AAPM-SCC Midwinter Workshop on 1/30/2026

Intensity-modulated TBI/TM(L)I: whole body irradiation in the modern era

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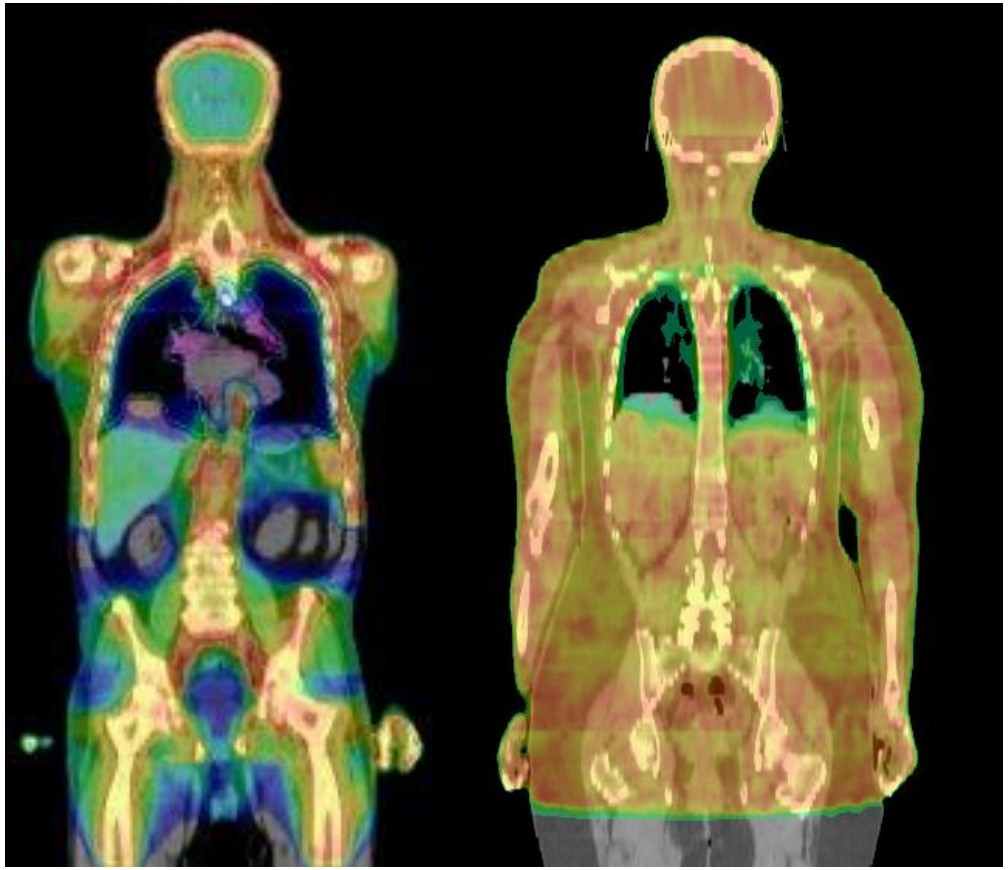
Disclosure

- I received research grants from Varian Medical Systems, Inc., on development of software tools on the Varian Eclipse platform.
- I received research grants from RefleXion Medical, Inc.

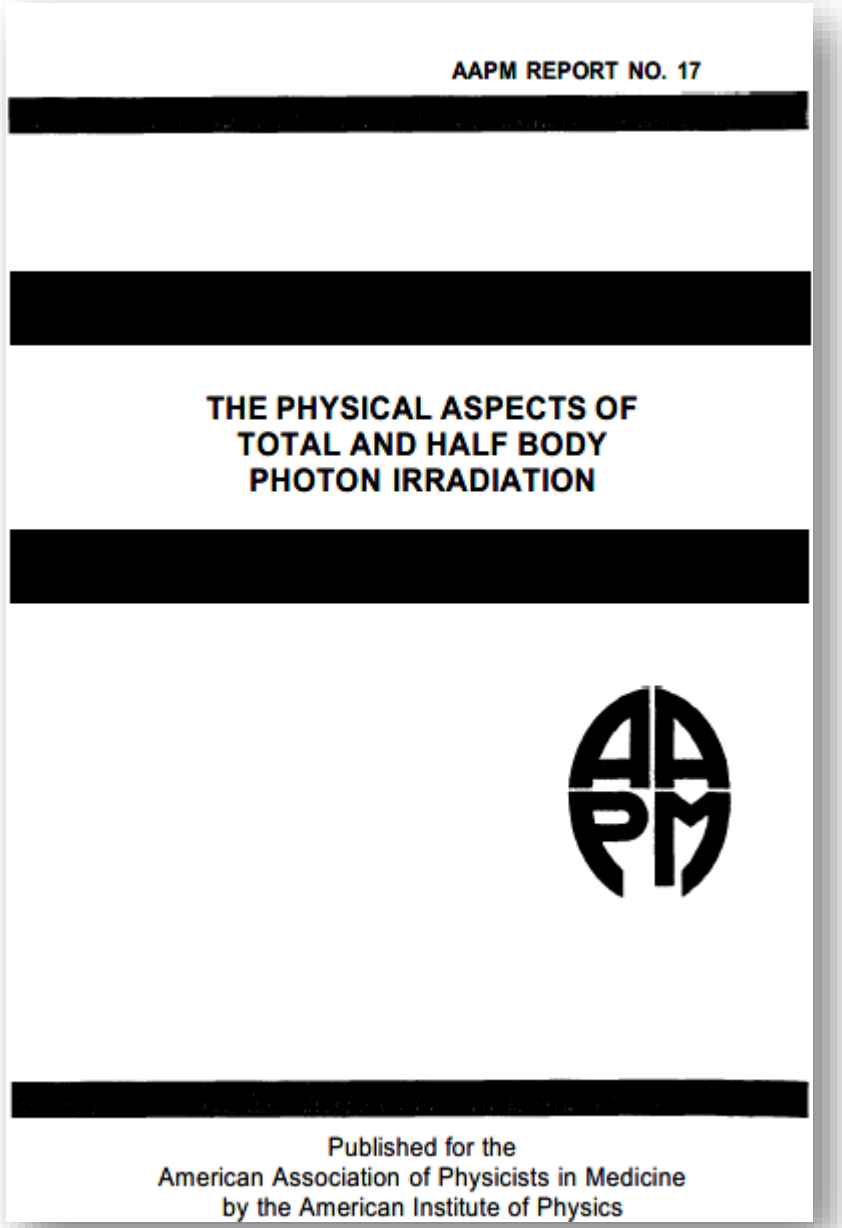
Content

- Historical overview of whole-body irradiation.
- Modern intensity-modulated techniques for TBI/TM(L)I in the context of AAPM Task Group 379 report.
- The COH experience on IM-TBI/TM(L)I.
- The AAPM Grand Grace Kim Memorial Challenge in 2026: Advancing Total Body, Marrow, and Lymphoid Irradiation.



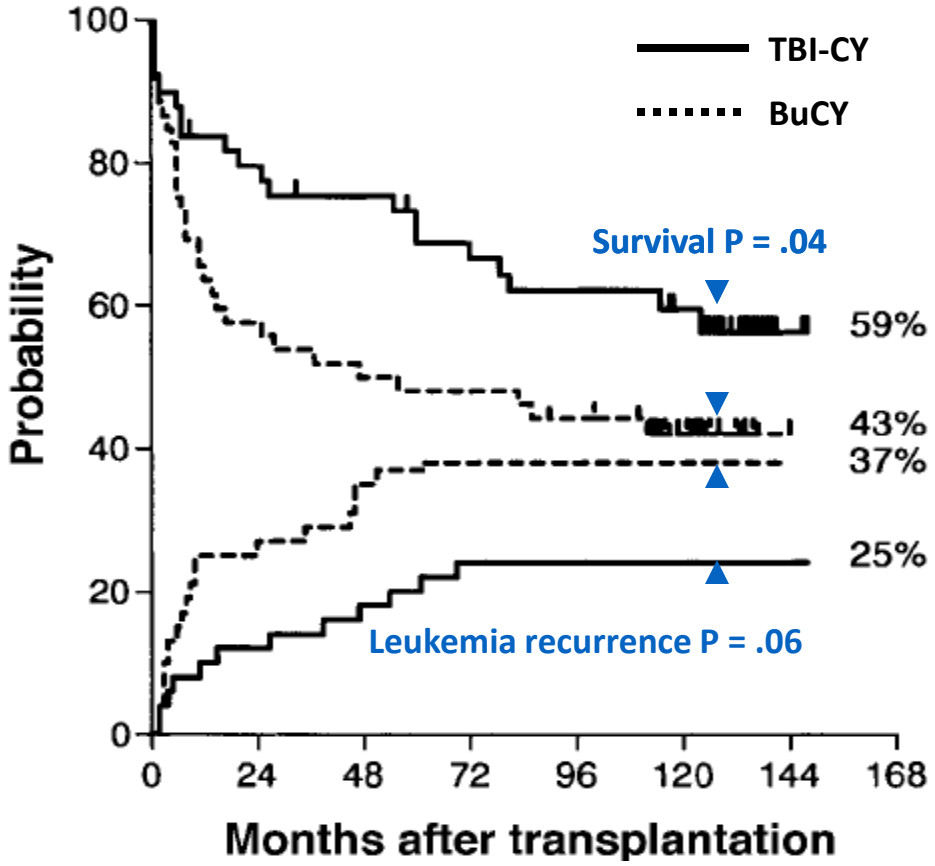
Total Body Irradiation

- In the 1970's, TBI was established as a standard component of conditioning regimen for patients undergoing stem cell transplant.
- Purpose of the TBI:
  - Eradicate disease especially at "sanctuary sites" where chemotherapy agents could not reach.
  - Immunosuppression to allow for successful engraftment of donor marrow.
- AAPM Task Group 29 published Report No. 17: The Physical Aspects of Total and Half Body Photon Irradiation in 1986.



Role of TBI

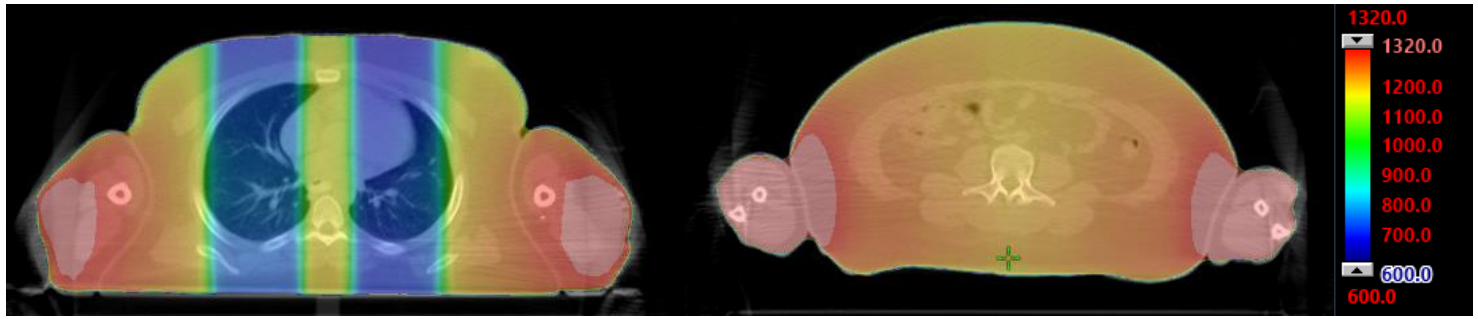
- In a Phase III randomized trial, cyclophosphamide + TBI was compared against cyclophosphamide + busulfan for AML patients in CR1 receiving marrow grafts.
  - 49 patients in the CYTBI group; 51 in the BUCY group.
  - Most patients in the CYTBI group received 12 Gy BID.
- In the long-term update with a median follow-up of 10.8 years, the CYTBI group had significantly higher overall survival, with a lower leukemia recurrence rate.



Blaise et al. Blood, 2001;97:3669-3671.

Conventional TBI delivery

- Traditionally, TBI was typically delivered with parallel opposing beams at an extended SSD.
- A spoiler may be used to increase dose in the superficial region.
- Cerrobend attenuation blocks are used to shield OARs (lungs, kidneys).
- Tissue compensators are used to account for thickness variations.



Simulated cross sectional dose distribution for TBI with lung shielding blocks and a spoiler.

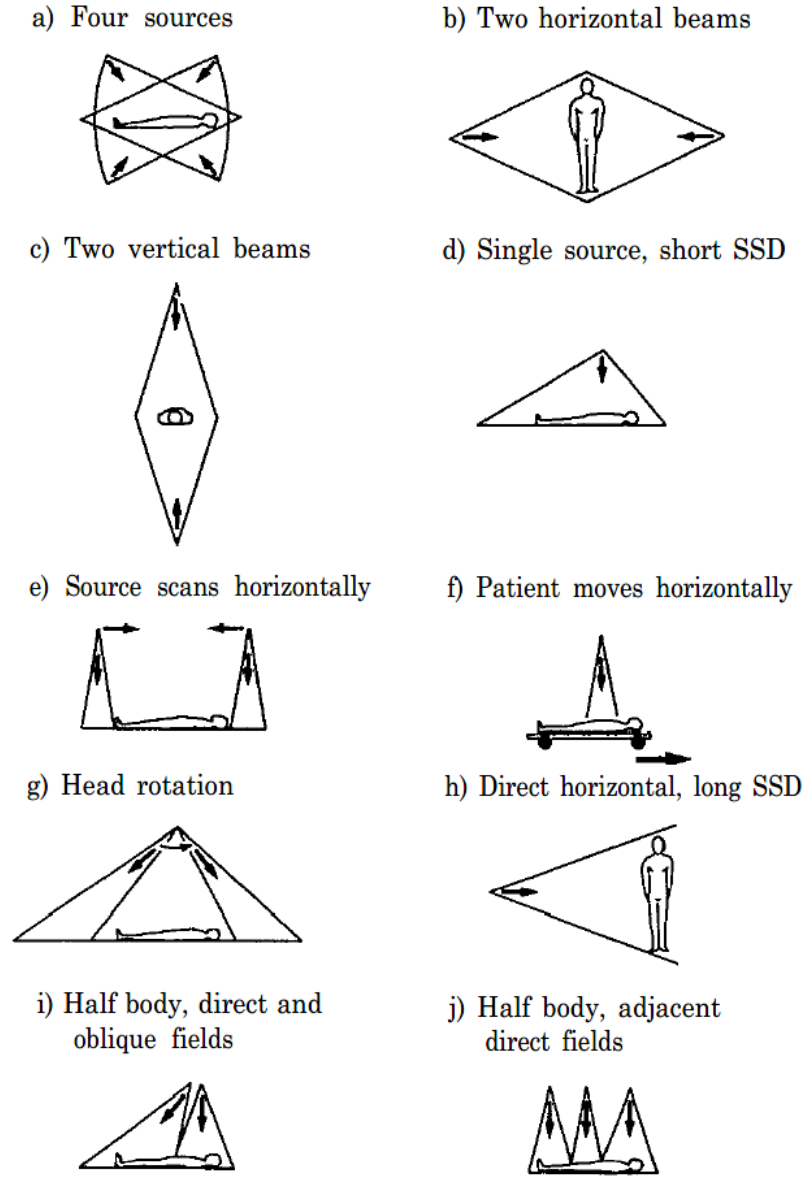
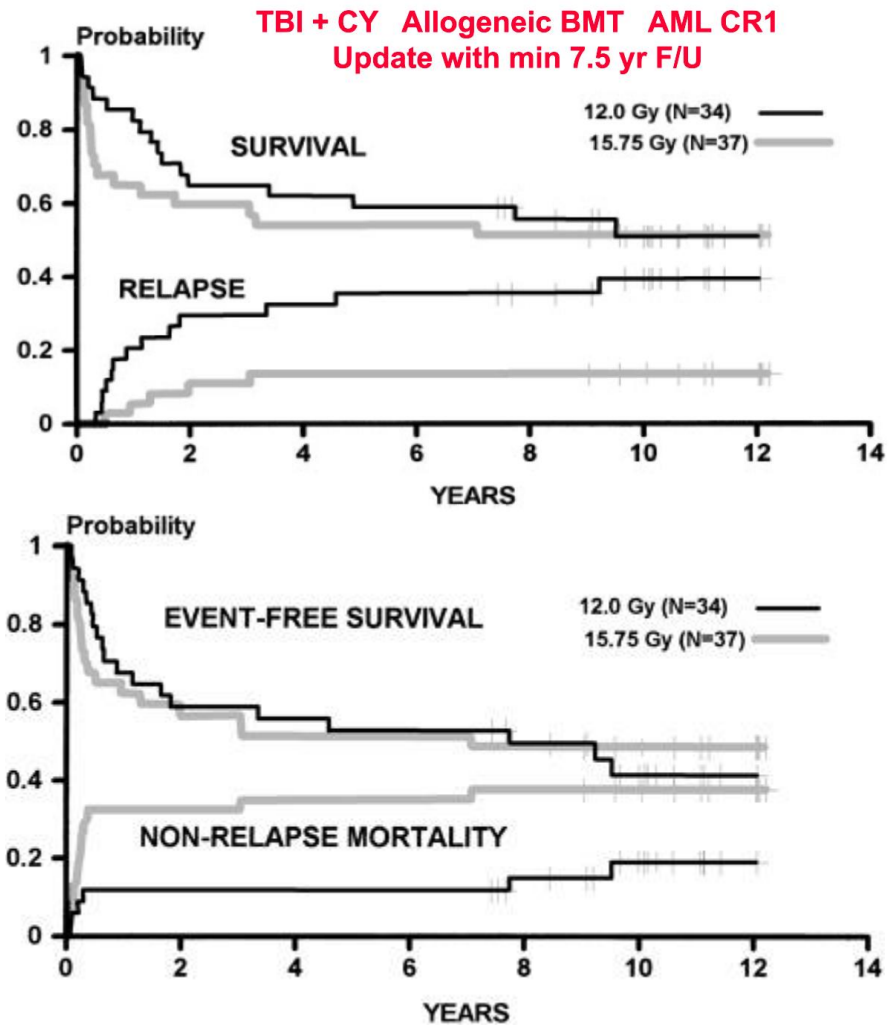


Figure 1. AAPM Report No. 17.

