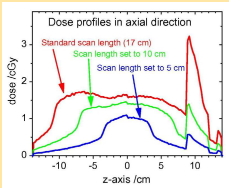
Image Guidance: Collimation to Reduce Scan Length and Dose

Length=16cm Length=5cm





Ding et al, Radiotherapy and Oncology 2010

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Pediatric Proton Therapy

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Pediatric Proton Therapy: Trend

- 13,500 children and adolescents diagnosed with cancer each year in US (~10,000 excluding leukemias) (COG data 2014).
- 3000 US children may be candidates for proton therapy
  465 treated with protons in 2010
  613 in 2011
  694 in 2012 (Pediatric Proton Foundation and National Association for Proton Therapy)
- 44 different pediatric cancers were treated with protons including brain tumors (medulloblastoma and ependymoma the most), lymphomas, sarcomas and other solid tumors (pediatric proton foundation).
- 14 US proton therapy centers are in operation and 12 under construction.
- However, 60% of pediatric patients were treated at a net loss (Indiana U data – J Am Coll Radiol 2014).
- Will see more IMPT delivered with pencil-beam spot scanning technique

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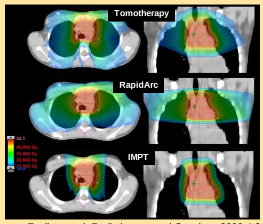
Pediatric Proton Therapy: Advantages and Challenges

- **Dosimetric Advantage**: IMPT has been shown to have a lower integral dose and better OAR sparing than rotational IMRT in selected pediatric cancers. But there are many other pediatric cancers and locations as well as treatment techniques (radioactive plaque, HDR, gamma knife, cyberknife, etc).
- Debate in Red Journal (Oct 2013) "Pediatric CSI: Are Protons the Only Ethical Approach?"



Fogliata et al, Radiotherapy and Oncology 2009:4:2

- **Issues and Challenges**
  - Additional margin to account for range uncertainty (e.g. 3.5% range, reduced with dual energy CT)
  - Spot sizes at lower energies are larger (conformity of shallow target, but technology is improving)
  - Longer wait for beam ready after patient setup (motion?, beam switching from room to room)
  - Longer delivery time (dose rate, layer switching, longer scanning with larger volume with repainting)
  - Managing interplay effects with spot scanning (many mitigation strategies were proposed)
  - Yet to demonstrate the dosimetric advantage leads to improved toxicity profile
  - High cost (compact, more cost-effective, and single-room solutions available or being developed)

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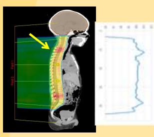
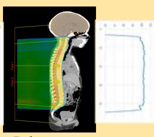
Pediatric Proton Therapy: CSI with IMPT

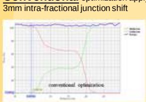
- Reduce GI toxicity, risk of second cancer, and ovary and uterine dose for female patients
- Robust optimized IMPT plan with spot scanning without the need for junction changes and less sensitive to junction mismatch.
- IMPT with spot scanning for whole brain may provide a better sparing of cochlea and lens than passive scattered plans while maintaining coverage of the cribriform plate.

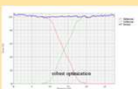


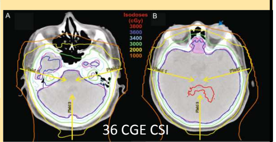
Conventional optimization applying 3mm intra-fractional junction shift



Robust optimization applying 3mm intra-fractional junction shift







Cochlea dose 36 CGE →28 CGE
Lens dose 22 CGE →12 CGE

Dinh et al, Radiotherapy Oncology 2013:8:289

Courtesy of Xiaodong Zhang. Liao et al. AAPM 2014 TH-C-BRD-12

St. Jude Children's Research Hospital

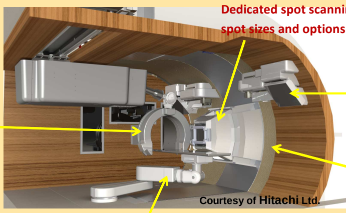
Access to Proton Therapy Through Partnership and Collaboration

- Since 2009, St. Jude has collaborated with University of Florida Proton Therapy Institute to offer proton therapy for selected pediatric cancers (craniopharyngioma, rhabdomyosarcoma, and very young children with embryonal brain tumors, high-grade glioma, choroid plexus carcinoma or ependymoma)
- Patients receive baseline evaluations (including CT/MRI for tumor delineation) at St. Jude, receive proton therapy at UFPTI, and return to St. Jude for 5-10 years of long-term follow-up.
- St. Jude physicists transfer imaging data to and receive delivered proton plans from UFPTI, perform comparative planning and data archiving, conduct collaborative research, and gain experience for proton therapy.

St. Jude Red Frog Events Proton Therapy Center

- Entered agreement with Hitachi Ltd. in Feb 2012 for synchrotron-based pencil beam scanning proton therapy system in 3 rooms (2 gantry, 1 fixed beam).
- Facility installation completed and currently under manufacturer's technical commissioning.
- Scheduled to open in fall 2015. Offer volumetric image guided IMPT.

Pediatric Proton Therapy: St. Jude



Additional features within the proton center

- MRI and PET units for tumor delineation, localization, motion assessment, adaptive therapy, and range verification
- New-generation CT for scan dose reduction and improved range estimation
- Anesthesia induction and recovery rooms
- Dedicated patient setup rooms outside the treatment rooms

Summary (Key Points)

- CT and MR simulation for pediatric patients should tailor CT scan protocols and MR pulse sequences to different anatomical sites and patient size.
- Efforts to reduce radiation exposure from CT Sim and CBCT imaging should be made.
- Radiotherapy guidelines in clinical trials are currently the best resources for setting normal tissue planning constraints. PENTEC reports will be published for treatment planning guidance.
- More and more pediatric cancer patients are receiving proton therapy. State of the art facilities will soon offer robust optimized IMPT with pencil beam scanning and volumetric image guidance.

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