JOINT ICTP-IAEA WORKSHOP ON RADIATION PROTECTION IN IMAGE-GUIDED RADIOTHERAPY (IGRT)

Imaging frequency justification

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Outline

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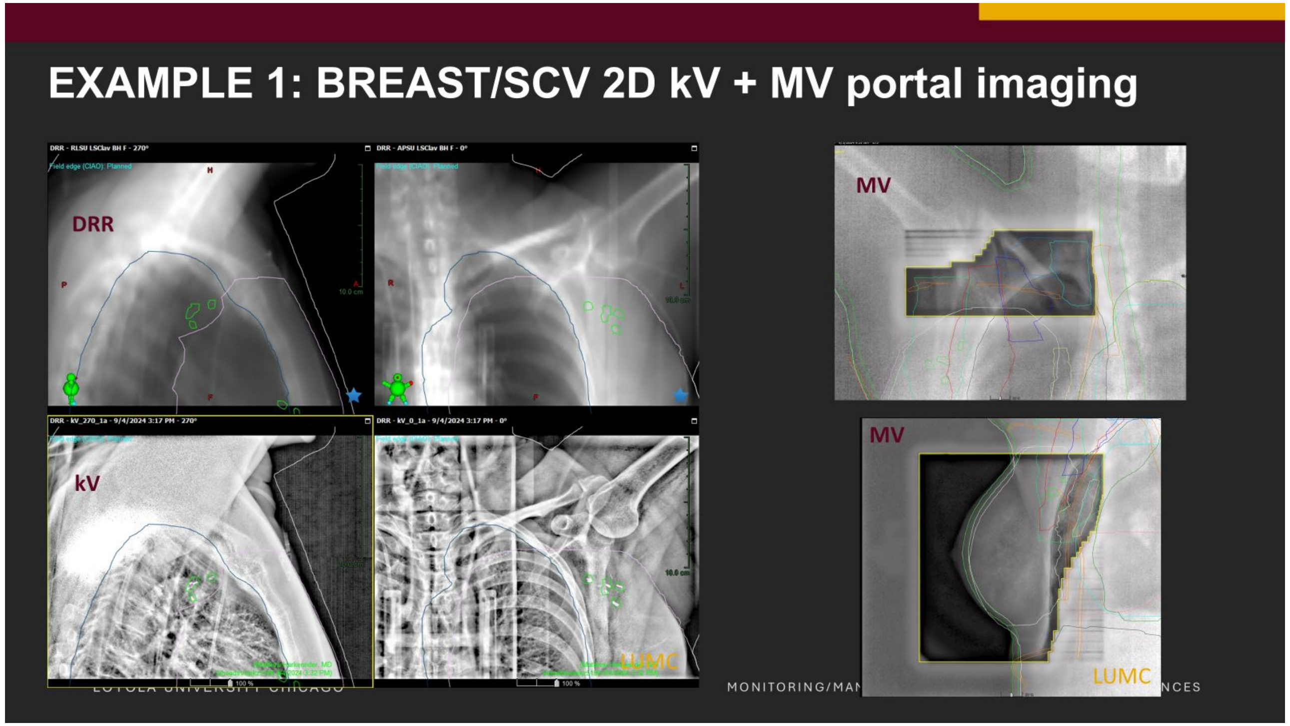
2. Clinical Scenarios That Influence Imaging Frequency
3 Trade-offs: Accuracy vs. Cumulative Dose
4. International Guidelines and Recommendations
5. Technological Advances and Impact on Imaging Frequency
6. Dose Optimization Strategies
7. Conclusion and Future Directions