TBI toxicity & dose escalation

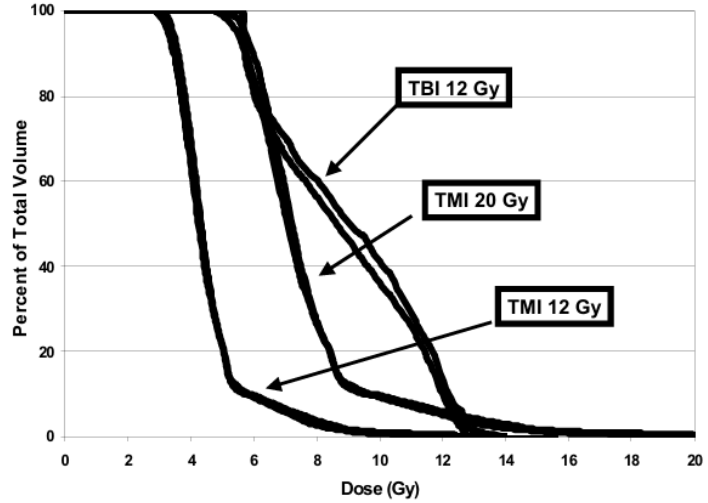
- Conventional myeloablative TBI is associated with many types of acute and late toxicities:
  - Nausea, vomiting, diarrhea.
  - Pulmonary toxicity: interstitial pneumonitis & fibrosis.
  - Cardiac toxicity.
  - Renal toxicity.
  - Hypothyroidism.
  - Cataract formation: ~20%.
  - Mucositis: ~34% with grade 3 severity.
  - Parotiditis / xerostomia: 15 – 30%.
  - Secondary malignancies.
- In a TBI dose escalation trial, higher TBI dose led to lower relapse rate without survival benefits due to non-relapse mortalities.



Clift et al. Blood, 1998;92:1455-1456.

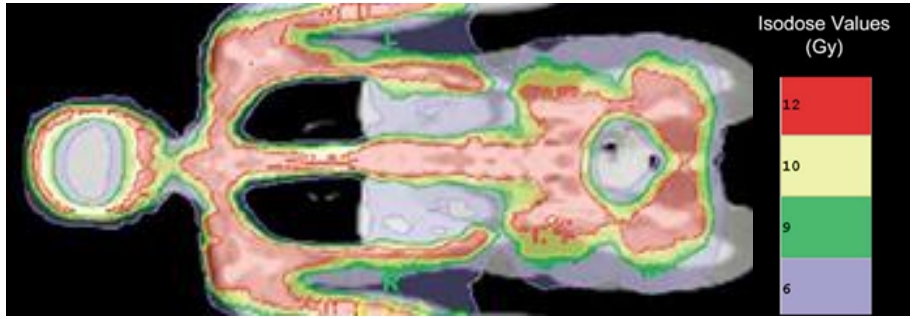
Intensity-modulated TBI/TM(L)I

- Total marrow w/ or w/o lymphoid irradiation (TM(L)I) was proposed in the early 2000's as a more targeted form of TBI to allow for improved OAR sparing and dose escalation.
  - Dose as high as 20 Gy has been delivered to skeletal bones and lymph nodes with TMLI.



Wong, JYC, et al. 2006.
doi:10.1016/j.bbmt.2005.10.026

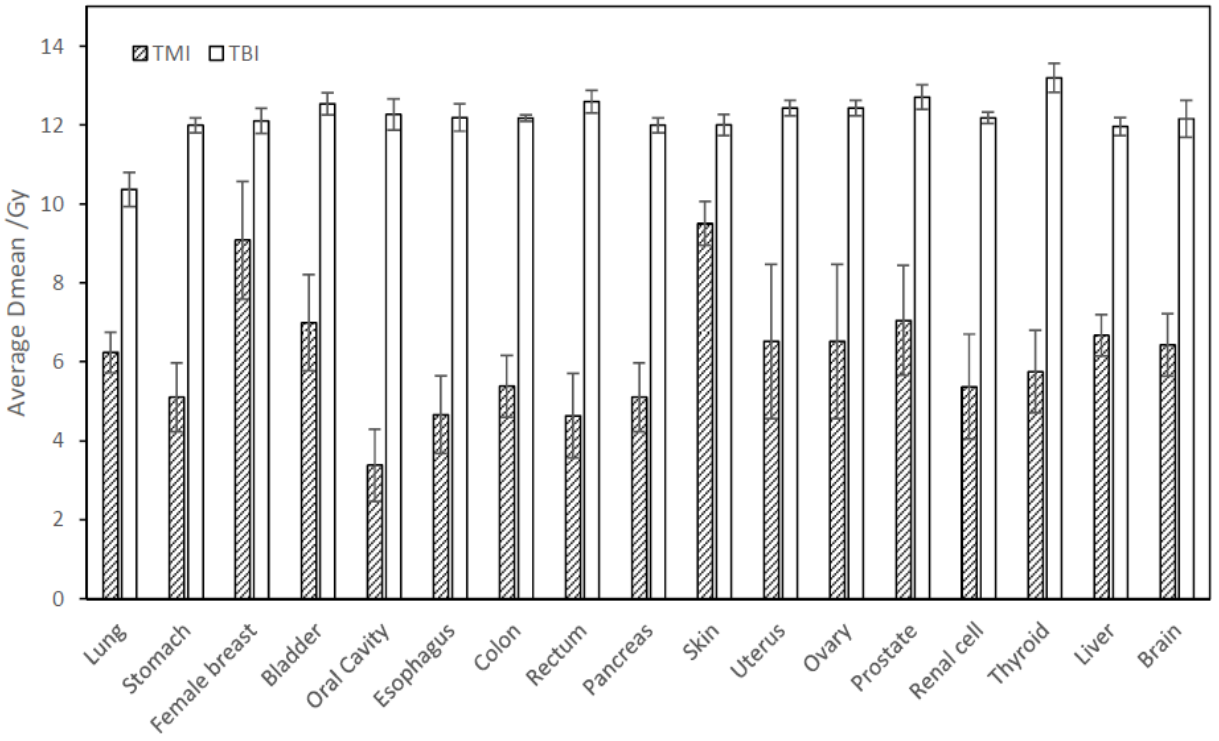
- Intensity-modulated techniques were later also used to deliver TBI:
  - Improved patient comfort in a supine position.
  - Improved sparing of lungs & kidneys.
  - Ability to selectively spare certain anatomical regions.
  - No need for a large vault with an extended SSD.



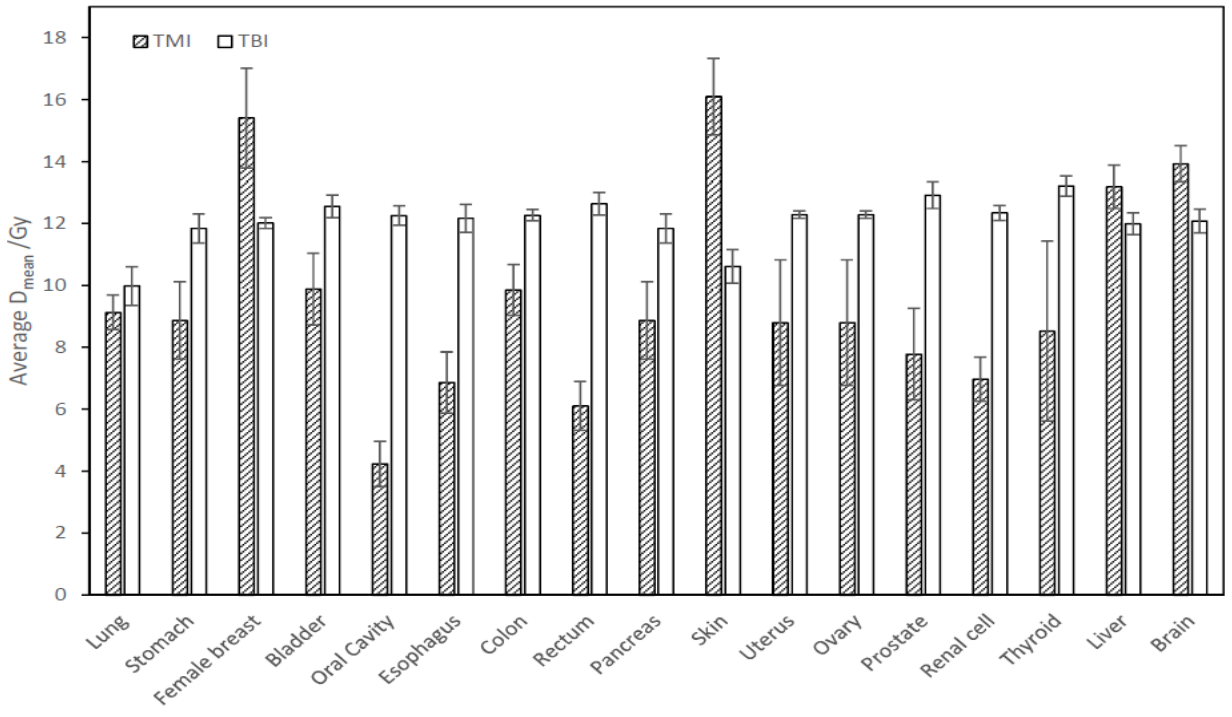
TMLI dose escalation

- OAR dose in TMLI plans compares favorably to that in conventional TBI even at escalated dose up to 20 Gy.

10 TMI plans from a trial with Rx = 12 Gy.



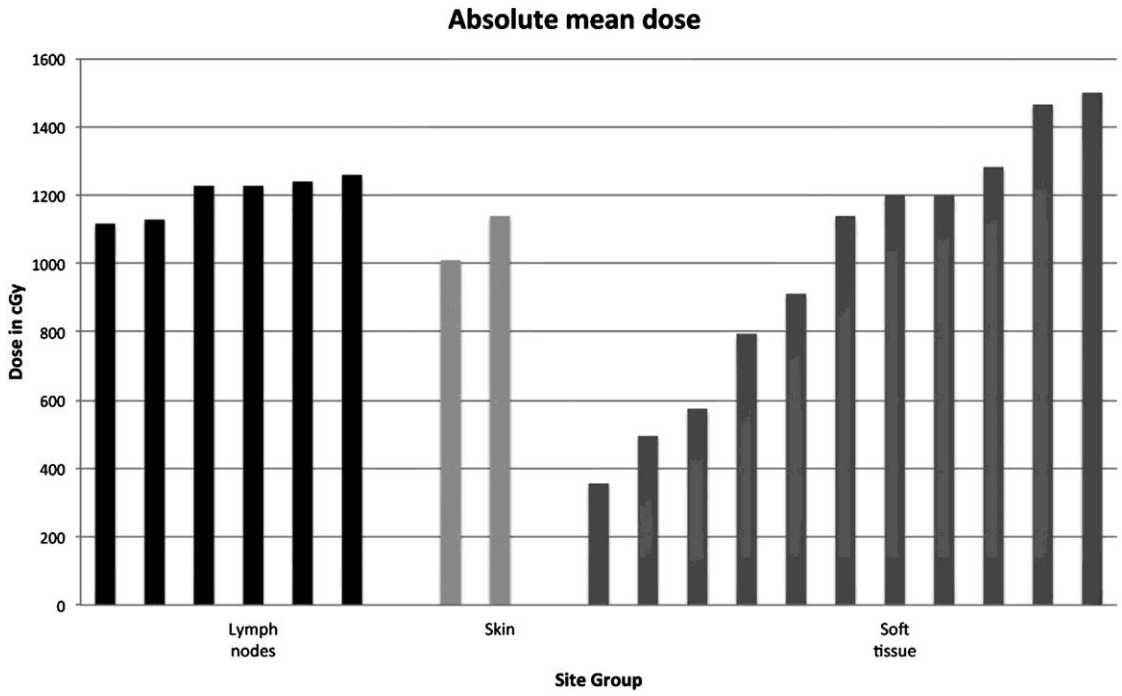
10 TMI plans from a clinical trial with Rx = 20 Gy.



Han C et al. ***Pract Radiat Oncol 2020;10:E406-414.***

Extramedullary relapse with TMLI

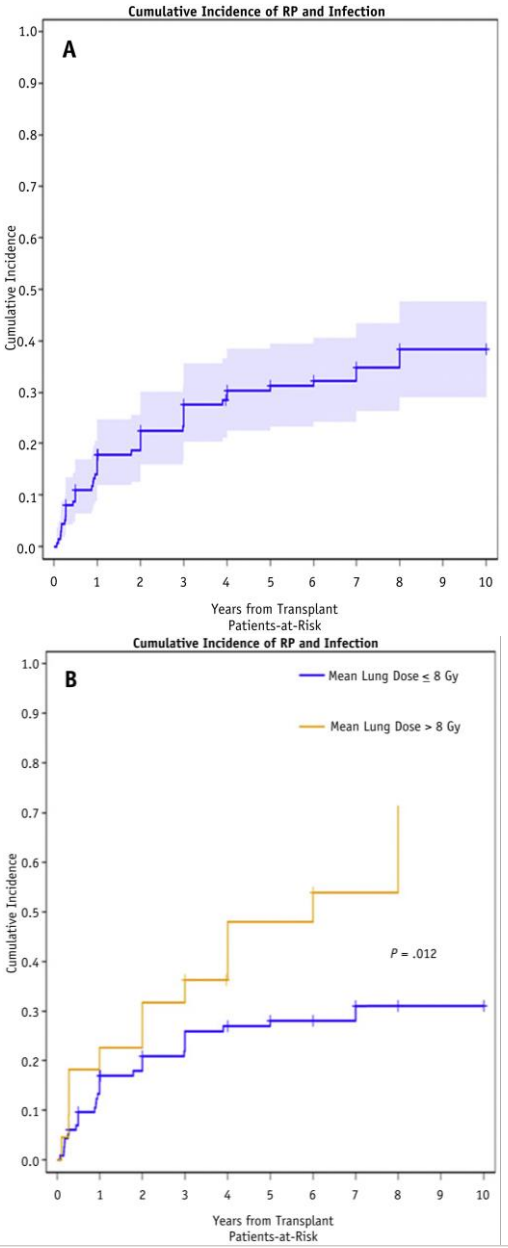
- Patients treated in one of three TMLI trials at COH from 2006 to 2012 were reviewed.
- Total 101 TMLI patients were included.
- Rx dose 12 to 15 Gy.
- Median follow-up of 12.8 months.
- 13 patients had EM relapse: 11 in soft tissue, 6 in LNs, 2 in skin.
- Site of EM relapse was not dose dependent.
  - EM relapse rate was as frequent in regions receiving ≥ 10 Gy as those receiving < 10 Gy.
- EM relapse rate was comparable to published TBI rates (5 – 20%).



