Task Group 116 Workshop: Radiological Protection Aspects of Imaging in Radiotherapy

PEDIATRIC IMAGING IN RADIOTHERAPY

Thomas E. Merchant, DO, PhD
Chair, Department of Radiation Oncology
St. Jude Children's Research Hospital
Memphis, Tennessee, USA

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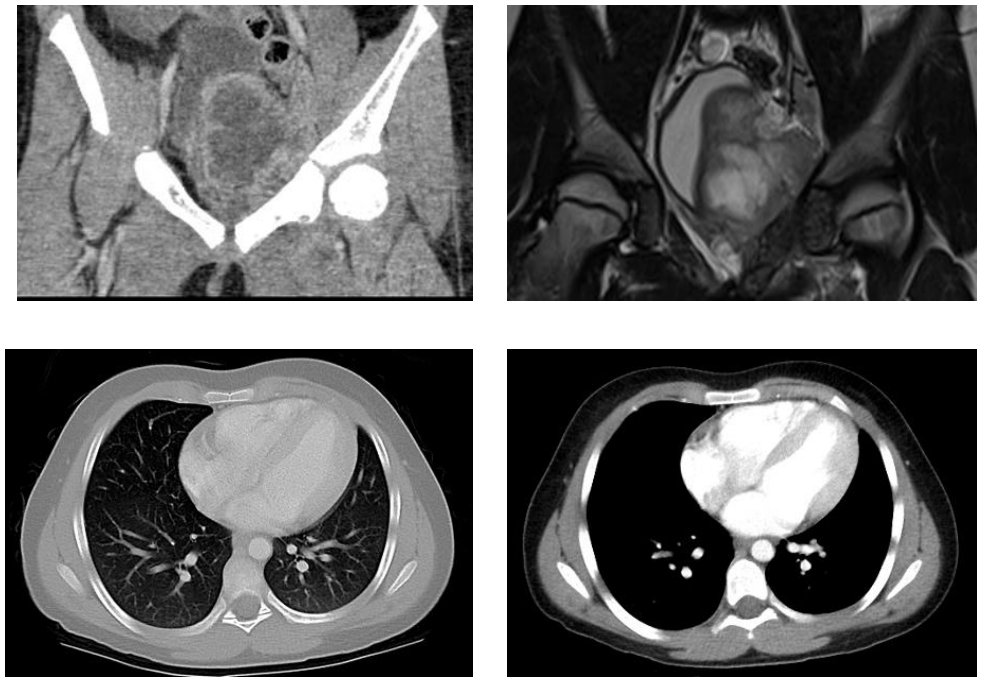
X-Ray (CT) in Pediatric Cancer Evaluation

Key Applications

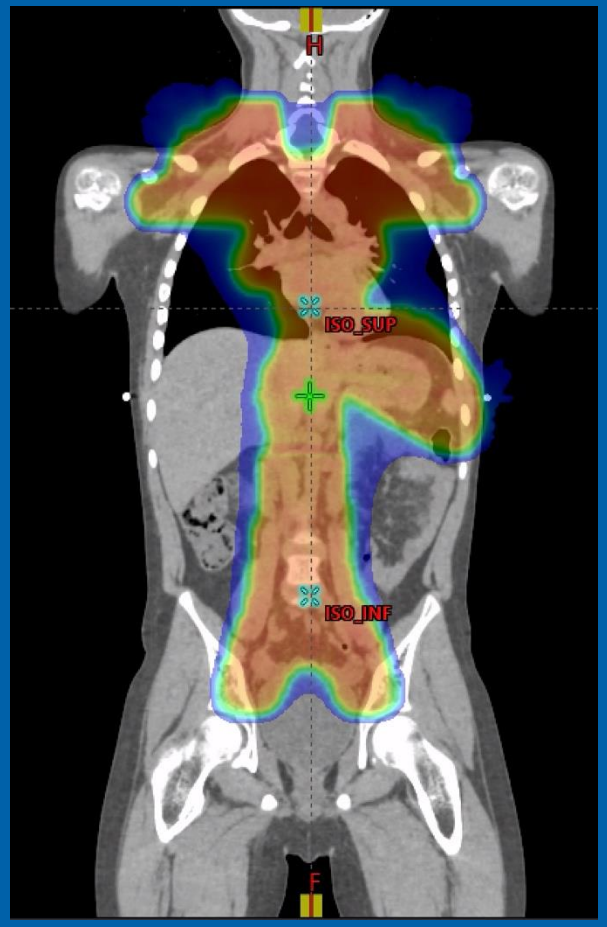
- Initial Diagnosis and Staging:
  - First imaging modality for suspected pediatric cancer.
  - Critical for evaluating:
    - Brain tumors
    - Musculoskeletal tumors
    - Pediatric-specific tumors (e.g., Wilms tumor, neuroblastoma).
- Pulmonary Metastatic Disease:
  - Preferred technique for detecting lung metastases in musculoskeletal and solid tumors with high metastatic potential.