1. INTRODUCTION TO IMAGING FREQUENCY JUSTIFICATION

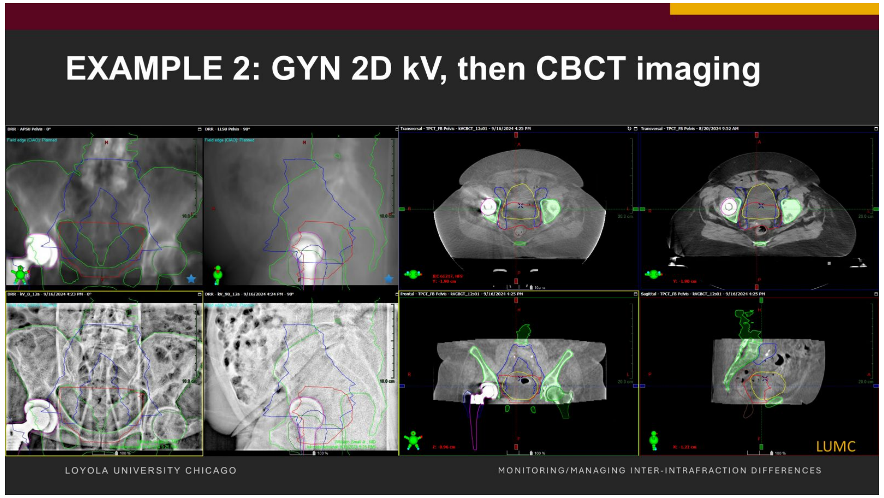
Clinical Justification of Imaging in Radiotherapy

- Imaging ensures accurate tumor targeting.
- Justification of imaging is essential to balance benefit vs. risk
- Adaptive Radiotherapy (ART) often requires increased imaging for adaptation.



ALARA and ICRP's Recommendations

- ICRP emphasizes the **ALARA** principle for imaging frequency.
- Justification depends on clinical scenarios, tumor type, and treatment modality.
- Aim to reduce exposure while ensuring precise targeting



2. CLINICAL SCENARIOS THAT INFLUENCE IMAGING FREQUENCY

Key Factors Influencing Imaging Frequency

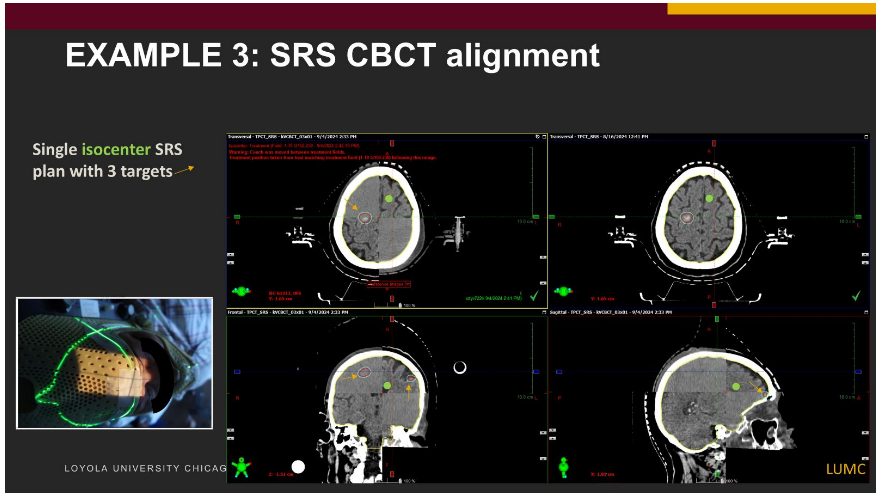
- Tumor location and treatment technique affect imaging needs.
- Patient-specific factors may require adaptive imaging schedules.
- High-precision techniques like **SBRT** demand more frequent imaging.

Imaging Considerations for Specific Sites

Head and Neck: Frequent imaging due to anatomical changes (e.g., weight loss).

Thorax: Real-time or **4D-CBCT** imaging for respiratory motion.

Prostate: Daily imaging due to variability in bladder/bowel filling.



3 TRADE-OFFS: ACCURACY VS. CUMULATIVE DOSE

Balancing Precision and Radiation Dose

Imaging improves precision but adds to **cumulative radiation dose**.

ICRP TG-116: Balance benefits (e.g., accuracy, tumor control) with dose risks.

Justification involves considering **margin reduction** vs. radiation risk.