Kim JH et al. *IJROBP 2014;89:75-81.*

Radiation-related toxicities in TMLI

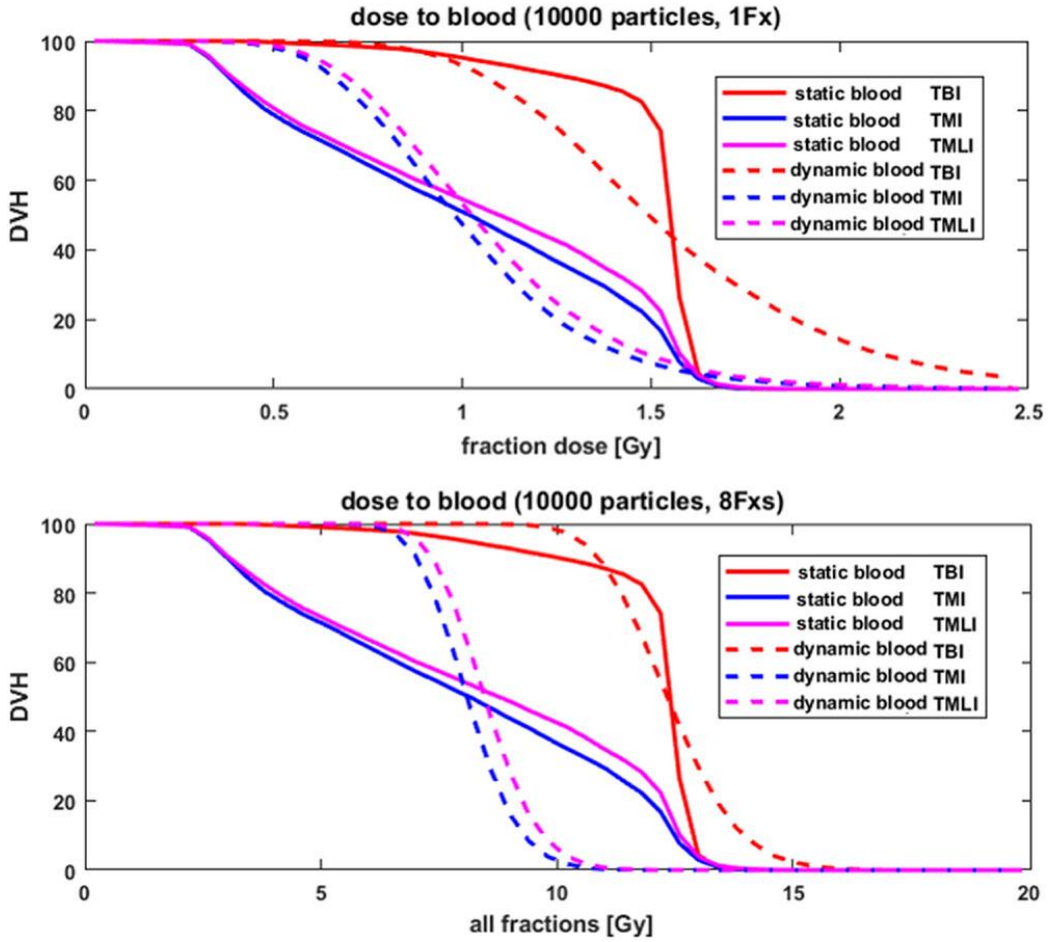
- A study of 142 patients treated by TMI or TMLI in one of three prospective trials at COH.
- Median dose 14 Gy (10 – 19 Gy) with 1.5 to 2 Gy/fx BID.
- All patients treated by helical tomotherapy with a nominal dose rate of 850 or 1,000 MU/min.
- Median follow-up: 2 years.
- Crude incidence of radiation pneumonitis (RP): 1/142 (0.7%).
  - MLD < 8 Gy predictive for lower rates of infection/pneumonitis.
- Hypothyroidism: 6.0%.
- Cataracts: 7.0%.
- No radiation induced nephropathy.



Shinde A et al. *IJROBP 2019;105:1025-1033.*

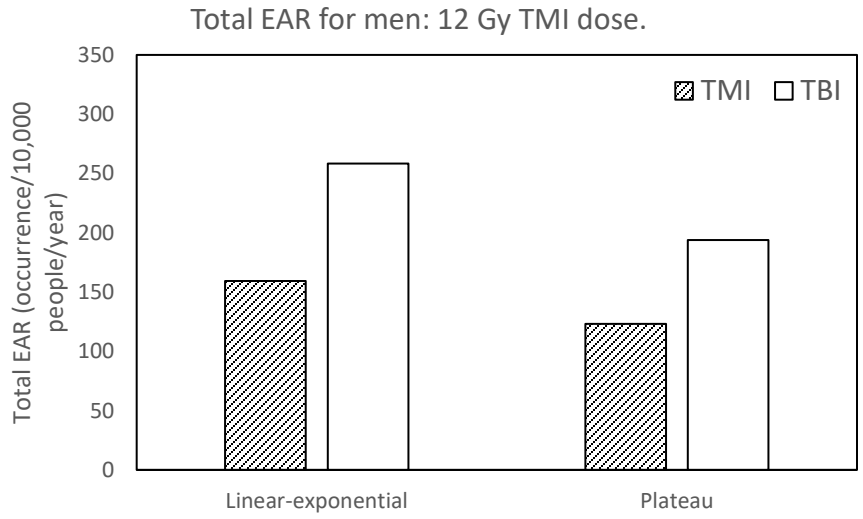
Dose to circulating blood cells

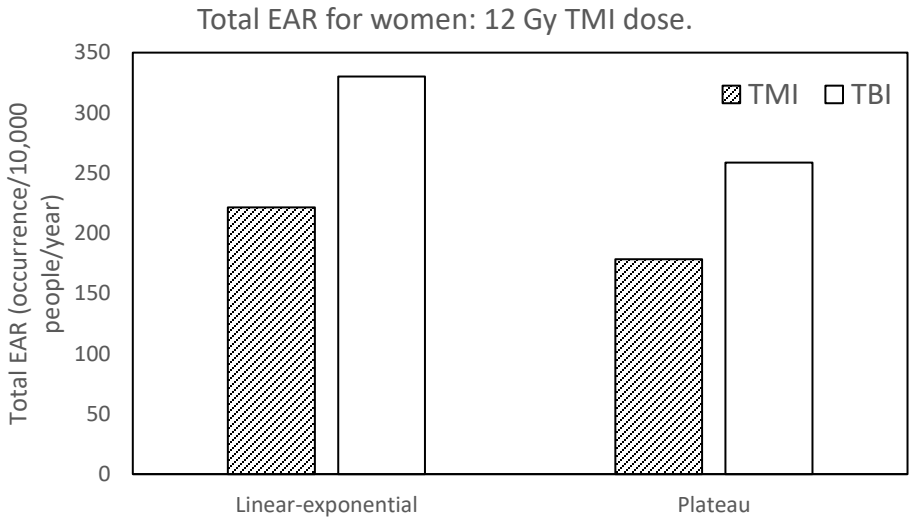
- Guo et al. used a whole-body blood circulation model to estimate dose to circulating blood with multi-iso VMAT TBI/TMI/TMLI.
- Based on the computerized model, fractionated VMAT TBI/TMI/TMLI gives more homogeneous dose to circulating blood.
- For VMAT TBI/TMI/TMLI delivered in 8 fractions, the mean blood dose is 105%, 69%, and 73% of the Rx dose, respectively.

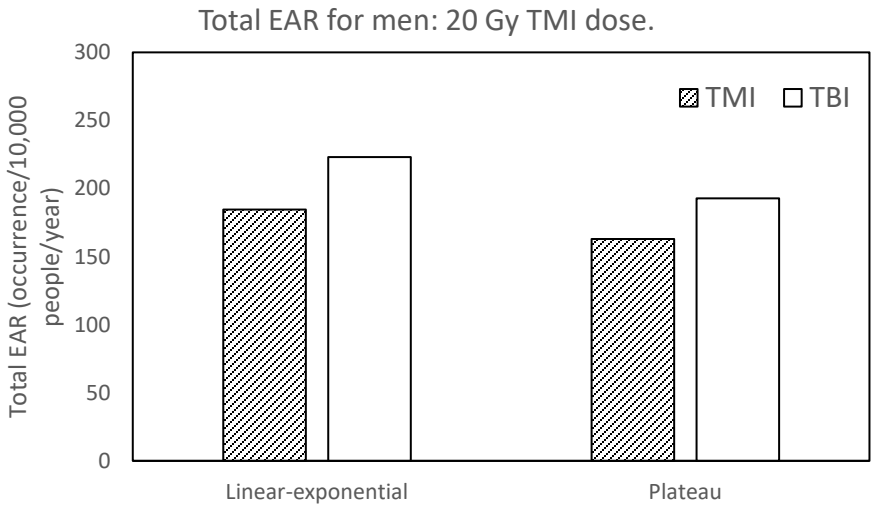


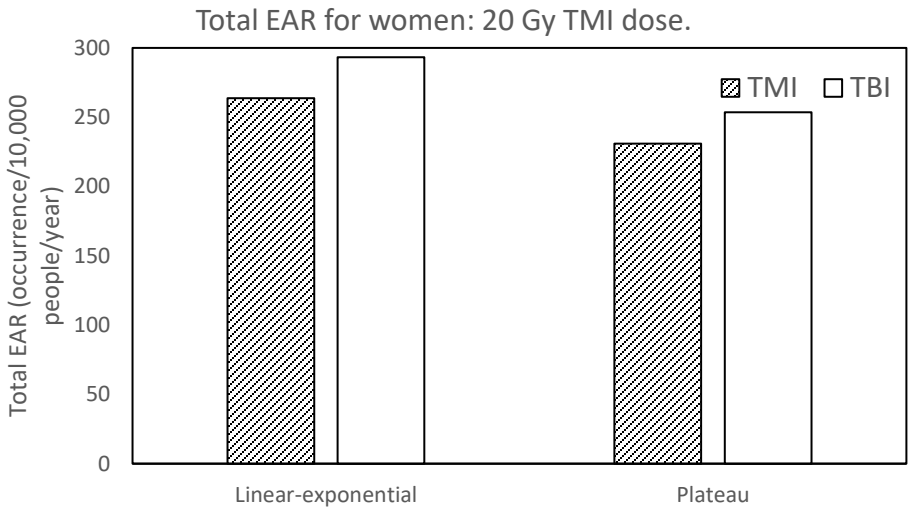
Guo B et al. *Med Phys 2025;52:e17913.*

Secondary cancer risks









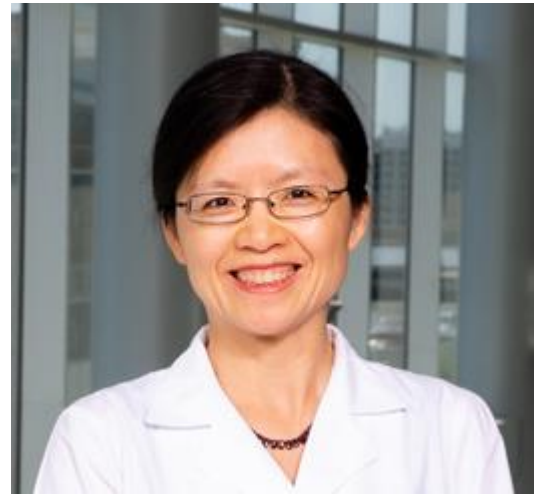
Han C et al. *Pract Radiat Oncol 2020;10:E406-414.*

AAPM Task Group 379

- AAPM TG-379 was formed in 2022 to provide guidance and recommendations on delivering TBI/TMI/TLI with current techniques.
  - Former chair: Grace Gwe-Ya Kim, PhD.
  - Chair since 2025: Xuejun Gu, PhD.

- Based on existing literature and current practices, TG-379 will update recommendations in the original AAPM report No. 17.

Grace Kim, PhD



Xuejun Gu, PhD

TG-379 report

- The TG-379 report draft was completed last year and is currently under review by the Therapy Physics Committee (TPC).
- The report provides practical guidance on implementation and maintenance of an IMRT-based TBI/TMI/TLI program:
  - How much time do I need to commission an IM-TBI/TM(L)I program?
  - What are recommended OAR dose constraints?
  - How to achieve homogeneous dose in field junctions?
  - Optimal isocenter placement and beam geometry for VMAT TBI/TM(L)I.
  - How to minimize the “thread effect” in TBI/TM(L)I plans on helical tomotherapy?
  - Is a lower dose rate necessary in TBI/TM(L)I?
  - How to apply failure mode and effect analysis (FMEA) in TBI/TM(L)I?
  - How to deal with treatment interruptions and intra-fractional motion?

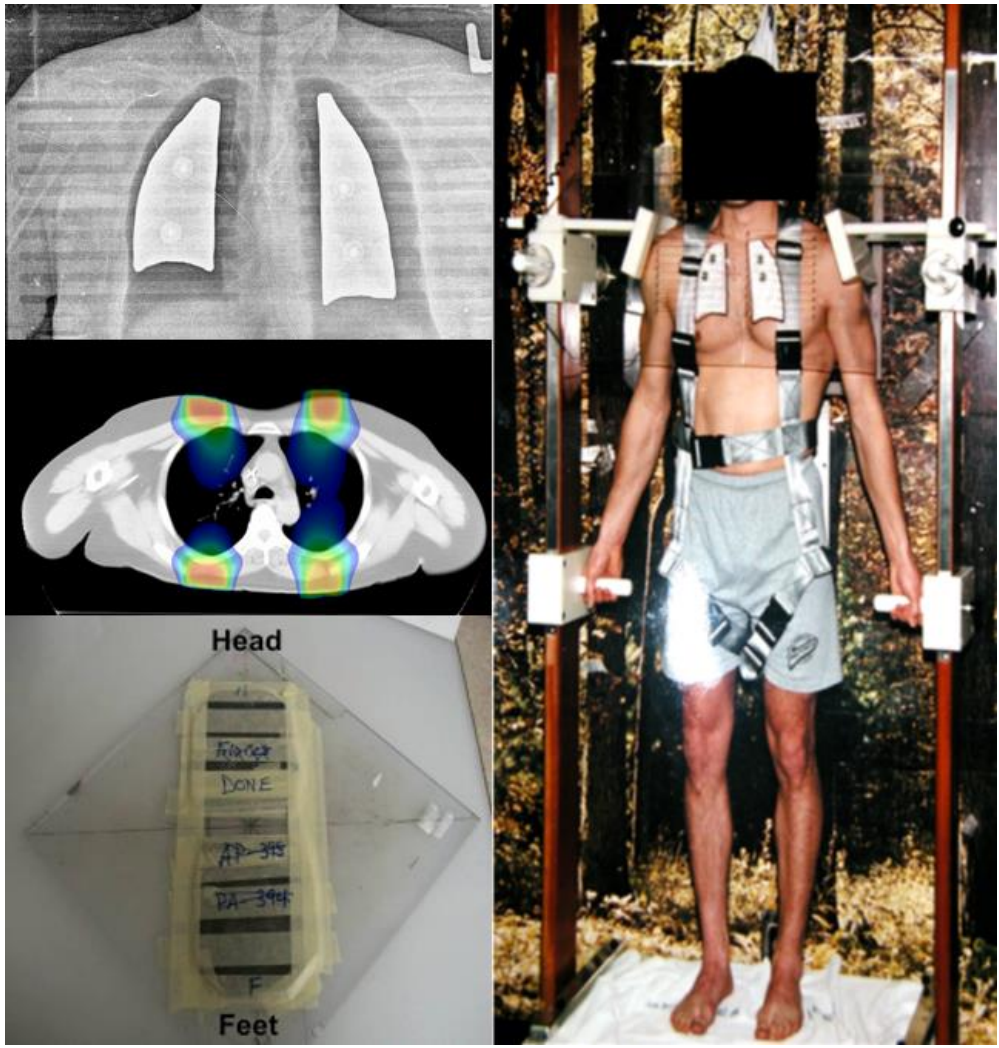
IM-TBI/TMLI: the COH experience

COH hematopoietic cell transplant program

- Established in 1975.
- Over 850 HCT per year.
  - Approximately 80% myeloablative.
  - Approximately 40 – 50% are allogeneic transplants.
- Over 200 TBI/TMLI patients treated per year.
  - In 2024, 180 patients received conventional TBI, and 62 received IMRT-TBI/TMLI.