Global Usage of Ionizing Radiation

- Developed Countries:
  - Use of ionizing radiation is limited after initial diagnosis and staging.
  - Primarily for monitoring pulmonary metastases or treatment complications.
- Low- and Middle-Income Countries:
  - X-rays often remain the sole diagnostic imaging modality due to resource limitations.

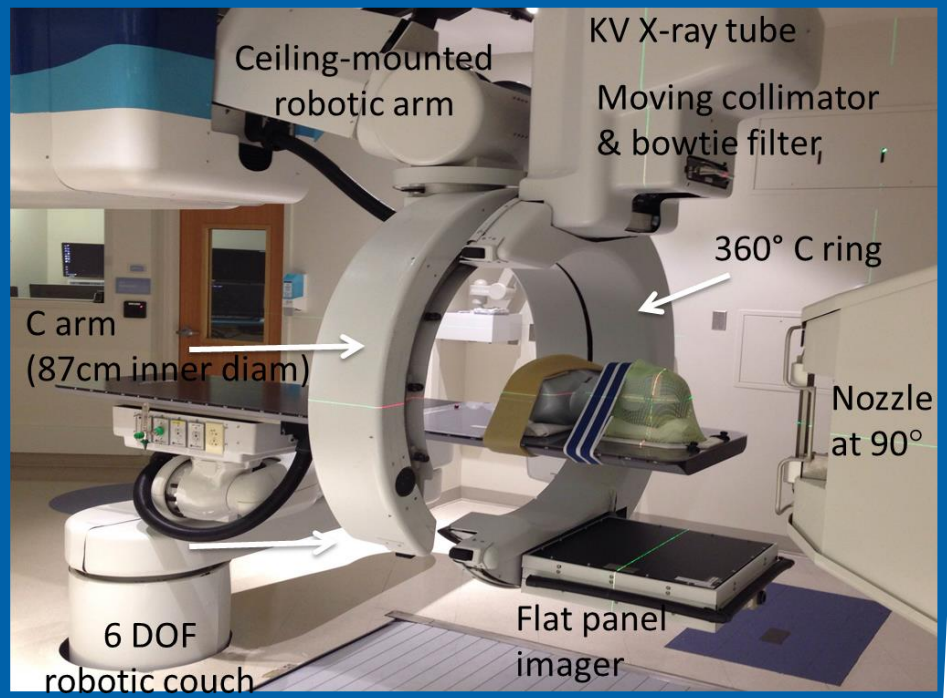


The Role of Radiotherapy in Childhood Cancer



- Prevalence of Radiotherapy Use
  - Over 50% of children diagnosed with cancer in developed countries receive radiotherapy as part of frontline management.
  - This statistic persists despite the removal of radiotherapy from CNS-directed therapy for children with acute lymphoblastic leukemia in developed countries.
- Applications in Pediatric Tumor Types
  - Brain and Spinal Cord Tumors:
    - Essential for treating medulloblastoma, ependymoma, gliomas (high/low grade), craniopharyngioma, and germ cell tumors.
    - Often utilized even in the youngest patients.
  - Musculoskeletal Tumors:
    - High-dose radiotherapy frequently required depending on surgical resection extent.
    - For soft tissue tumors, doses may be reduced based on resection extent and systemic therapy response.
  - Unique Solid Tumors:
    - Critical for treating residual tumor or subclinical microscopic disease.
    - Lower radiotherapy doses are typically sufficient compared to other tumor types.