Quantifying Cumulative Dose from Imaging

Example: CBCT adds **1-2 mGy per session**; cumulative dose becomes significant over time.

Low-dose protocols should be used when frequent imaging is necessary.

Track cumulative dose and optimize imaging frequency.

4. INTERNATIONAL GUIDELINES AND RECOMMENDATIONS

Overview of International Recommendations

Recommendations guide imaging for **treatment precision** and **radiation protection**.

High-precision treatments often require **frequent imaging**.

Guidelines emphasize **appropriate modality** and **patient-specific** protocols.

Practice Guideline > Am J Clin Oncol. 2020 Jul;43(7):459-468.
doi: 10.1097/COC.0000000000000697.

ACR-ASTRO Practice Parameter for Image-guided Radiation Therapy (IGRT)

Join Y Luh [1], Kevin V Albuquerque, Cheewai Cheng, Ralph P Ermoian, Nima Nabavizadeh, Homayon Parsai, John C Roeske, Stephanie E Weiss, Raymond B Wynn, Yan Yu, Seth A Rosenthal, Alan Hartford

Affiliations + expand

PMID: 32452841 DOI: 10.1097/COC.0000000000000697

Applying Guidelines to Clinical Practice

Tailor imaging frequency to **treatment type** and **tumor location**.

Daily imaging for **high-precision treatments** (e.g., SBRT).

Apply **low-dose protocols** when frequent imaging is necessary.

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Scenario	Suggested imaging approach
High accuracy requirements (e.g. SBRT/SRS)	Volumetric imaging prior to delivery, consider post-treatment imaging to assess impact of intrafraction motion
High risk treatment (e.g. proximity to sensitive structures)	Volumetric imaging prior to delivery, also intrafraction monitoring in cases of motion
Paediatric radiotherapy	Low dose imaging, consider frequency necessary
Systematic difference between planning and treatment expected (e.g. weight loss)	Frequency of imaging balanced with the magnitude of errors expected and the requirement for margin reduction
Random variations expected between fractions (e.g. bladder filling, intestinal motion)	Consider high frequency of imaging balanced with the magnitude of errors expected
Significant intrafraction motion expected (breathing)	frequent imaging during delivery or use of surrogate markers to monitor motion and link to imaging prior to delivery.

5. TECHNOLOGICAL ADVANCES AND IMPACT ON IMAGING FREQUENCY

Adaptive Radiotherapy (ART) and Real-Time Imaging

ART allows real-time adjustments to treatment.

Frequent imaging enables monitoring of tumor and anatomical changes.

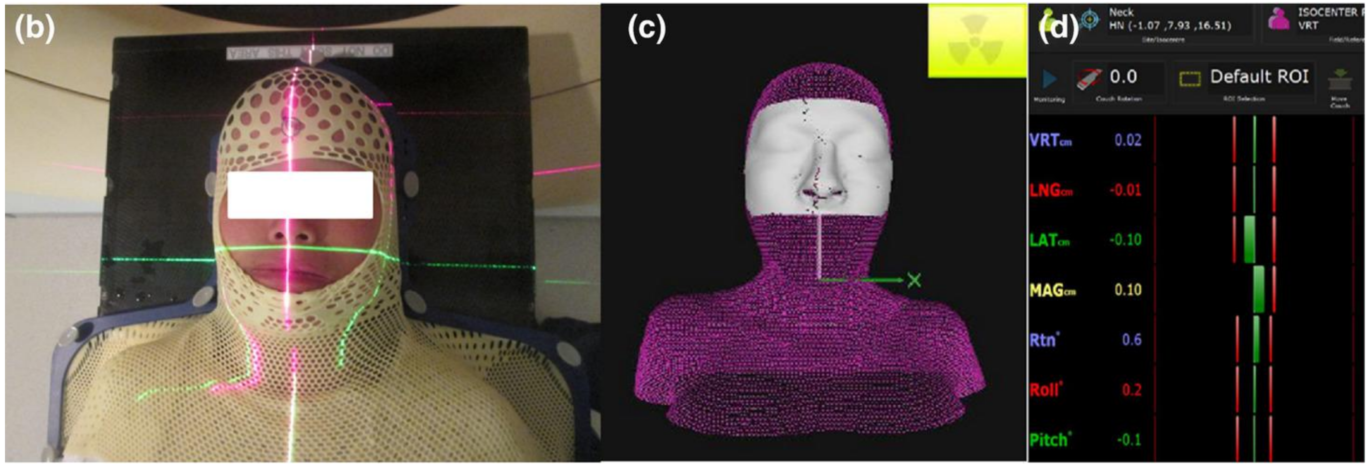
Real-time imaging technologies ensure precision during treatment delivery.