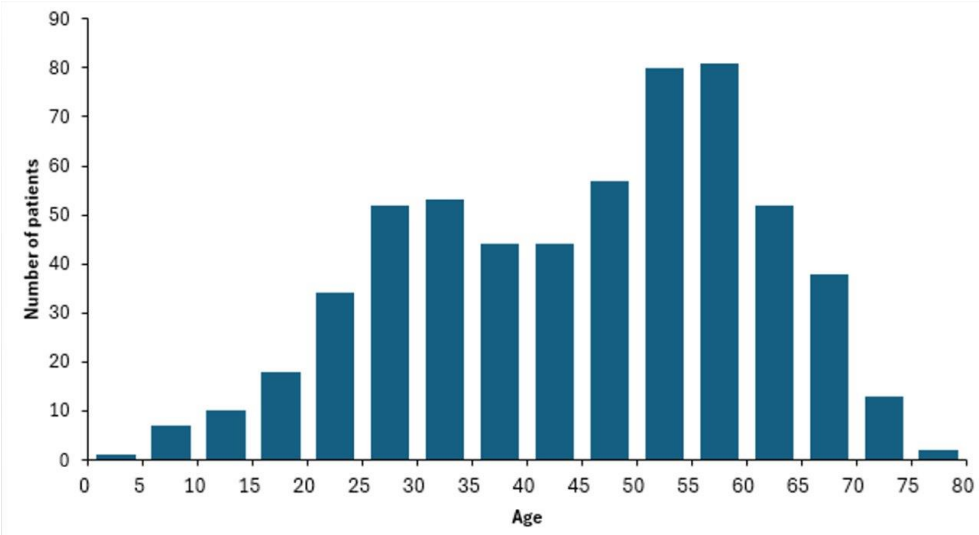
Conventional TBI at COH

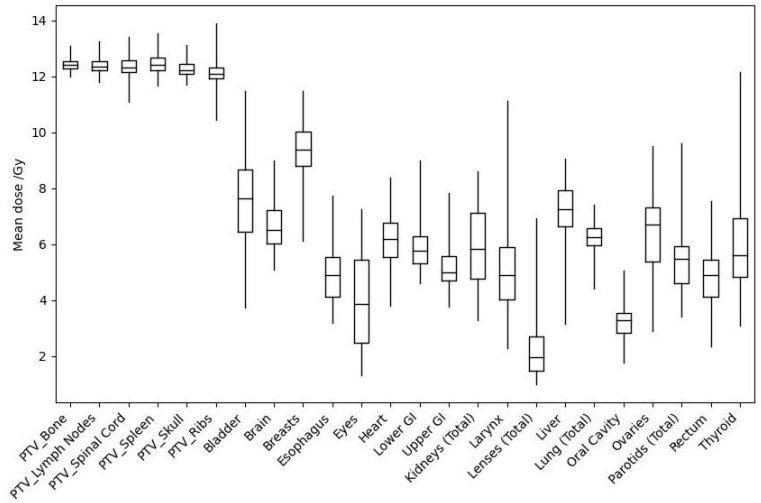
- Patient standing (AP/PA) or lying on the side.
- Treated at an extended distance of ≈ 4 meters from the linac source.
- Dose rate: 5 – 20 cGy/minute.
- 5 – 6 hours between fractions.
- Lung shielding with Cerrobend blocks.
- Lead strip compensator for dose uniformity.
- Chest wall boost using electron beams.
- 1 inch Plexiglass spoiler to increase skin dose.

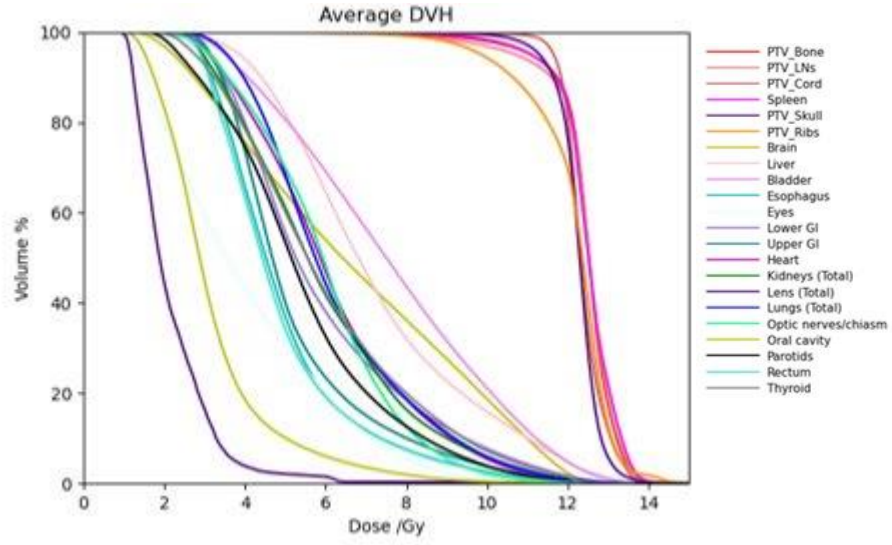


IM-TBI/TM(L)I at COH

- Started TMI on tomotherapy in 2005.
- Started TBI on tomo in 2010.
- Started clinical VMAT TMLI & TBI in 2020.
- Over 700 IMRT-TBI/TM(L)I patients treated.
  - Most are adult patients.







Han C et al.. *Front. Oncol. 12:946725.*

Treatment options

Patients with complete remission:

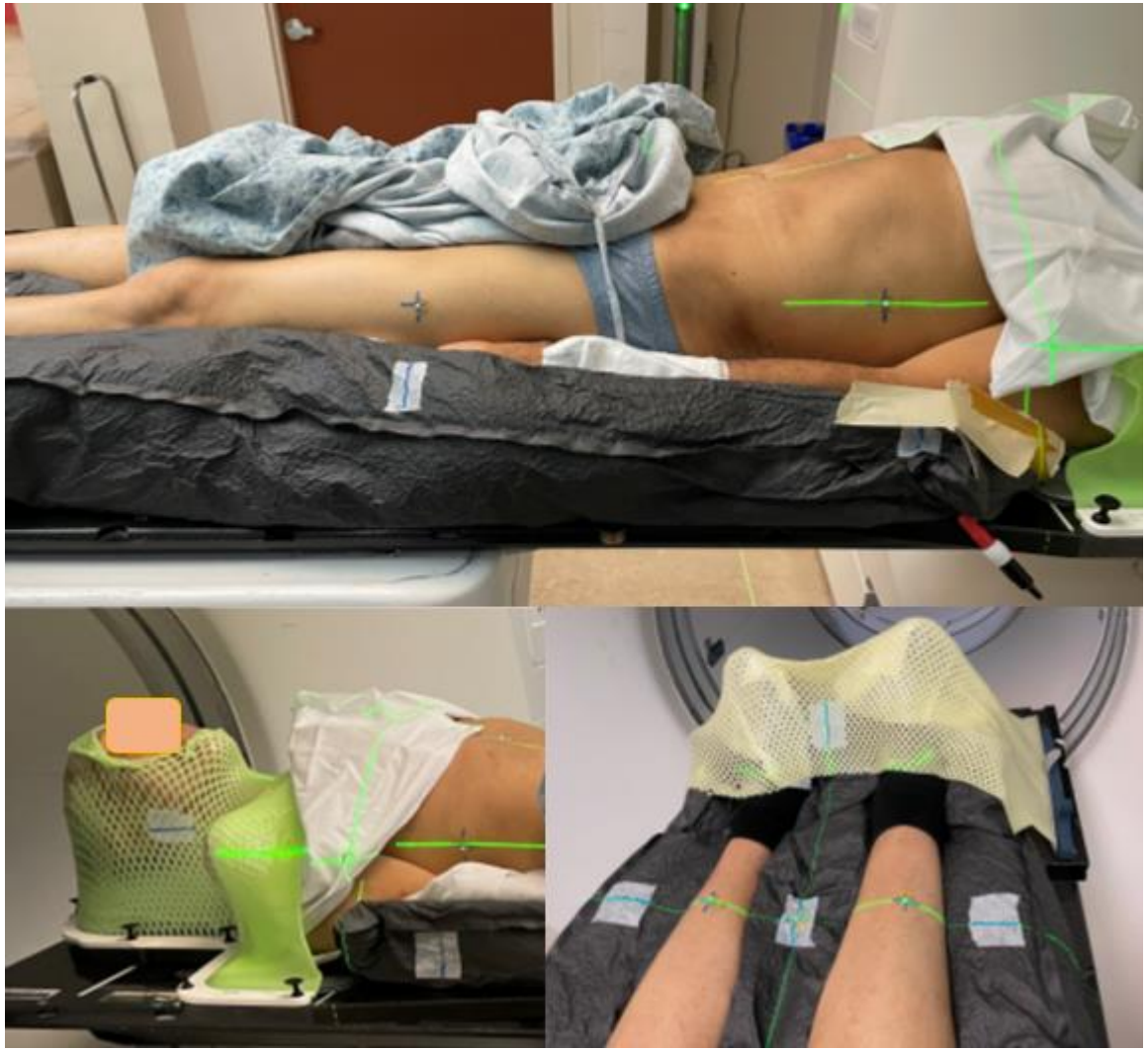
- Conventional TBI.
  - Not suitable for older patients.
  - No dose escalation.
- Intensity modulated TBI.
  - Not suitable for older patients.
  - No dose escalation.
- TMLI:
  - Feasible for older patients.
  - Dose escalation possible.

Patients with relapsed / refractory acute leukemia:

- For older patients (> 60 yr) or those with co-morbidities:
  - TMLI given to bone marrow, LNs, and spleen with Rx of 12 – 16 Gy.
  - TMLI is combined with reduced intensity chemotherapy regimen of fludarabine and melphalan.
- For younger patients (< 60 yr):
  - TMLI given to bone marrow, nodes, and spleen with Rx of 20 Gy; liver and brain: 12 Gy.
  - Combined with cyclophosphamide and etoposide.

Patient immobilization

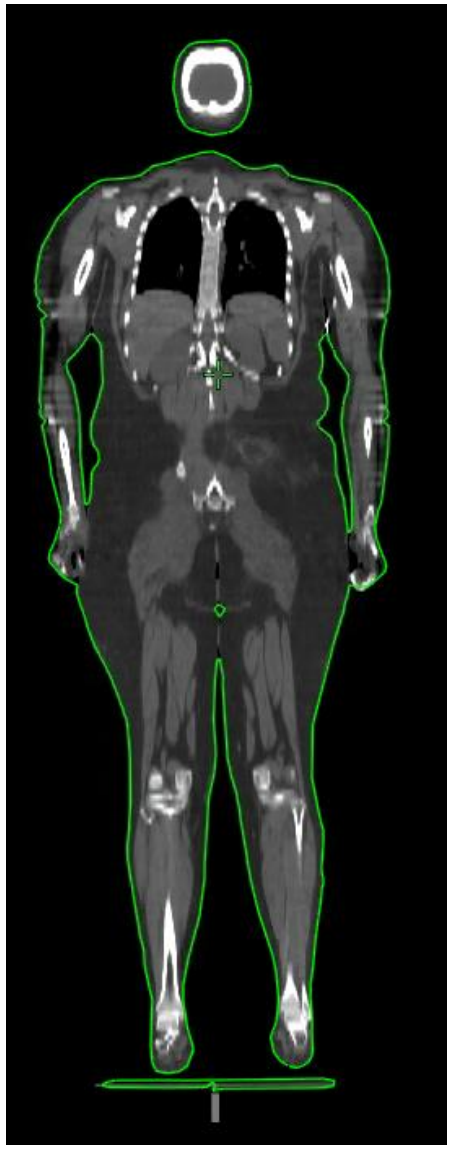
- Supine, arms at sides. Hands in loose fists.
- Accuform molded cushion from neck to shoulders.
- S-frame thermoplastic mask for head & shoulder.
- Body Vac-lok.
- 3 sets of radiopaque BBs, 1 placed at proximal thigh (and inferior to the hands) to help define the inferior extent of upper body TMLI targets for planning.



CT simulation image concatenation

- For short patients, one whole body CT simulation is performed from the top of skull to the feet with the patient in shallow breathing.

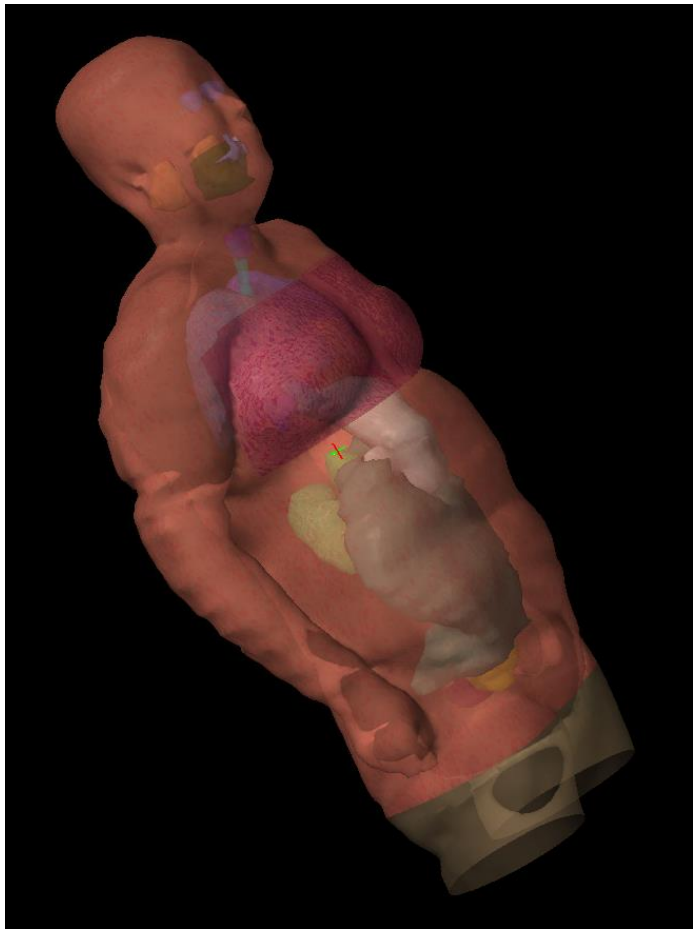
- For adult patients with two scans, it helps to concatenate the upper-body and leg CT images scans into one whole-body CT image set.
    - With a whole-body image, the leg plan can be used as the base plan in upper body plan optimization.
    - Some commercial software systems can concatenate images.
    - We have developed an Eclipse-based software tool to concatenate images. (*Han C, Rosa L, Rayn K, et al. Total X Irradiation helper: publicly available scripting toolset to assist in VMAT planning for total body and total marrow plus lymphoid irradiation. Med Phys 2023;50:e743-744*).