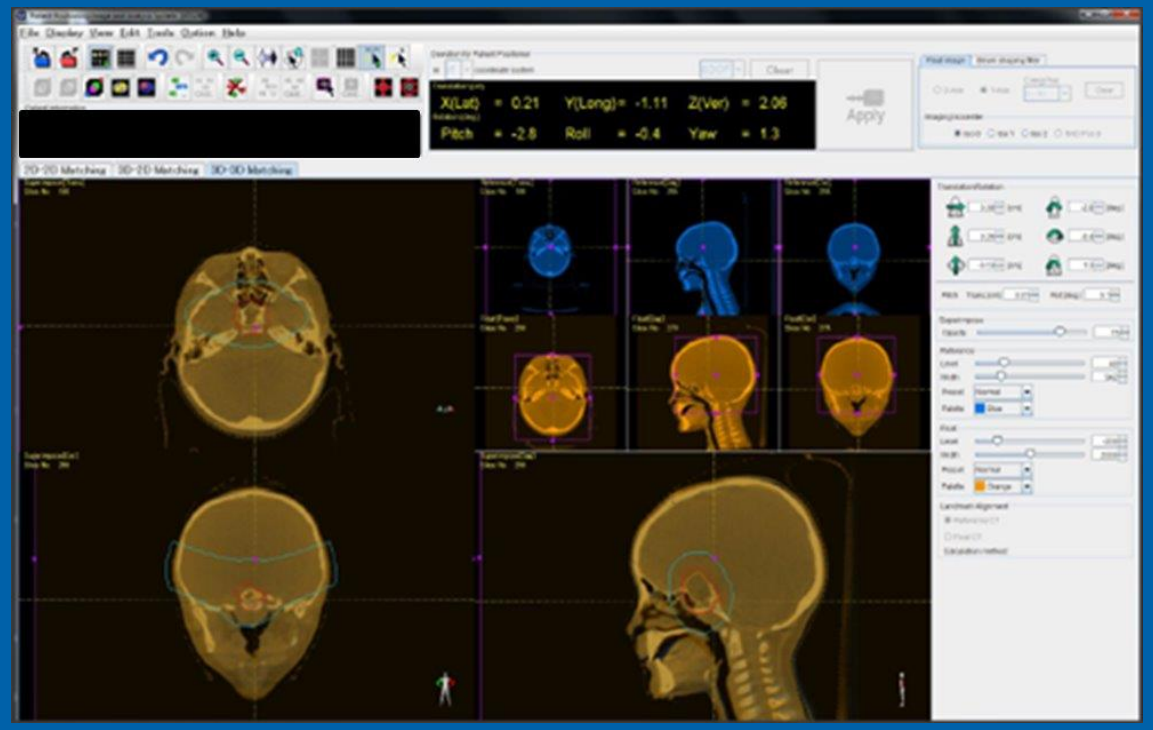
X-Ray Modalities in Pediatric Radiotherapy Planning



- Key Roles
  - Localization and Verification:
  - Routinely used prior to treatment for accurate patient positioning.
  - CT for Tissue Composition:
  - Essential for assessing electron density and spatial tissue representation.
  - Serves as the coordinate system for registering other imaging modalities.
  - Daily Cone-Beam CT (CBCT):
  - Evolved as the standard for in-room localization and verification for most pediatric patients.
- Multisequence MRI for Tumor Delineation
  - Most pediatric tumors are best visualized and delineated using multisequence MRI.
  - However, CT remains crucial for radiation dose calculation and planning.
- Emerging Interest in MRI for Treatment Planning
  - Efforts to replace x-ray CT with MRI for treatment planning are limited.
  - Currently applied only to patients receiving photon therapy.