Surface-Guided Radiation Therapy (SGRT)

SGRT: Non-ionizing technology for precise patient alignment.

Reduces the need for ionizing imaging in certain treatments.

Useful for **breast** and **head and neck** radiotherapy.



Feature	SGRT	CBCT
Type of imaging	Non-ionizing (optical tracking)	Ionizing (X-ray based)
Radiation exposure	None	Adds Cumulative dose X ~X mGy per scan
Best for Treatmetn Sites	Sites where soft tissue movement is minimal, e.g., breast, head, and neck	Sites with high anatomical movement or internal organ motion, e.g., thorax, prostate
Frequecy of use	Can be used for continuous or real-time alignment monitoring	Typically used pre- and post-treatment for verification
Advantages	No radiation dose; can be used in real-time for continuous patient monitoring; improves patient comfort by avoiding additional scans	Provides internal anatomy visualization, including tumor and organ positions; necessary for cases with complex motion (e.g., respiratory motion)
Limitations	Not suitable for tracking internal structures (e.g., tumors); limited to surface-based alignment	Increases patient's cumulative dose; requires additional time for image acquisition and analysis
Technological Integration	Compatible with non-ionizing surface tracking technologies (e.g., optical cameras)	Integrated with LINAC for in-room volumetric imaging
Application in Radiotherapy	Common in **breast cancer**, **head and neck**, and other external sites; especially useful in **deep inspiration breath hold** (DIBH)	Essential for **SBRT**, **SRS**, and cases with significant **intrafraction motion** (e.g., lung cancer, prostate)
Cost and Accessibility	Requires specialized surface-tracking equipment, but avoids the costs of repeated imaging	Widely available in most radiotherapy centers; however, repeated use can add to imaging costs and resource use

6. DOSE OPTIMIZATION STRATEGIES

Reducing Imaging Dose per Treatment Session

Low-dose protocols reduce radiation from frequent imaging.

Adjust imaging parameters to maintain **image quality** while reducing dose.

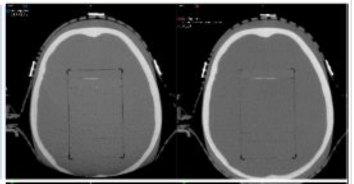
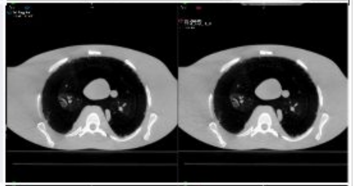
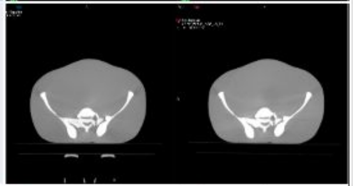
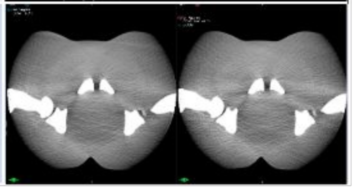
Consider **non-ionizing alternatives** (MRI, ultrasound) when appropriate.