A concatenated whole-body image

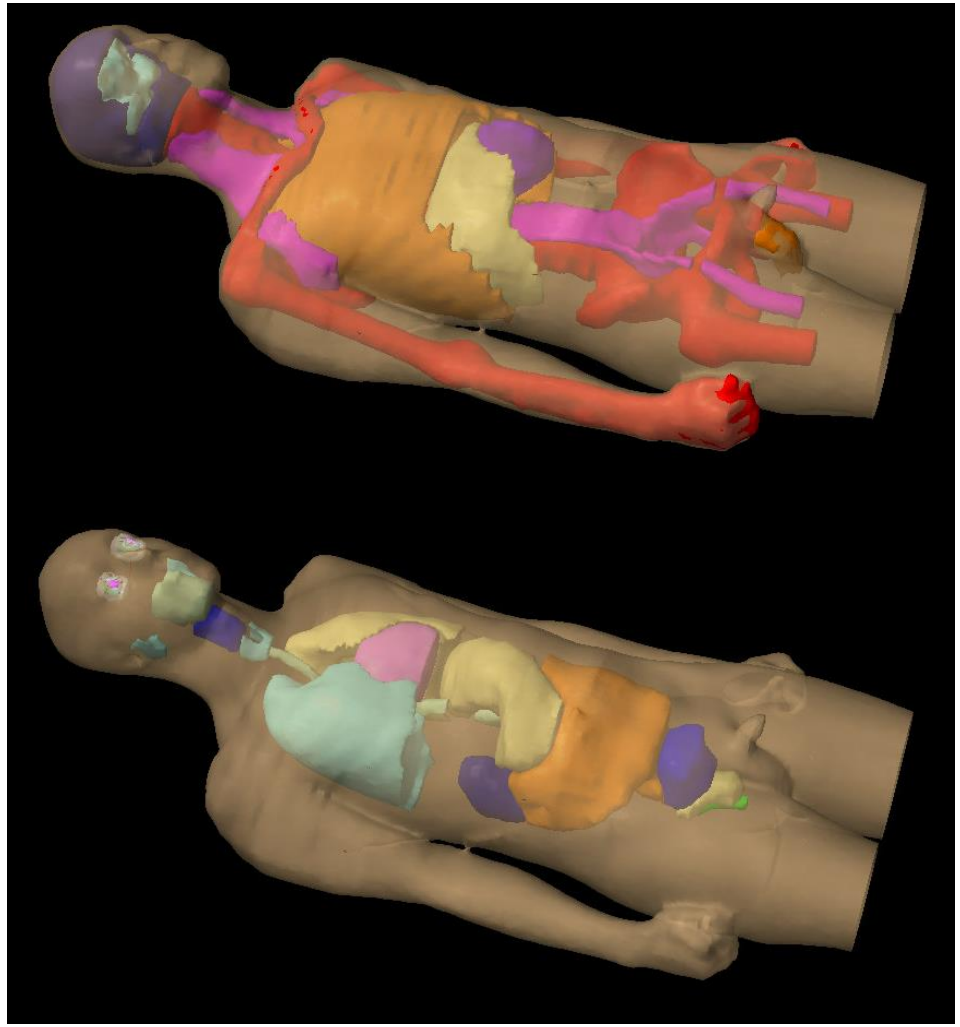
Structures for IM-TBI patients

- Target in a TBI plan: whole body minus the lung volume.
- Critical organ to spare: the lung (also kidneys for certain protocols).
- Normal organs delineated to monitor dose in treatment planning to avoid hot spots:
  - Heart.
  - Esophagus.
  - Oral cavity.
  - Breasts.
  - Parotids.
  - Thyroid.
  - Stomach.
  - Intestine.
  - Ovary.
  - Bladder.
  - Optic nerves.
  - Eyes.
  - Lens.
  - Kidneys.
  - Liver.



Structures for TMLI plans

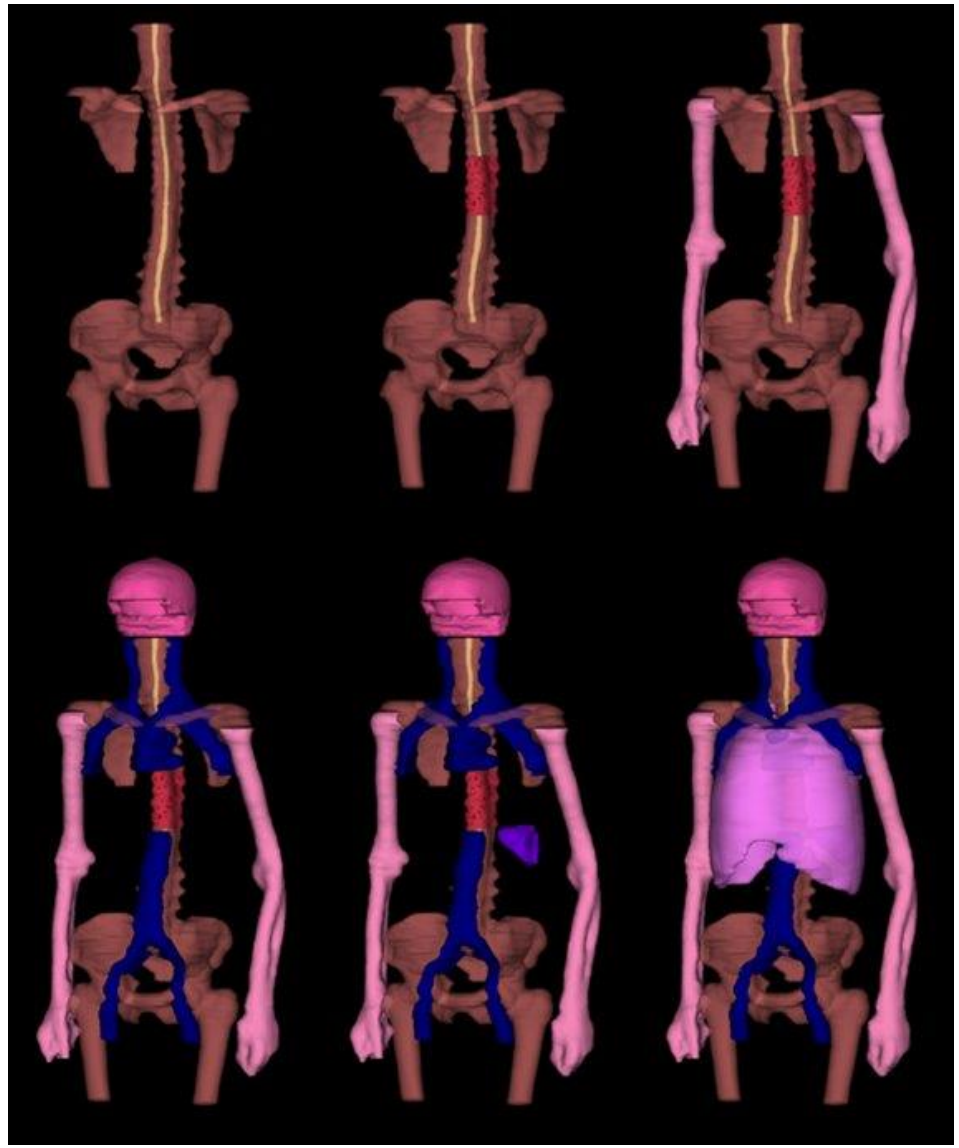
- Targets in a TMLI plan: Skeletal bones, spinal canal, lymph nodes, Spleen. Optionally: liver, testes, and brain.
    - Mandible & maxilla are excluded from the targets.
    - Margins for bones: 5 – 10 mm margin in areas with high set-up variability (shoulder, extremities, spinous process).
    - The skull and ribcage are contoured separately to allow separate dose control in plan optimization.
- Respiratory motion is included in contours for the kidneys, ribs, livers, and spleen.



Helper structures in TMLI plans

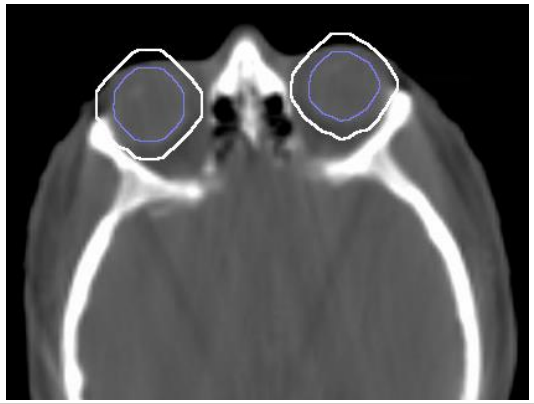
- Lymph nodes and spleen as separate PTVs from skeletal bone targets.

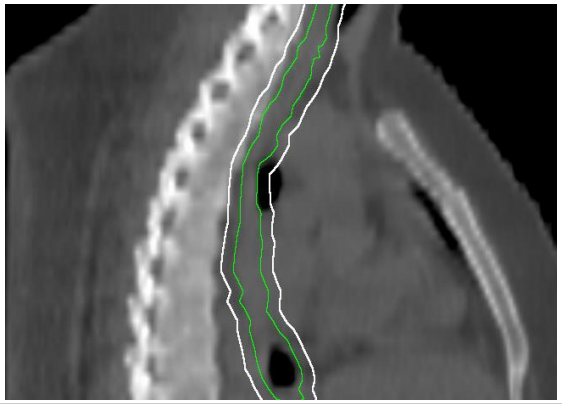
- Helper structures can improve dose coverage at specific regions of the bone PTV:
  - Arm PTV to improve lateral coverage.
  - Vertebral column segment in the thorax region where dose tends to be low.
  - Skull and ribcage for individual control.

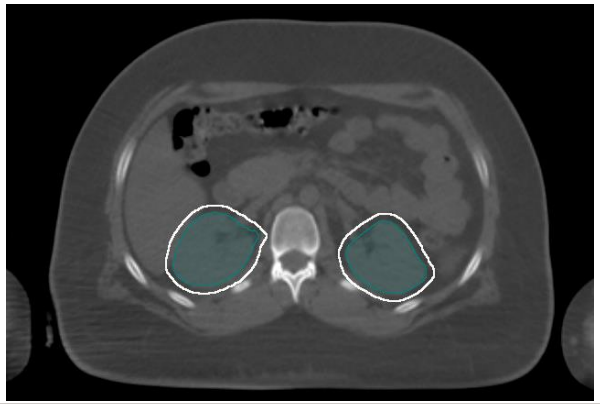


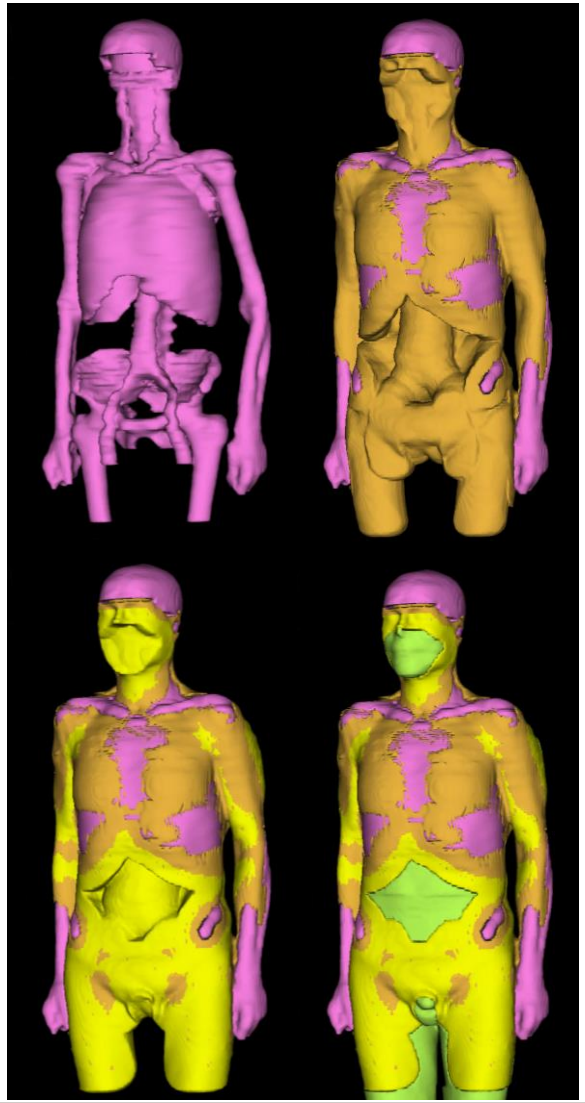
OAR and tissue helper structures

- In addition to the OARs, additional helper structures can be added to aid plan optimization:
  - OAR + margin: to improve dose control to OARs. Example: eyes + margin, esophagus + margin, kidneys + margin, etc.
  - “Ring” structures outside the combined PTVs: to avoid hot spots in normal tissue.