CBCT Utilization in Pediatric Radiotherapy

European Perspective

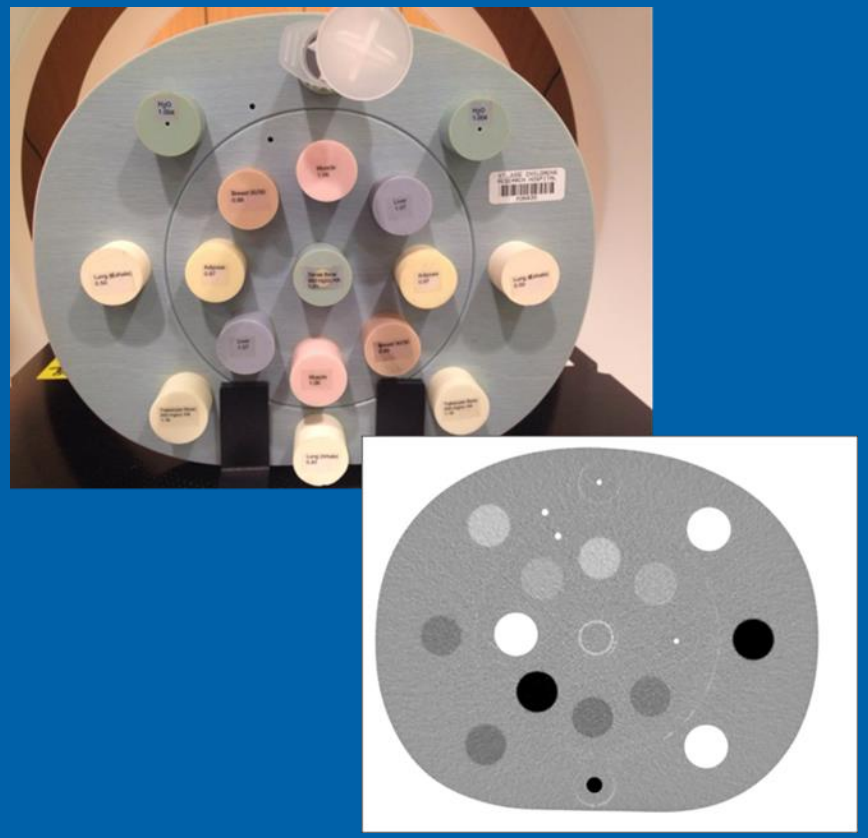


- Key Findings
  - Extensive Use in IGRT:
  - Investigators from SIOP Europe report widespread use of CBCT for pediatric radiotherapy.
  - Daily CBCT is the standard for treatment verification in most cases.
  - Site-Specific Utilization:
  - **Brain/Head Sites: 84% of centers use CBCT as the standard imaging modality.**
  - **Abdominal Sites: 70% of centers employ CBCT for treatment verification.**
- Challenges
  - Radiation Exposure Concerns:
  - Pediatric patients are more sensitive to cumulative radiation doses.
  - Lack of Optimized Protocols:
  - Pediatric-specific protocols are underdeveloped, leading to inconsistent application across institutions.
- Call to Action
  - Address radiation safety concerns by developing standardized, dose-optimized CBCT protocols tailored to pediatric patients.

Østergaard DE, Bryce-Atkinson A, Skaarup M, et al. Paediatric CBCT protocols for image-guided radiotherapy; outcome of a survey across SIOP Europe affiliated countries and literature review. Radiother Oncol. 2024. PMID: 38406888.