Implementation of low dose CBCT protocols

Lowering imaging dose by 80%-50% retained clinically acceptable imaging quality with minimal interference from aliasing artifacts (low frames) or noise (low exposure)

Goals:

1. Maintain clinically appropriate IQ
2. Lower dose
3. Limit artifacts

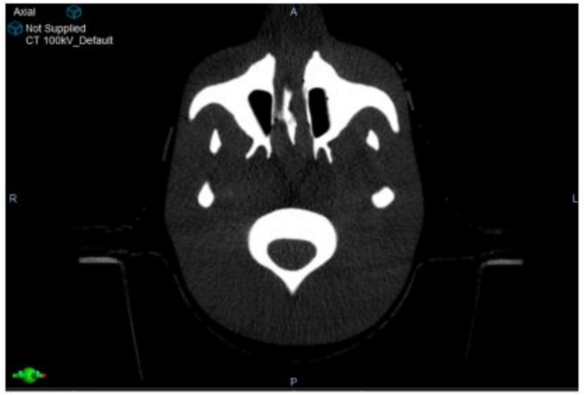
Protocol	Exposure (mAs)	Projections	K_{air} (mGy)	Dose relative to default	Example images Default Optimized
HEAD	112.5	500	4.13	78%	
THORAX	135	900	11.11	57%	
PELVIS	540	900	33.11	52%	
LARGE PELVIS	850.5	900	67.90	51%	
SPOTLIGHT	563.5	500	33.87	76%	

Implementation of Pediatric Head CBCT protocol

- 11 years old boy with metastatic neuroblastoma in bilateral mastoid region
  - Already received multiple courses of palliative RT
  - 21.6 Gy, 1.8 Gy x 12
  - CBCT daily

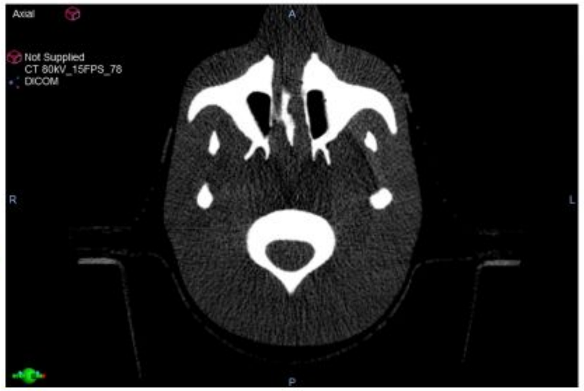
- Pediatric low dose HEAD protocol implementation
  1. Default HEAD 100 kVp → 80 kVp: measured relative Ak
  2. Phantom study for Iage Quality with lower exposure /dose reviewed with CNS physician
  3. Set 2 protocols:
     - HEAD_PEDS: 500 frames, 75% dose reduction
     - HEAD_PEDS_LD: 367 frames, 88% dose reduction