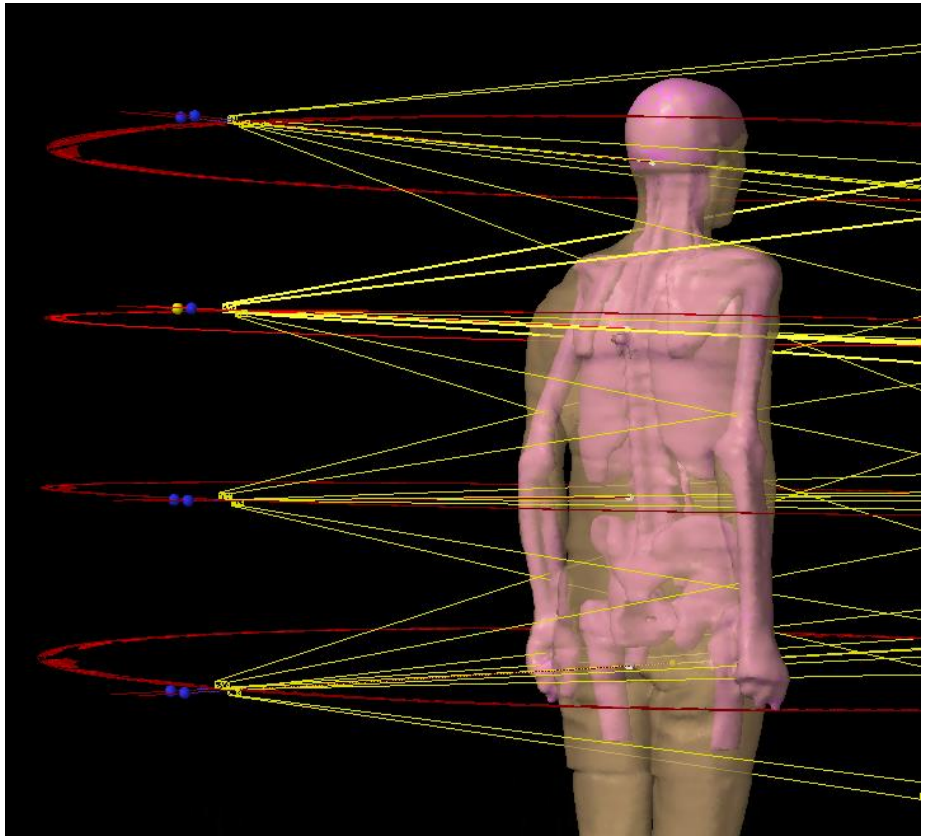






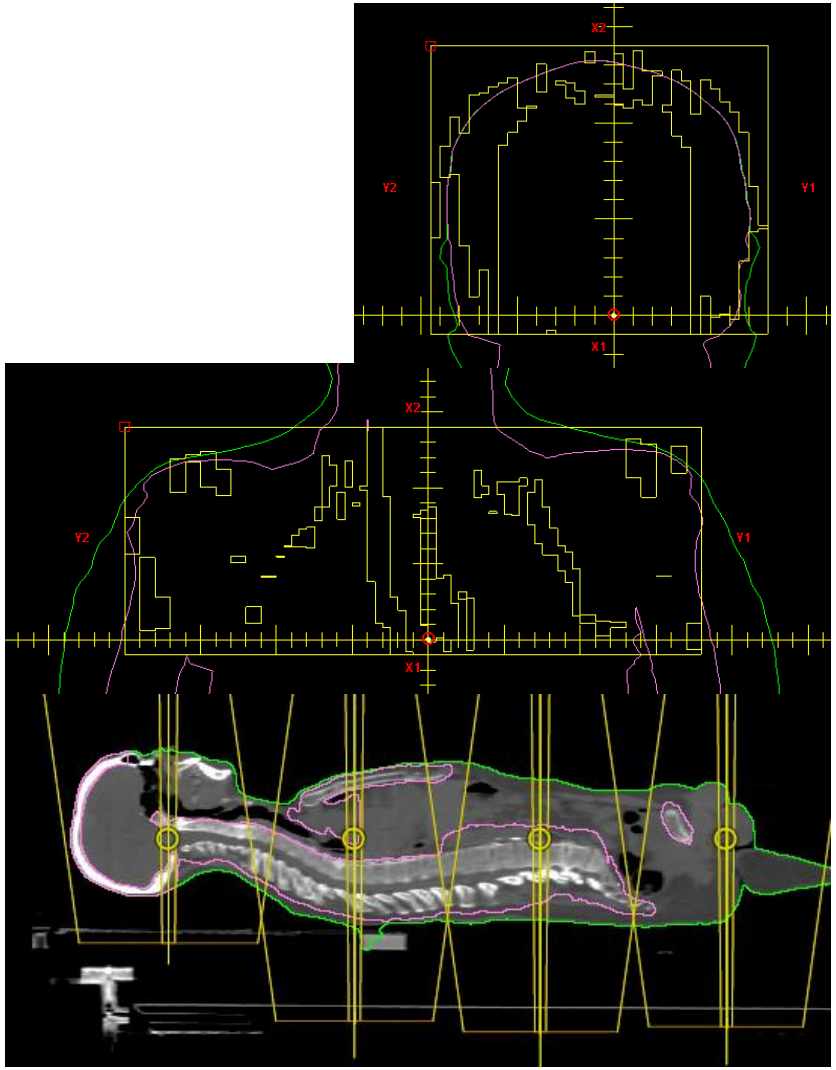
VMAT plan setup for C-arm linacs

- We use 6 MV VMAT fields for TBI/TMLI on a Varian TrueBeam linac with a 120-leaf MLC.
    - Max field width: 40 cm x 40 cm.
    - Max MLC leaf travel per carriage position: 15 cm.
    - Maximum dose rate: 600 MU/min.
    - Maximum gantry speed: 4.8 degrees/second.
- For an adult patient, 4 – 5 isocenters are typically used for the upper body to the mid-thigh with two VMAT fields per isocenter (one or two VMAT fields at the most inferior isocenter).



VMAT field configuration

- Use uniform 90-degree collimator angle for all the VMAT fields.
    - Use Y-jaw size of 40 cm except the head field.
- With a Varian 120-leaf Millenium MLC, we use a jaw separation in the longitudinal direction of no more than 15 cm due to MLC travel limit.
    - Use asymmetric X-jaw for better coverage with each isocenter.
    - Isocenter separation is typically ≤ 26 cm.



Dosimetric goals in TBI

- COH IMRT-TBI clinical trial constraints are shown on the right:
  - Also allows 12 Gy in 6 fractions.
- COG ASCT2031 trial goals:
  - 12 Gy in 6 fxs or 13.2 Gy in 8 fxs, twice a day.
  - Mean lung dose <= 8 Gy.
  - PTV V(100%) >= 90% (85% acceptable)
  - PTV D(1 cc) <= 120% (130% acceptable)

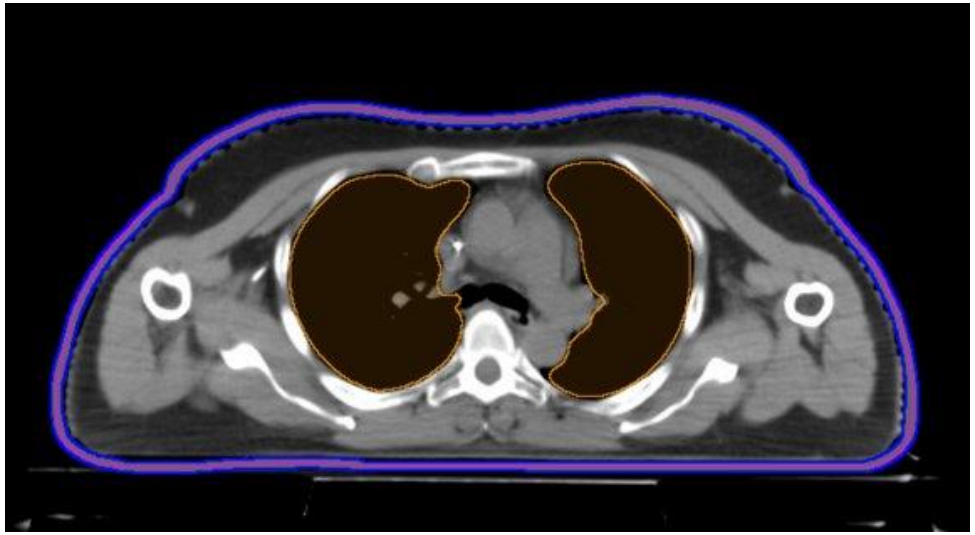
Prescribed Dose: 1.65 Gy x 8 Fraction = 13.2 Gy total

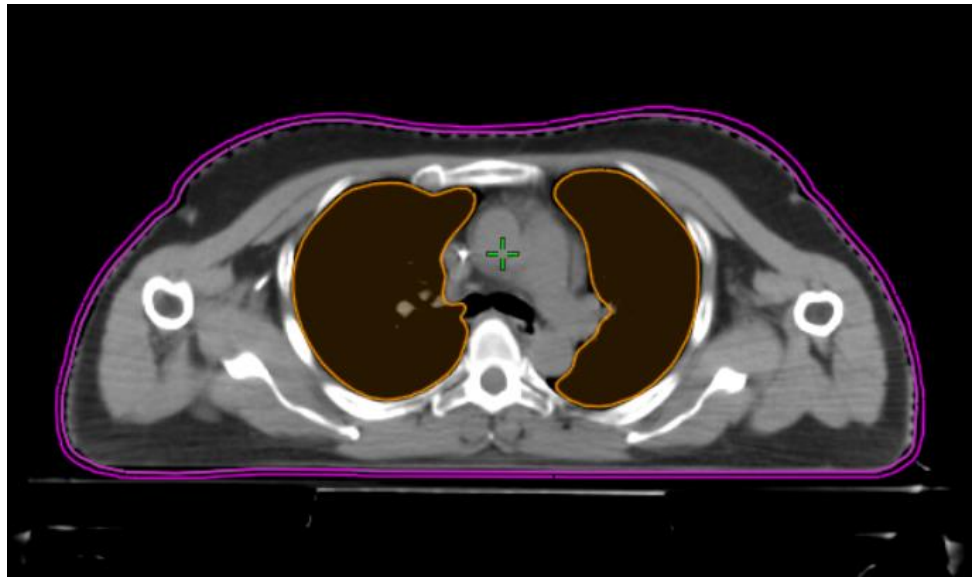
Target	Parameter	Constraint
PTV	V(13.2 Gy) %	≥ 85%
PTV	Maximum Dose /Gy	≤ 130% Rx (17.2 Gy)

OAR	Parameter	Constraint
Lung	Mean Dose /Gy	< 8 Gy
1. Heart	Maximum Dose /Gy	
2. Kidneys	Maximum Dose /Gy	
3. Esophagus	Maximum Dose /Gy	
4. Oral cavity	Maximum Dose /Gy	
5. Breasts	Maximum Dose /Gy	
6. Parotids	Maximum Dose /Gy	≤ 115% Rx (15.2 Gy)
7. Thyroid	Maximum Dose /Gy	
8. Stomach	Maximum Dose /Gy	Protocol Acceptable: ≤
9. Intestine (bowel)	Maximum Dose /Gy	130% Rx (17.2 Gy)
10. Ovary	Maximum Dose /Gy	
11. Bladder	Maximum Dose /Gy	
12. Optic nerve	Maximum Dose /Gy	
13. Eyes	Maximum Dose /Gy	
14. Lens	Maximum Dose /Gy	

Virtual bolus in TBI plans

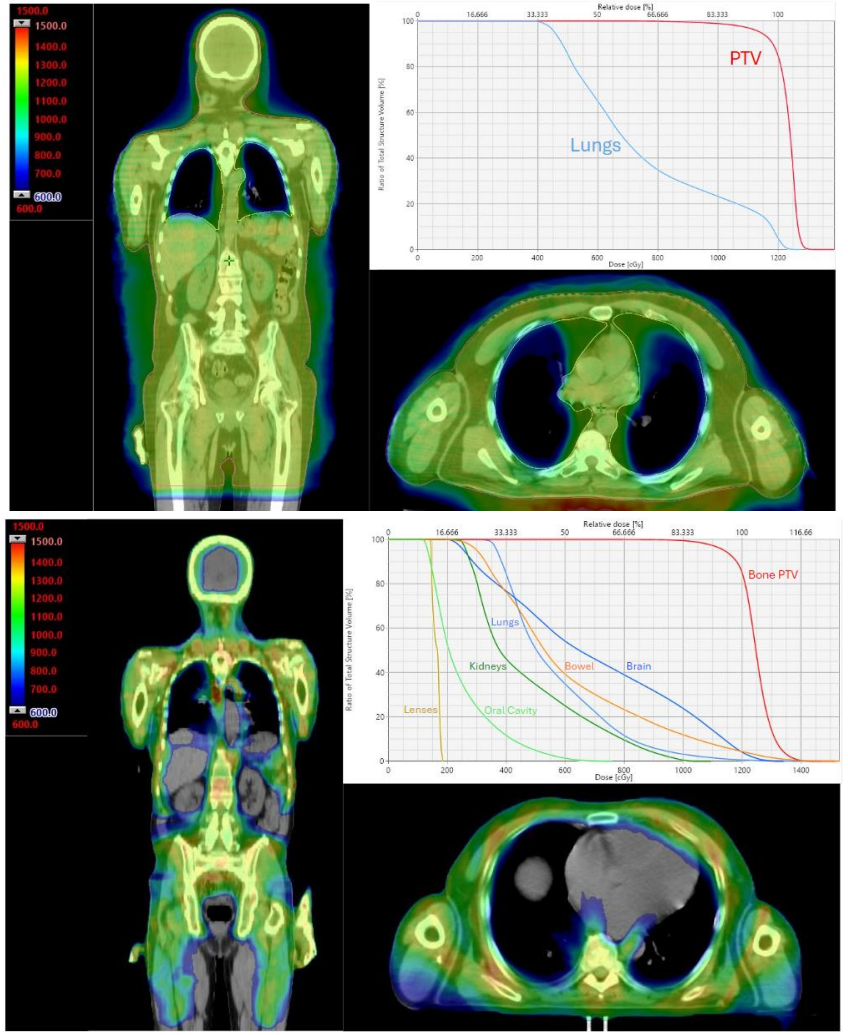
- To account for setup uncertainty and intra-fractional motion, the virtual bolus technique is used in VMAT plans.
    - Not available in HT planning.
- Add a margin to the PTV to form a “PTV-opt” so that it extends beyond the body contour.
    - Currently we use a 3-mm margin to generate “PTV-opt”.
    - A 6-mm bolus will be used in plan optimization.
    - The extra 3 mm thickness on top of the “PTV-opt” is used to remove surface dose uncertainty for “PTV-opt” in dose calculation during plan optimization.





VMAT plan evaluation

- TBI planning:
  - 85% of the PTV receives at least the prescription dose.
  - Limit mean lung dose < 8 Gy.
  - Maximum dose to normal organs and the whole body within tolerance (aim for ≤ 115% Rx, but acceptable if ≤ 130% Rx).
- TMLI planning:
  - 85% of the skeletal bone PTV receives at least Rx.
  - Limit mean lung dose < 8 Gy.
  - Normal organ dose within the range in reference tables, based on historical TMLI plan data at COH.
  - Limit overall maximum dose.



Reference dosimetric tables for TMLI plans

Structure	D80 (Gy)			D10 (Gy)		
	Avg ± StdDev	1st quartile	3rd quartile	Avg ± StdDev	1st quartile	3rd quartile
Skeltal bones	**12.2 ± 0.1**	**12.1**	**12.3**	**13.0 ± 0.4**	**12.7**	**13.3**
Lymph nodes	**12.2 ± 0.3**	**12.0**	**12.4**	**13.0 ± 0.4**	**12.7**	**13.3**
Spinal canal	**12.1 ± 0.5**	**11.9**	**12.3**	**12.7 ± 0.4**	**12.4**	**13.0**
Spleen	**12.2 ± 0.4**	**12.0**	**12.4**	**13.0 ± 0.4**	**12.6**	**13.3**
Skull	**12.0 ± 0.3**	**11.9**	**12.2**	**12.7 ± 0.4**	**12.5**	**12.8**
Ribs	**11.5 ± 0.7**	**11.3**	**11.8**	**13.0 ± 0.4**	**12.7**	**13.1**
Brain	3.7 ± 1.0	3.0	4.4	10.8 ± 0.7	10.3	11.4
Liver	5.4 ± 0.9	4.8	6.0	10.8 ± 1.2	10.3	11.5
Bladder	5.6 ± 1.4	4.2	7.0	10.6 ± 1.5	9.9	11.6
Female breasts	7.7 ± 1.2	6.9	8.5	11.8 ± 0.8	11.3	12.4
Esophagus	3.9 ± 0.7	3.3	4.4	6.9 ± 1.7	5.6	7.8
Eyes	2.8 ± 1.3	1.7	3.7	5.9 ± 2.2	3.7	7.9
Heart	4.6 ± 1.0	3.9	5.4	8.8 ± 1.2	8.2	9.5
Lower GI	4.2 ± 0.9	3.6	4.6	9.1 ± 1.2	8.1	10.0
Upper GI	4.0 ± 0.7	3.4	4.4	7.4 ± 1.6	6.1	8.8
Kidneys (total)	4.7 ± 1.3	3.6	5.6	8.5 ± 1.8	7.2	10.0
Larynx	3.4 ± 1.2	2.6	3.8	7.8 ± 1.9	6.3	9.3
Lens (total)	1.9 ± 0.7	1.3	2.3	2.6 ± 1.4	1.7	3.2
Lungs (total)	4.6 ± 0.7	4.0	5.1	9.0 ± 0.9	8.4	9.6
Optic nerves and chiasm	5.0 ± 1.3	3.9	5.9	7.4 ± 1.8	6.1	8.6
Oral cavity	2.3 ± 0.6	1.9	2.7	5.0 ± 1.2	4.3	5.8
Uterus and ovaries	4.8 ± 1.6	3.6	5.5	9.1 ± 2.3	7.8	10.6
Parotids (total)	4.0 ± 1.2	2.8	4.7	8.0 ± 1.3	7.2	8.7
Rectum	3.9 ± 0.8	3.2	4.4	6.8 ± 1.9	5.4	8.1
Thyroid	4.6 ± 1.7	3.4	5.3	8.2 ± 1.9	6.9	9.7

The target volumes are denoted with bold font. The structure of skeletal bones does not include the ribs or skull.

TMLI dosimetric table for Rx at 12 Gy.

