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

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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

Anesthesia, CT Sim, MR Sim

- 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.
- CT scan anesthesia induction room
- CT scan central anesthesia recovery
- Supplemental oxygen is provided by face mask.
- Oxygen tubing is used instead for patients in prone position to avoid the head/neck obstruction, and areas on the neck area are used, affecting neck curvature.

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.
- AAPM SAMI 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 SI than children but in general <10 mm.
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Pediatric Simulation: Respiratory Motion

- Our 4DCT protocol: measured CTDI of 33 mGy (33cm diameter plastic body phantom).
  120 kV, 400 effective mAs,
  0.5-3s rotation,
  0.1 pitch, 3mm slice,
  1.2 mm collimation.

- 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.

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 Planning Guidelines

- Many pediatric patients are enrolled on clinical trials (CDG, 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. AAWESSL for childhood nasopharyngeal carcinoma (N=1.4-6.6 Gy).

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 OAR to cochlea <35 Gy is often recommended for preserving hearing after RT.
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 patients. 80% of 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**
- As large as whole abdomen
- As small as a finger

4 y/o male
Finger

20 y/o male
Whole abdomen

1. Two treatment isocenters
2. St. Jude example CBCT cases

**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 anatomical 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

St. Jude example cases
Pediatric Proton Therapy: Trend

- 13,900 children and adolescents diagnosed with cancer each year in US (70,000 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.

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).
- 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).

Pediatric Proton Therapy: CSI with IMPT

- Reduce GI toxicity, risk of second cancer, and ovarny 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 less than passive scattered plans while maintaining coverage of the cribriform plate.

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.

November 2013
Lifting gantry parts through hatches into the vaults

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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