DEFAULT



HEAD_PEDS

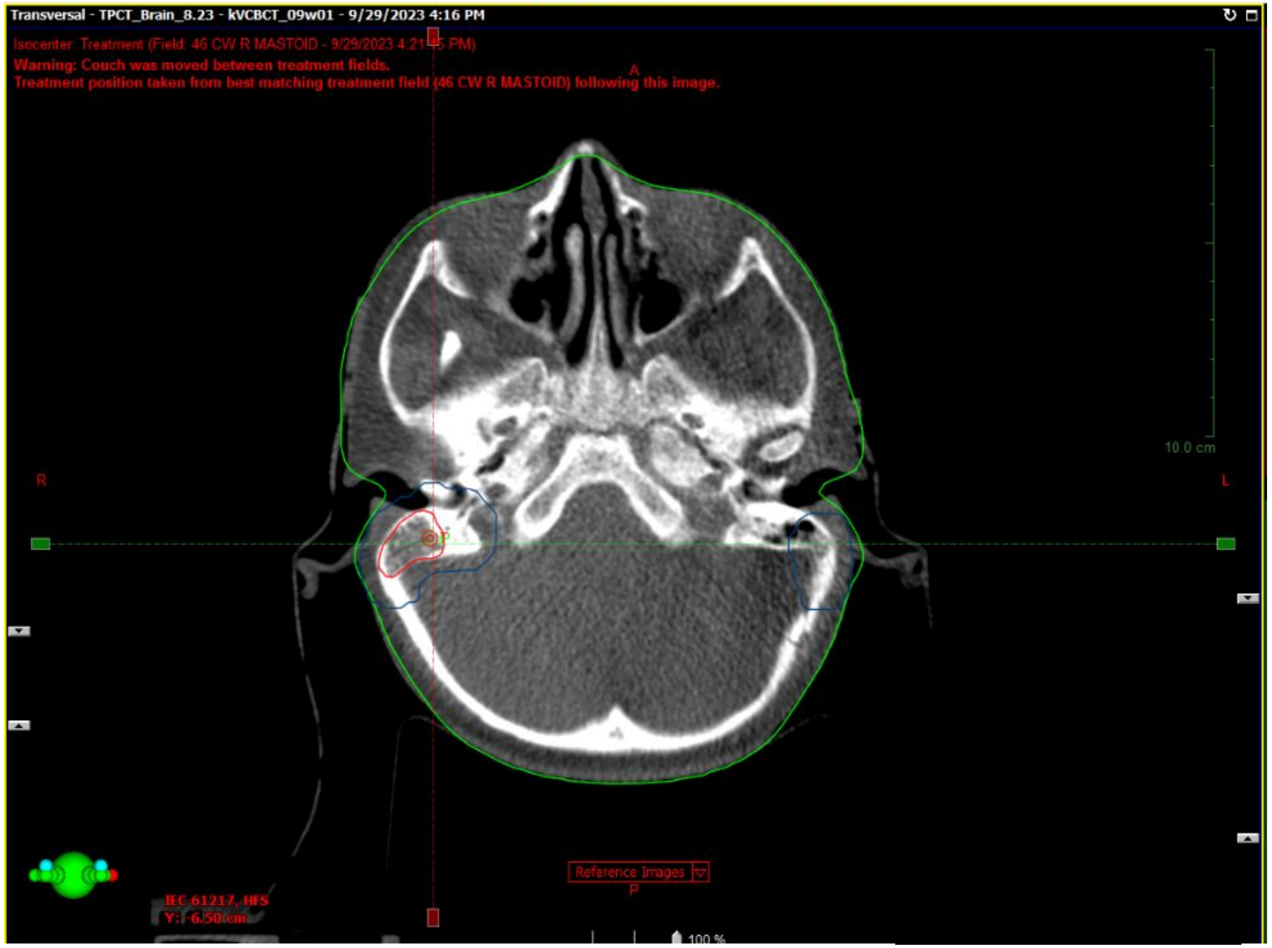
75% dose reduction

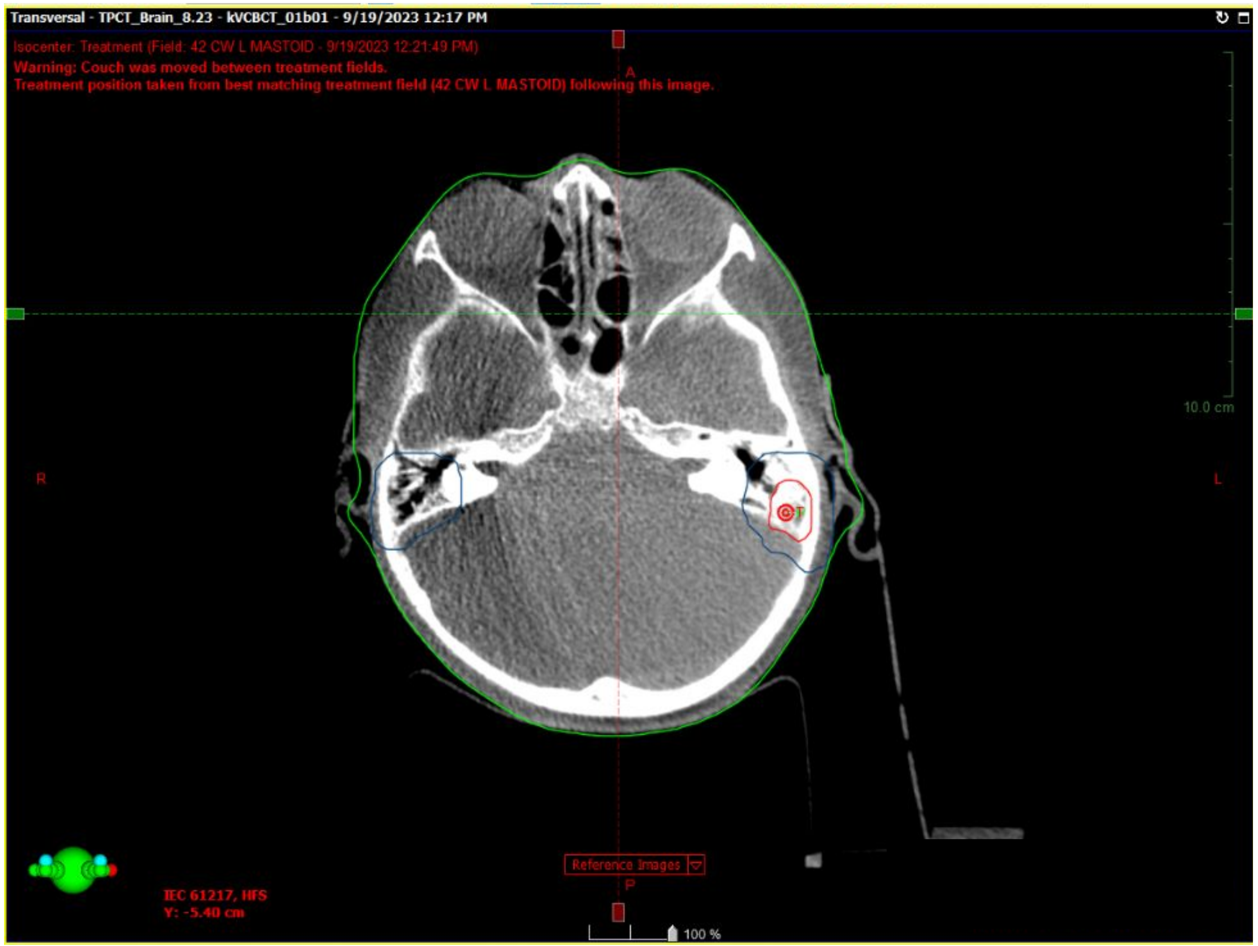


HEAD_PEDS_LD

88% dose reduction

- Left and right Mastoid targets aligned with HEAD_PEDS_LD CBCT protocol
    - GREAT bone/soft tissue contrast
    - VERY LOW soft tissue contrast