Structure	D80 (Gy)			D10 (Gy)		
	Avg ± StdDev	1st quartile	3rd quartile	Avg ± StdDev	1st quartile	3rd quartile
Skeletal bones	20.3 ± 0.3	20.3	20.5	21.7 ± 0.5	21.4	22.0
Lymph nodes	20.0 ± 0.6	19.8	20.4	21.6 ± 0.5	21.3	21.9
Spinal canal	20.2 ± 0.4	20.1	20.4	21.0 ± 0.5	20.7	21.3
Spleen	20.2 ± 0.5	20.0	20.5	21.6 ± 0.6	21.2	21.9
Skull	19.9 ± 0.5	19.7	20.2	21.6 ± 0.6	21.3	21.8
Ribs	17.9 ± 1.3	17.4	18.8	21.6 ± 0.6	21.3	21.8
Brain	12.2 ± 0.4	12.0	12.4	16.2 ± 1.5	14.7	17.6
Liver	12.1 ± 0.4	11.9	12.3	14.7 ± 1.3	13.7	15.4
Bladder	6.4 ± 1.3	5.4	7.0	15.4 ± 2.1	14.2	16.8
Female breasts	12.2 ± 1.9	11.0	13.1	19.8 ± 1.4	19.3	20.8
Esophagus	4.8 ± 0.6	4.4	5.1	9.6 ± 2.0	8.4	10.7
Eyes	2.7 ± 0.5	2.4	2.9	6.0 ± 1.6	4.9	6.6
Heart	5.0 ± 0.6	4.7	5.4	11.5 ± 1.1	10.8	12.2
Lower GI	6.3 ± 1.2	5.5	7.0	16.7 ± 1.5	15.8	17.6
Upper GI	6.3 ± 1.4	5.3	7.2	13.8 ± 1.9	12.7	15.1
Kidneys (total)	4.9 ± 0.6	4.5	5.3	12.0 ± 1.6	11.0	12.9
Larynx	4.7 ± 1.7	3.6	5.2	12.2 ± 3.1	10.2	14.2
Lens (total)	2.3 ± 0.3	2.1	2.4	2.9 ± 0.6	2.5	3.2
Lungs (total)	5.6 ± 0.6	5.3	6.0	13.3 ± 1.6	12.1	14.5
Optic nerves and chiasm	8.3 ± 2.5	6.7	9.9	13.0 ± 1.6	12.5	14.0
Oral cavity	2.8 ± 0.6	2.4	3.2	7.8 ± 2.4	5.8	9.1
Uterus and ovaries	5.8 ± 1.3	4.9	6.4	13.7 ± 3.8	11.3	16.2
Parotids (total)	4.7 ± 1.1	4.0	5.2	13.8 ± 2.0	12.3	15.0
Rectum	5.0 ± 0.7	4.6	5.5	9.5 ± 2.2	7.9	11.0
Thyroid	5.7 ± 1.9	4.5	5.8	11.9 ± 2.7	10.0	13.4

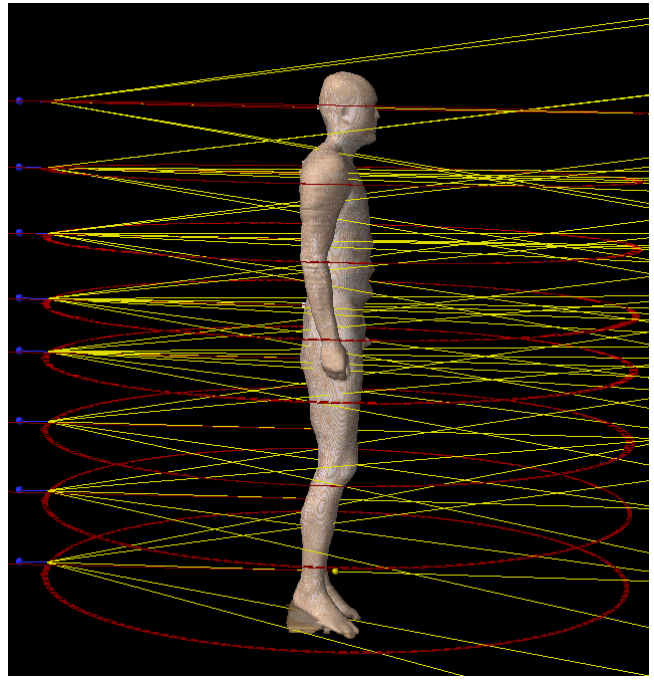
The target volumes are denoted with bold font. The structure of skeletal bones does not include the ribs or skull.

TMLI dosimetric table for Rx at 20 Gy.

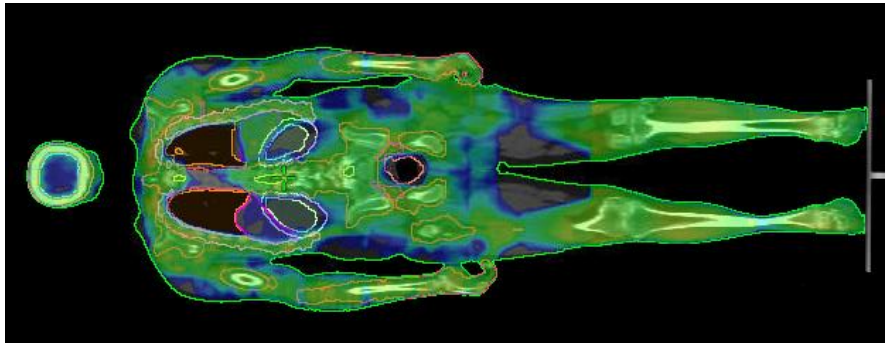
Han, C et al. Target coverage and normal organ sparing in dose-escalated total marrow and lymphatic irradiation: a single-institution experience. Front Oncol 2022;12:946725.

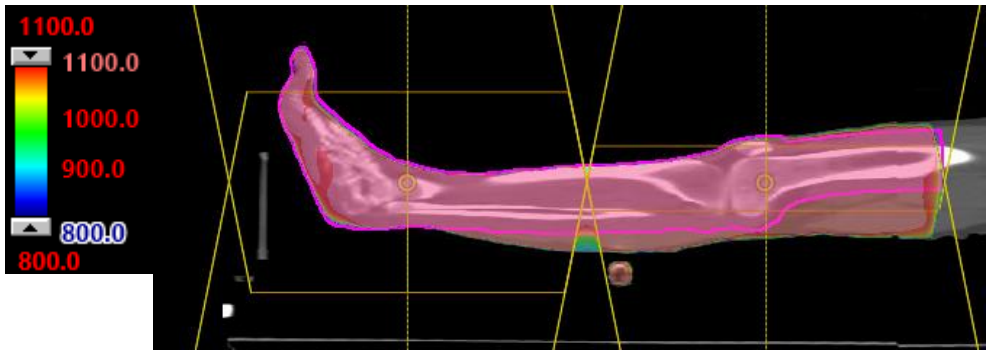
Treating lower extremities on C-arm linacs

- The lower extremities can be treated with VMAT fields or AP/PA fields.
  - The lower extremity plans can be created first and then be used as the based plan in upper body plan optimization.
- VMAT: 3 large-aperture VMAT fields are typically enough to cover lower extremities.
  - Sequential fields should overlap with a length of at least 2 cm for adequate dose in junction regions.
- 3D: 2 – 3 AP/PA field pairs are typically enough.



A whole-body plan with all VMAT fields.





Whole-body VMAT planning

- If VMAT fields are used for lower extremities, all the VMAT fields for the whole body can be optimized in one treatment plan.
- The lower extremity fields need to be rotated for treatment in a feet-in position.
- A software tool exist to rotate IMRT fields to accommodate patient orientation change:
    - Han C, Rosa L, Rayn K, et al. Total X Irradiation helper: publicly available scripting toolset to assist in VMAT planning for total body and total marrow plus lymphoid irradiation (2023 AAPM annual meeting).

Tomo/VMAT TBI plan dosimetry

- Multi-institutional pilot trial (NCT04281199) evaluating IMRT TBI with MLD < 8 Gy to prevent pulmonary toxicities.

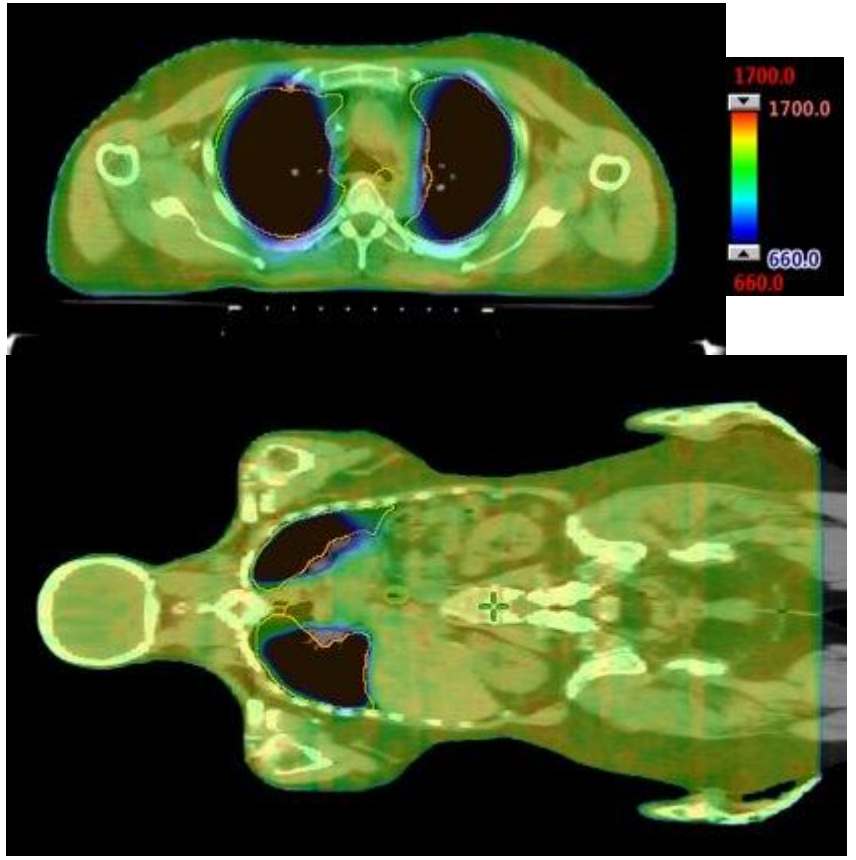
- Dosimetric comparison between the first four patients treated with the VMAT technique and those treated on helical tomotherapy.

	Mean lung dose /Gy			
Index in each modality	#1	#2	#3	#4
Tomo	7.2	8.0	7.7	7.9
VMAT	7.6	6.9	6.9	6.9*

*: Rx = 12 Gy.

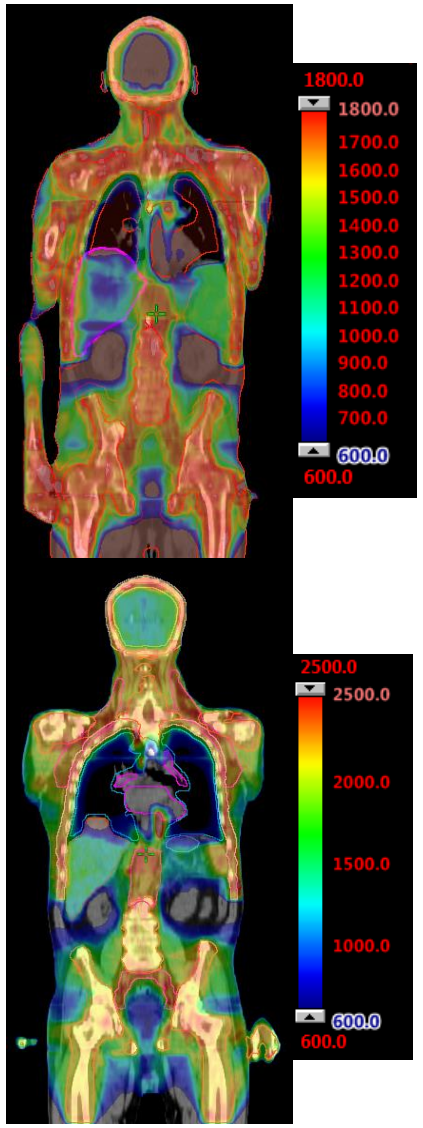
	Mean PTV dose /Gy			
Index in each modality	#1	#2	#3	#4
Tomo	13.5	13.7	13.6	13.5
VMAT	14.0	13.9	14.0	12.7*

*: Rx = 12 Gy.



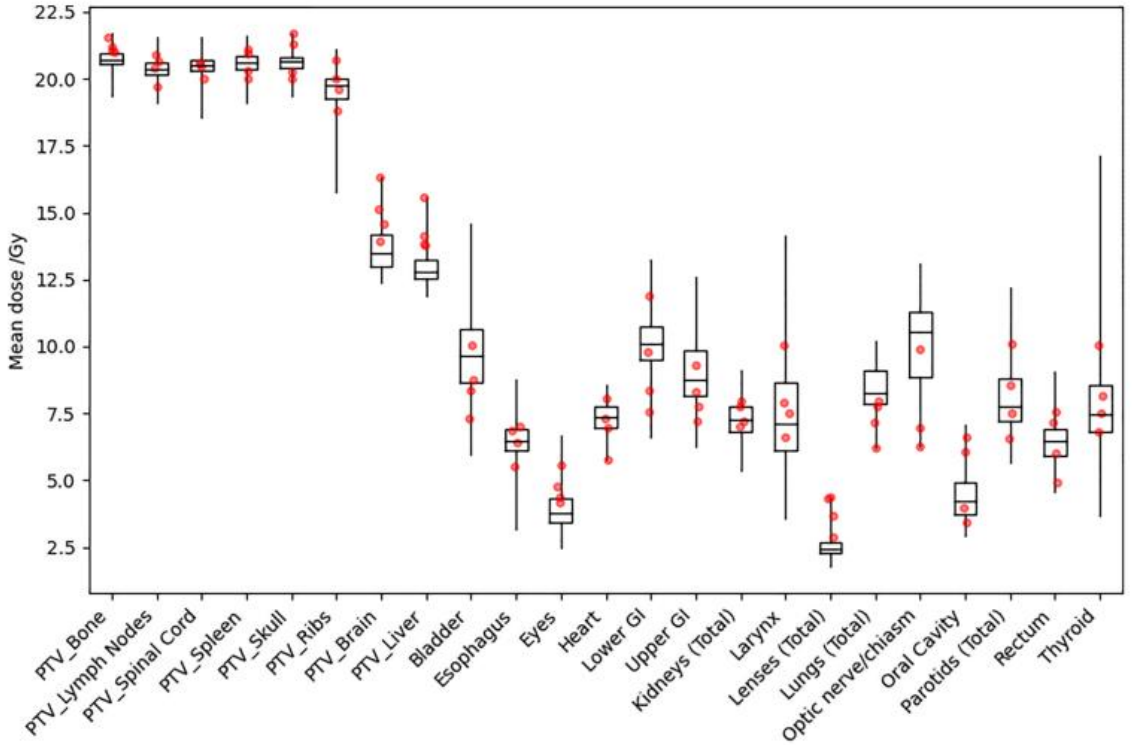
VMAT TMLI dose escalation

- First clinical VMAT TMLI case was treated in 12/2020 with Rx dose of 12 Gy.
- One VMAT TMLI plan with Rx of 16 Gy (12 Gy to spleen) was treated in 1/2021.
    - Mean lung dose = 7.0 Gy.
- First VMAT TMLI plan with Rx of 20 Gy (12 Gy to liver and brain) was treated in 3/2021.
    - Mean lung dose = 7.2 Gy.