Optimizing Pediatric CBCT Protocols in IGRT

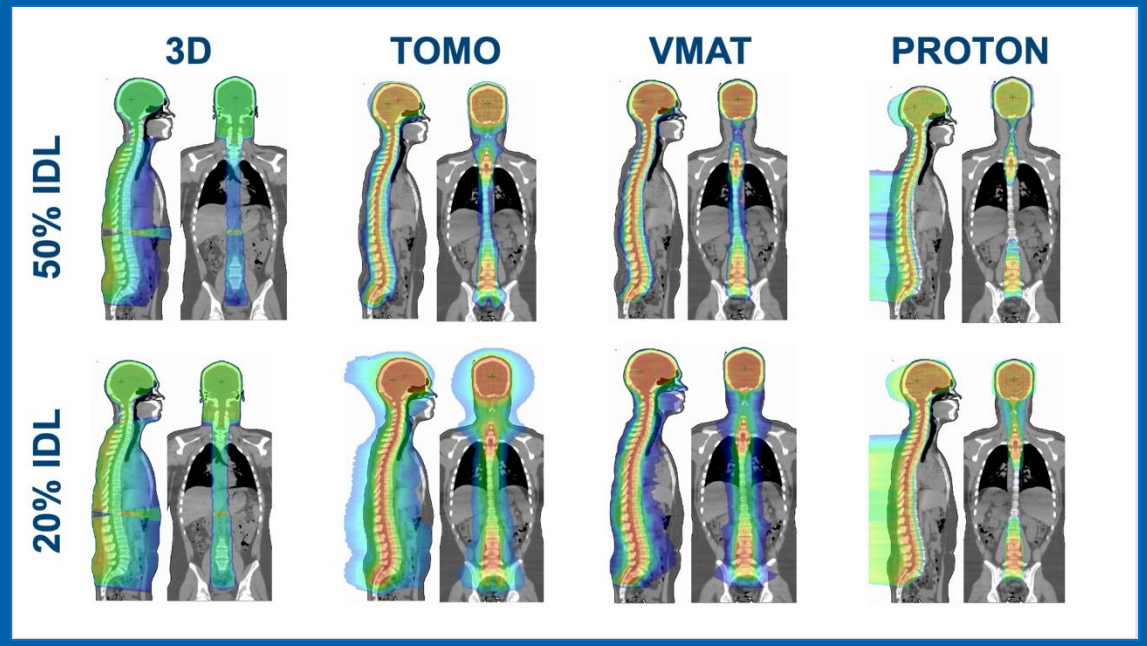
European Perspective



- Key Issues
  - Lack of Standardized Protocols:
  - Greater consistency for brain/head sites compared to abdominal sites.
  - Urgent need for dose-optimized protocols tailored to children.
  - Underutilization of Low-Dose Protocols:
  - Despite research support, low-dose CBCT protocols are underused, especially for abdominal sites.
  - Missed opportunity to reduce radiation exposure in sensitive pediatric patients.
- Dose Optimization Strategies
  - Lowering mAs settings.
  - Using bowtie filters.
  - Implementing motion management techniques.
  - Proven to reduce doses without compromising accuracy.
- Challenges in Adoption
  - Variability in patient size.
  - Lack of awareness among clinicians.
  - Limited resources for developing pediatric-specific protocols.
  - **Only 39% of surveyed facilities reported optimized exposure settings for pediatric patients.**

Image-Guided Radiotherapy in Pediatric Radiotherapy

North American Perspective

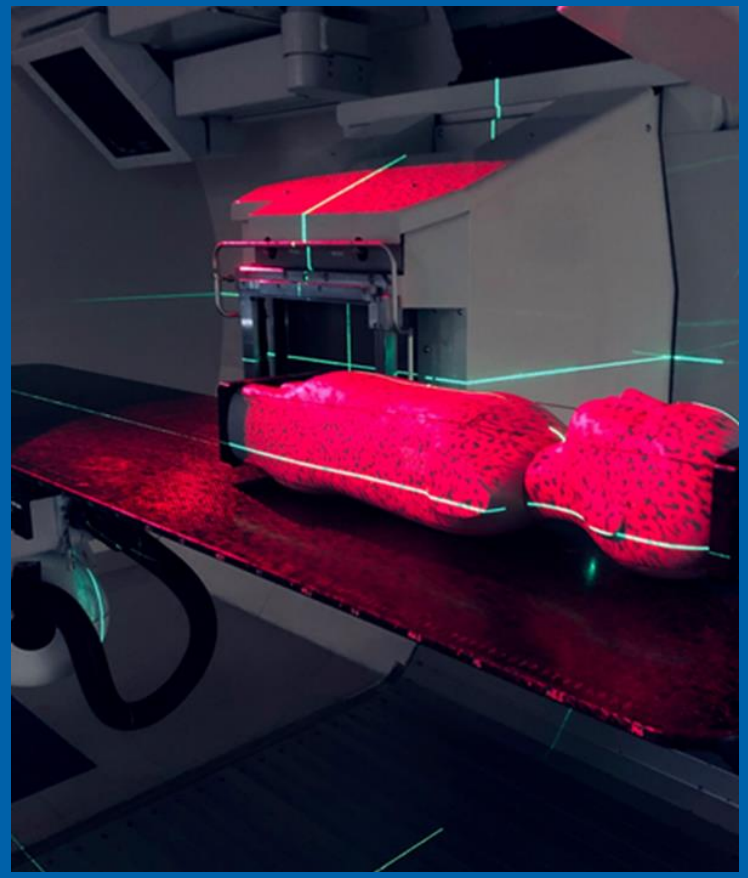


- Key Applications
  - Widely used for treatments requiring high precision:
  - Intensity-Modulated Radiation Therapy (IMRT)
  - Volumetric Modulated Arc Therapy (VMAT)
  - Proton Therapy (PT)
  - Enhances soft-tissue visualization and ensures precise patient positioning.
  - Utilization varies by disease site and institutional resources.
- Radiation Exposure Concerns
  - Pediatric patients are more sensitive to cumulative radiation exposure.
  - Efforts to minimize imaging doses include:
  - Lower-dose CBCT protocols.
  - Exploring non-ionizing imaging methods (e.g., MRI, surface imaging).
- Balancing Accuracy and Safety
  - CBCT improves treatment accuracy in complex cases.
  - Dose-reduction strategies are essential to ensure both effective treatment and long-term safety for pediatric patients.