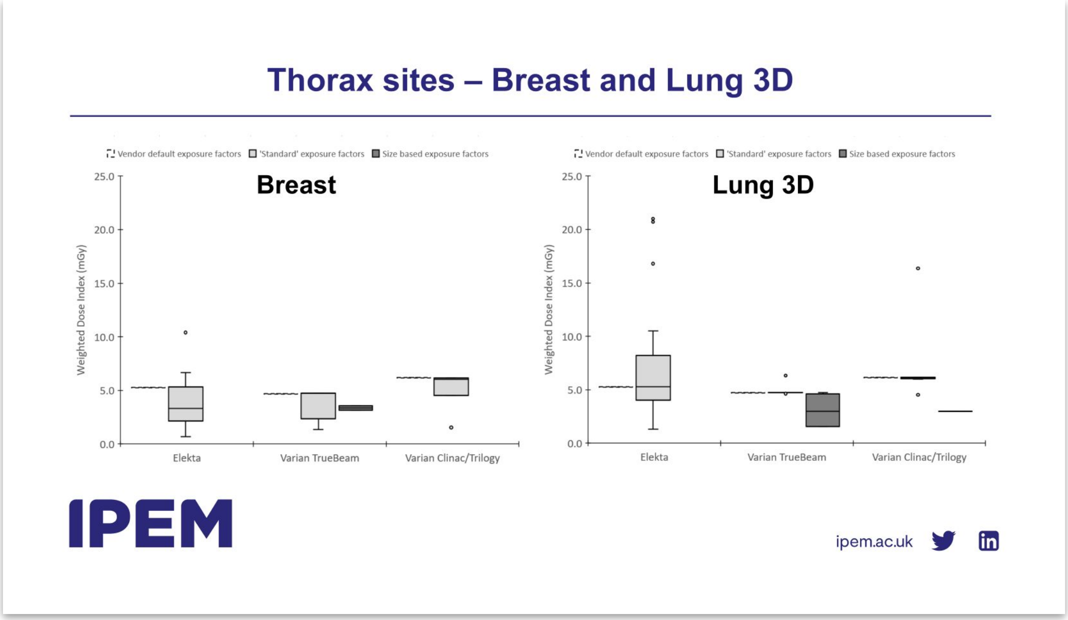


Diagnostic Reference Levels (DRLs)

DRLs set benchmarks for acceptable imaging dose levels.

Helps clinicians optimize imaging protocols.

Essential for special populations (e.g., **pediatrics**).



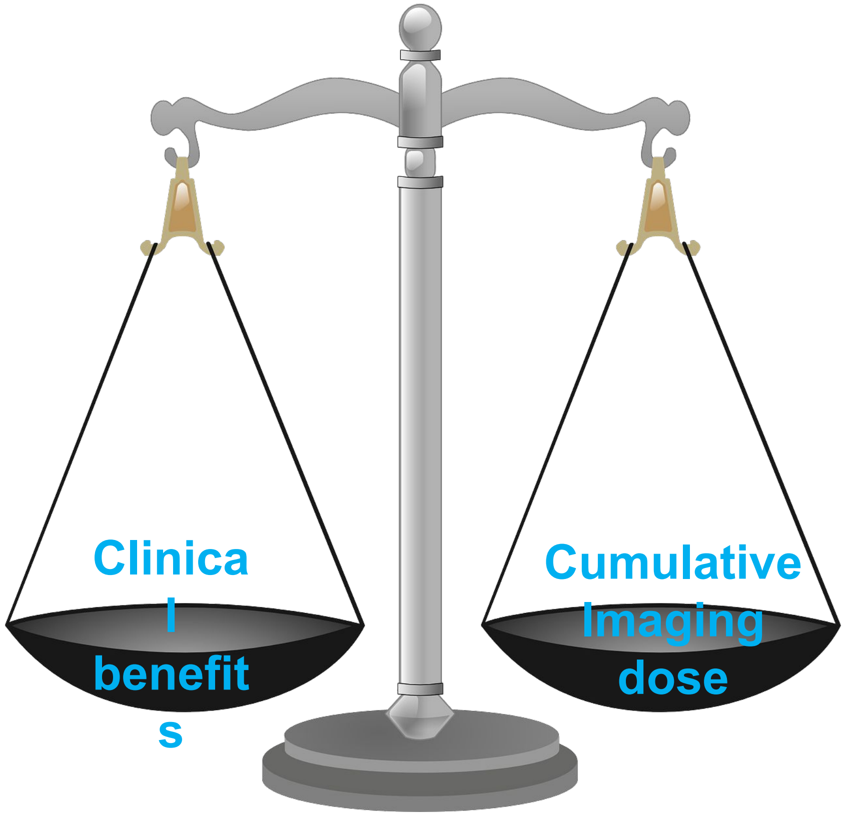
7. CONCLUSION AND FUTURE DIRECTIONS

Conclusion: Balancing Precision and Safety

Imaging ensures treatment precision but must be **justified**.

Balance clinical benefit vs. cumulative radiation dose.

Use **ALARA**, low-dose protocols, and non-ionizing methods to optimize.



Conclusion: Future Directions

Adaptive radiotherapy (ART) and **SGRT** reduce the need for frequent imaging.

AI and machine learning may predict imaging needs, improving precision.

DRLs will guide future dose optimization.