Hua CH, Vern-Gross TZ, Hess CB, et al. Practice patterns and recommendations for pediatric image-guided radiotherapy: A Children's Oncology Group report. Pediatr Blood Cancer. 2020. PMID: 32776500.

Image-Guided Radiotherapy in Pediatric Radiotherapy

North American Perspective

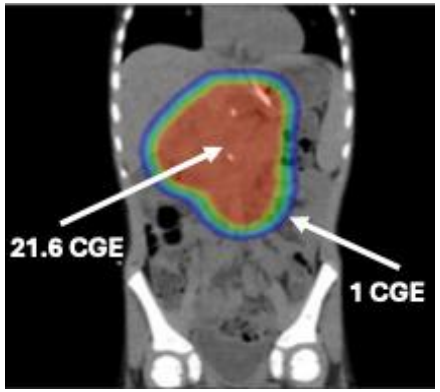


- Imaging Techniques and Frequency
  - Daily Imaging: Standard for pediatric radiotherapy.
  - Kilovoltage Imaging (kVi): Preferred for simpler treatments.
  - Cone-Beam CT (CBCT): Used for complex cases requiring precise localization.
  - Weekly Imaging: Rare, typically follows initial confirmation with daily imaging.
- Dose Reduction Strategies
  - Lower mAs and kVp settings.
  - Limit imaging fields.
  - Prioritize kV imaging over MV imaging.
  - Encourage non-ionizing methods (e.g., surface imaging, MRI guidance).
- Concerns About Secondary Malignancies
  - Cumulative imaging doses increase risks of secondary cancers.
  - Reduced safety margins and improved accuracy often outweigh these risks.
- Recommendations for Pediatric IGRT
  - Follow Children's Oncology Group (COG) guidelines:
  - Disease-specific imaging modalities.
  - Appropriate imaging frequency.

Image-Guided Radiotherapy in Pediatric Radiotherapy

Neuroblastoma & Rhabdomyosarcoma

- Neuroblastoma
  - **Conformal methods**
    - Minimize radiation exposure to radiosensitive organs (e.g., kidneys, vertebral bodies).
    - Proton therapy reduces doses to healthy tissues but requires advanced verification imaging due to smaller target margins.
  - **Imaging Protocols & Timing**
    - Therapy occurs post-high-dose chemotherapy consolidation, reducing anatomical shifts and replanning needs.
    - Imaging (CT/MRI) is conducted at key junctures: pre-treatment, post-chemotherapy, and post-consolidation.
  - **Potential for Non-Ionizing Imaging**
    - Interest in ultrasound for localization is growing to reduce collateral radiation exposure from x-ray–based imaging.



- Rhabdomyosarcoma
  - **Challenges with Tumor Dynamics**
    - Frequent imaging is needed due to anatomical changes (e.g., weight loss, tumor response).
    - Replanning and additional CTs are often required for conformal methods with small target margins.
  - **Proton Therapy & Imaging Needs**
    - Proton therapy reduces radiation exposure to healthy tissues, especially for large metastatic sites like lungs.
  - **Precise volumetric imaging is essential to address range uncertainties.**
    - Emergence of MRI for Treatment Planning
    - MRI is increasingly used for target delineation, avoiding ionizing radiation exposure while maintaining imaging quality.

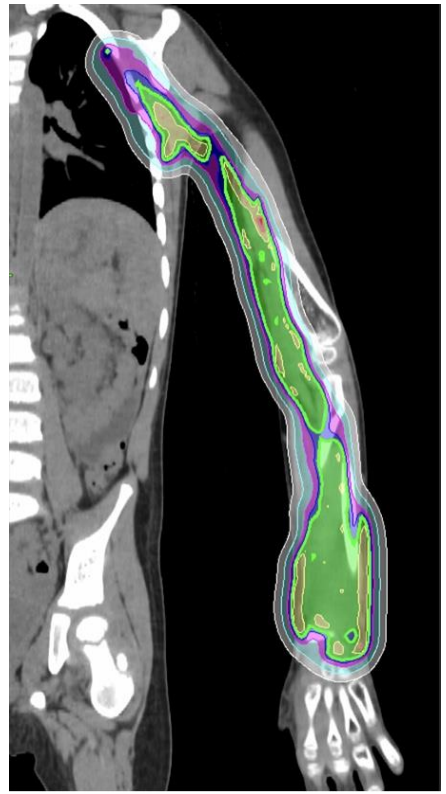
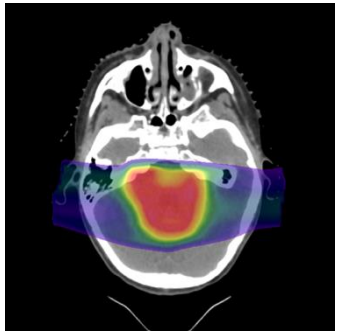


Image-Guided Radiotherapy in Pediatric Radiotherapy

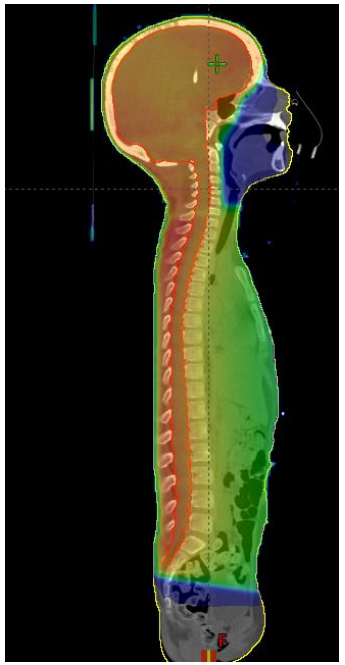
Ependymoma & Medulloblastoma

- Ependymoma
  - **Proton Therapy & Daily Verification Imaging**
    - Proton therapy minimizes radiation exposure to healthy tissues in critical neurovascular and CSF pathways.
    - Daily imaging with cone-beam CT (CBCT) or optical surface imaging ensures precision targeting.
  - **Image-Guidance Optimization for Young Patients**
    - Radiation therapy for children as young as 12 months requires tailored imaging protocols to reduce dose exposure.
    - Pediatric CBCT protocols often result in higher exposures compared to adults, emphasizing the need for dose-reduction strategies.
  - **Risk of Secondary Malignant Neoplasms**
    - Repeated diagnostic-quality x-ray imaging raises concerns about secondary cancers.
    - Advanced imaging technologies and non-ionizing methods are critical for long-term safety.
- Medulloblastoma
  - **Craniospinal Radiation Therapy**
    - Precision imaging during craniospinal irradiation is essential to target subarachnoid spaces while sparing healthy tissues.
    - Daily imaging is common with advanced techniques like IMRT or proton therapy; weekly imaging may suffice for less advanced methods.
  - **Boost Phase Imaging & Precision**
    - Additional CT scans during the boost phase improve accuracy for targeting smaller margins, despite increased exposure.
  - **Adverse Effects & Collateral Dose Concerns**
    - Severe acute and long-term complications include risks of secondary malignancies and cataracts.
    - Optimized imaging protocols and non-ionizing imaging alternatives are essential to mitigate collateral radiation exposure.

Ependymoma



Medulloblastoma



Optimizing Radiation Therapy Imaging in Pediatrics

Long-Term Considerations

- Pediatric radiation oncologists must balance effective tumor coverage with minimizing long-term complications.
- Imaging plays a critical role in assessing tumor coverage and reducing risks of future complications.

Imaging Objectives

- **Primary:** Verify patient positioning using x-ray-based imaging.
- **Secondary/Tertiary:** Evaluate external contours, tumor changes, and internal tissue deformities impacting dosimetry.

Awareness of Imaging Risks

- Limited awareness exists about the risks of repeated diagnostic-quality x-rays exposing healthy tissues during IGRT.
- Often overlooked in clinical protocols, consent forms, and follow-up procedures.

Need for Consensus and Guidelines

- Concerns about low-dose radiation exposure have led some institutions to prefer 3D-conformal techniques over IMRT or VMAT.
- Standardized guidelines and greater discussions are necessary to address these concerns.

Optimizing Pediatric Imaging

- Employ technical advancements to minimize radiation exposure:
  - Reduce field of view.
  - Use iterative CT reconstruction.
  - Adopt non-ionizing imaging methods (e.g., MRI and optical surface guidance).

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