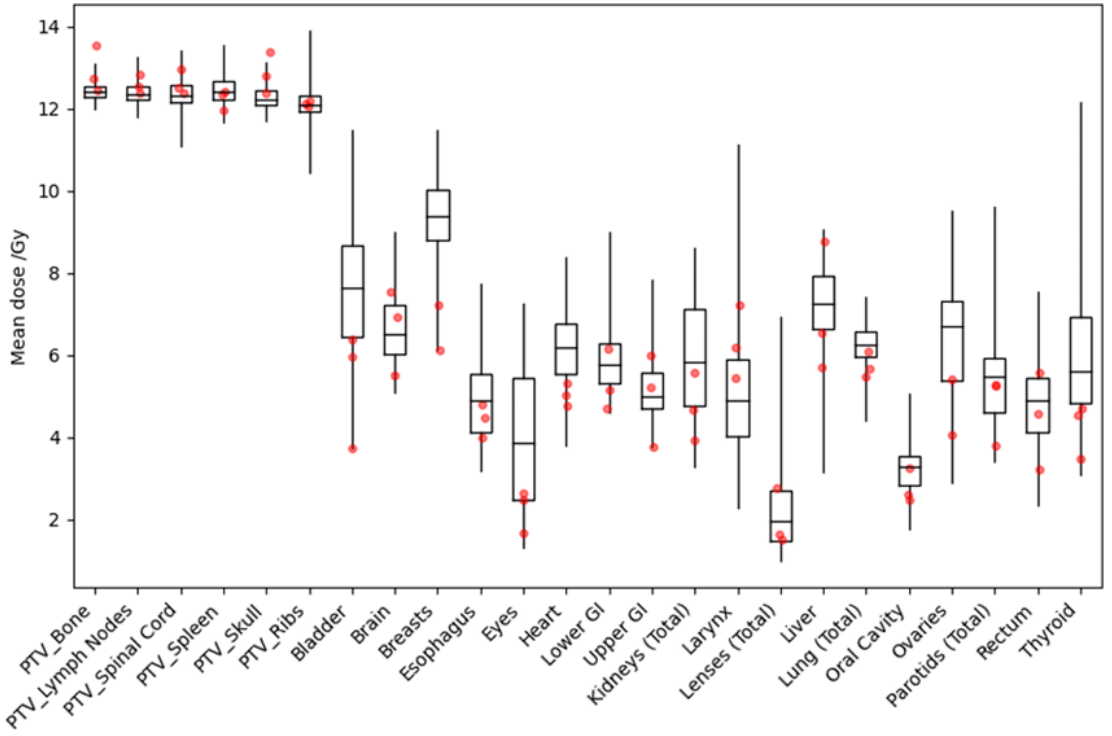


Comparison with historical tomo plan data

- Based on reviews of historical TMLI plan data at City of Hope, TrueBeam VMAT TMLI plans could achieve adequate target coverage and sparing of normal organs compared to historical tomotherapy TMLI plans at both 12 Gy and 20 Gv Rx dose levels.



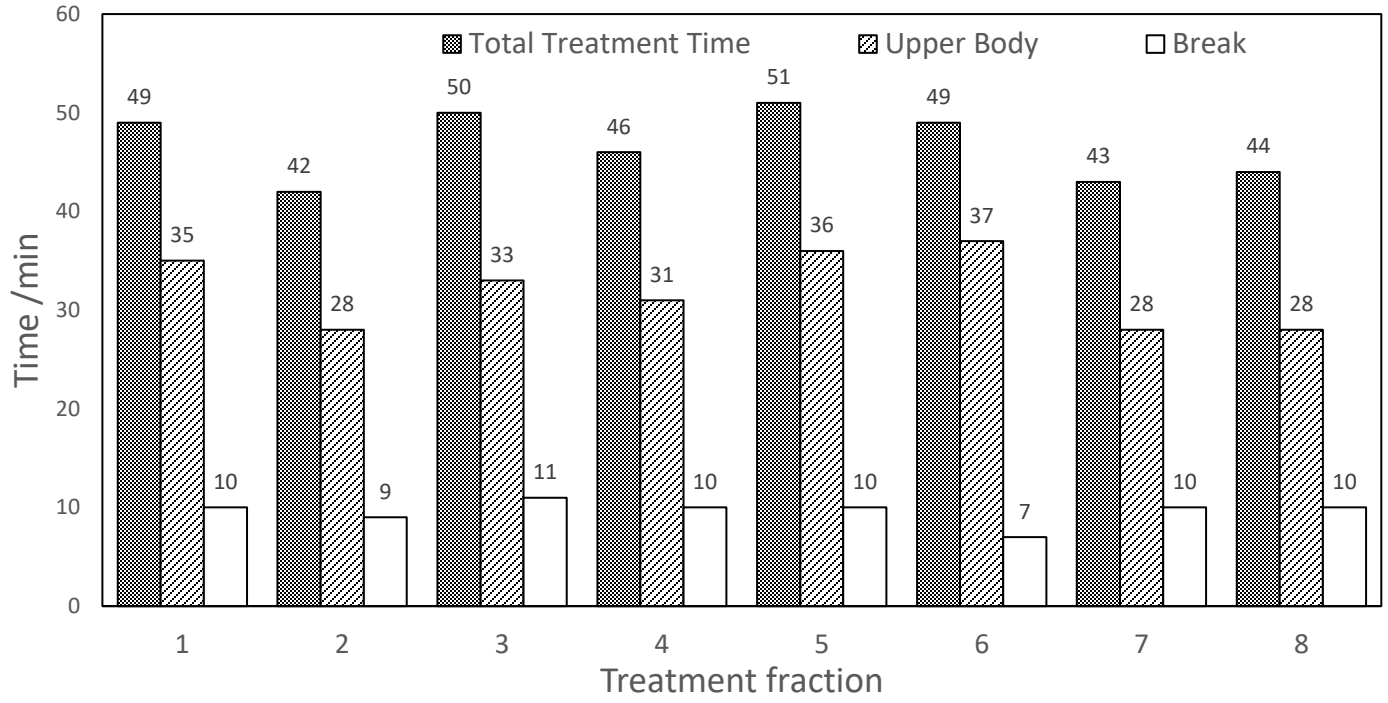
Han, C et al. Front Oncol 2022;12:946725.

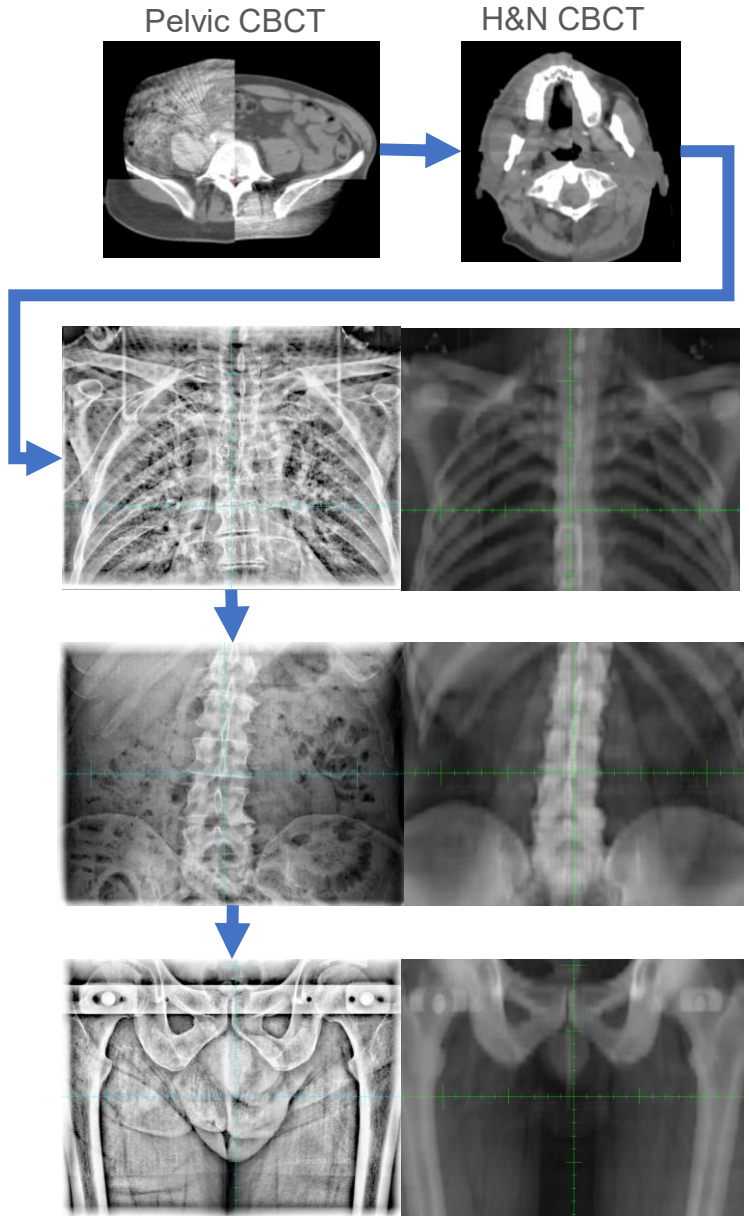


Ladbury C et al. Front Oncol 2023;12:1042652.

VMAT TMLI treatment efficiency

- Patient setup with surface guidance and isocenter verification with MV portal imaging were found to improve TMLI treatment efficiency.



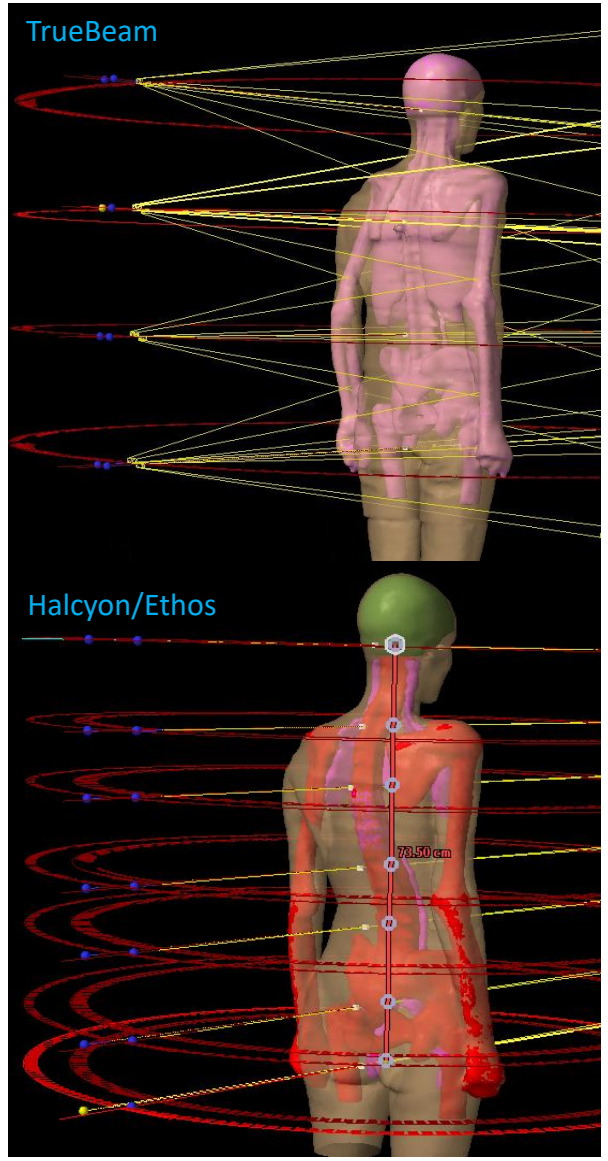


MV port compared against DRR at each isocenter.

Halcyon/Ethos TMLI planning

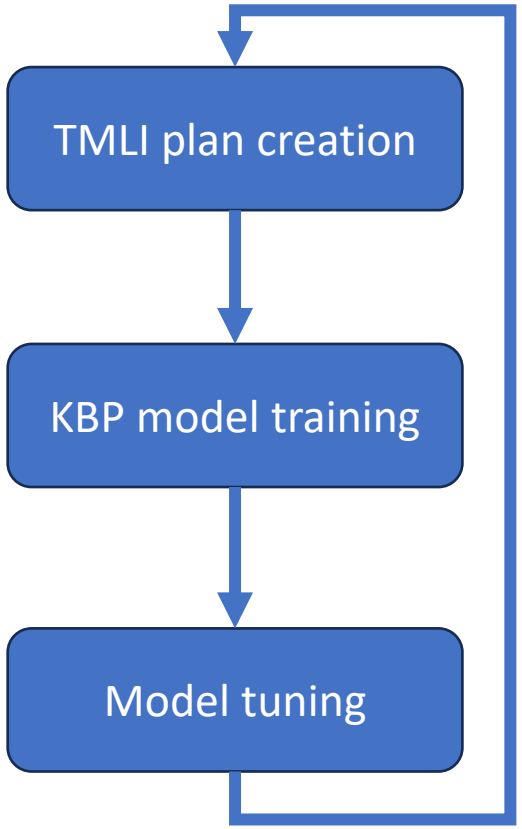
The installed base is growing for Varian Ethos/Halcyon linacs, but these machines pose unique challenges for TBI/TMLI planning and delivery:

- ✓ Halcyon/Ethos machines have a smaller maximum field width of 28 × 28 cm^2, which could negatively impact coverage to lateral aspects of the targets.
- ✓ Due to a smaller field size, TBI/TMLI plan optimization may take more times and resources due to the use of more VMAT fields to cover the targets.
- ✓ TBI/TMLI delivery may take longer time due to the use of more VMAT fields with more isocenters.



Knowledge-based planning for TMLI

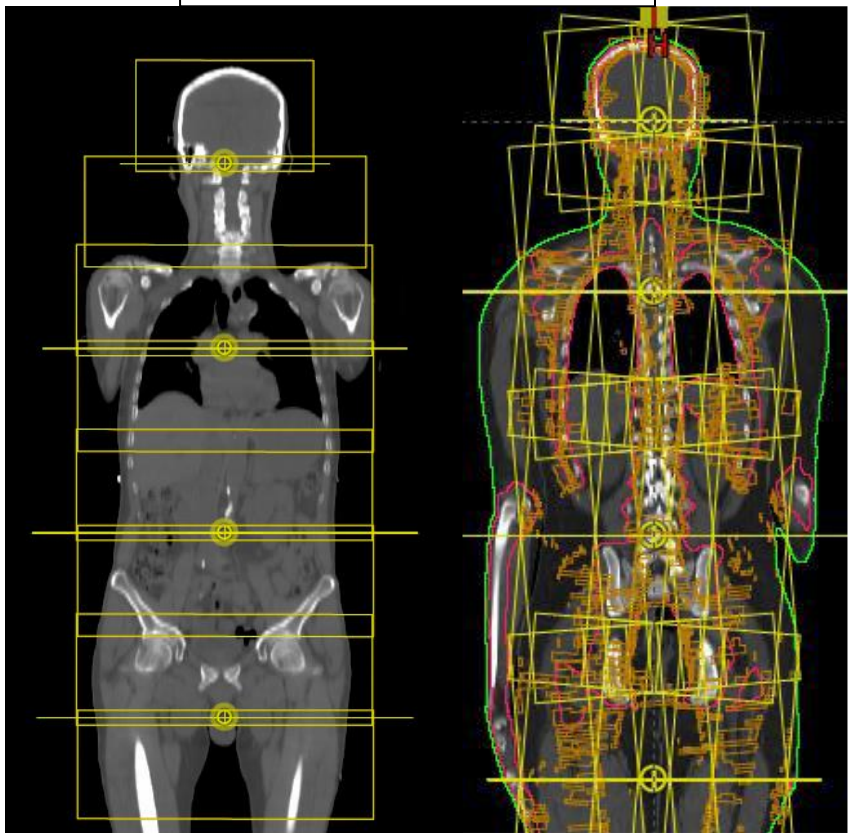
- In recent years, we collaborated with the Varian Medical Affairs team to streamline VMAT TMLI planning (especially for Halcyon/Ethos machines) using the knowledge-based planning (KBP) technique.
- A cohort of 25 previous TMLI cases were re-planned using Halcyon VMAT fields. A comprehensive plan quality metric was assessed based on 130+ dosimetric parameters. Based on the Halcyon TMLI plans, a KBP model (RapidPlan model) was trained and subsequently tuned to maximum the plan quality metric.
- New Halcyon TMLI plans were created using the KBP model. Updated TMLI plans were then used to create an improved KBP model.
- Multiple iterations were used to obtain the final KBP model that are used to optimize TMLI plans with clinically acceptable dosimetry without user intervention.



Study supported by Varian Medical Systems, Inc.

Isocenter placement in VMAT TMLI plans

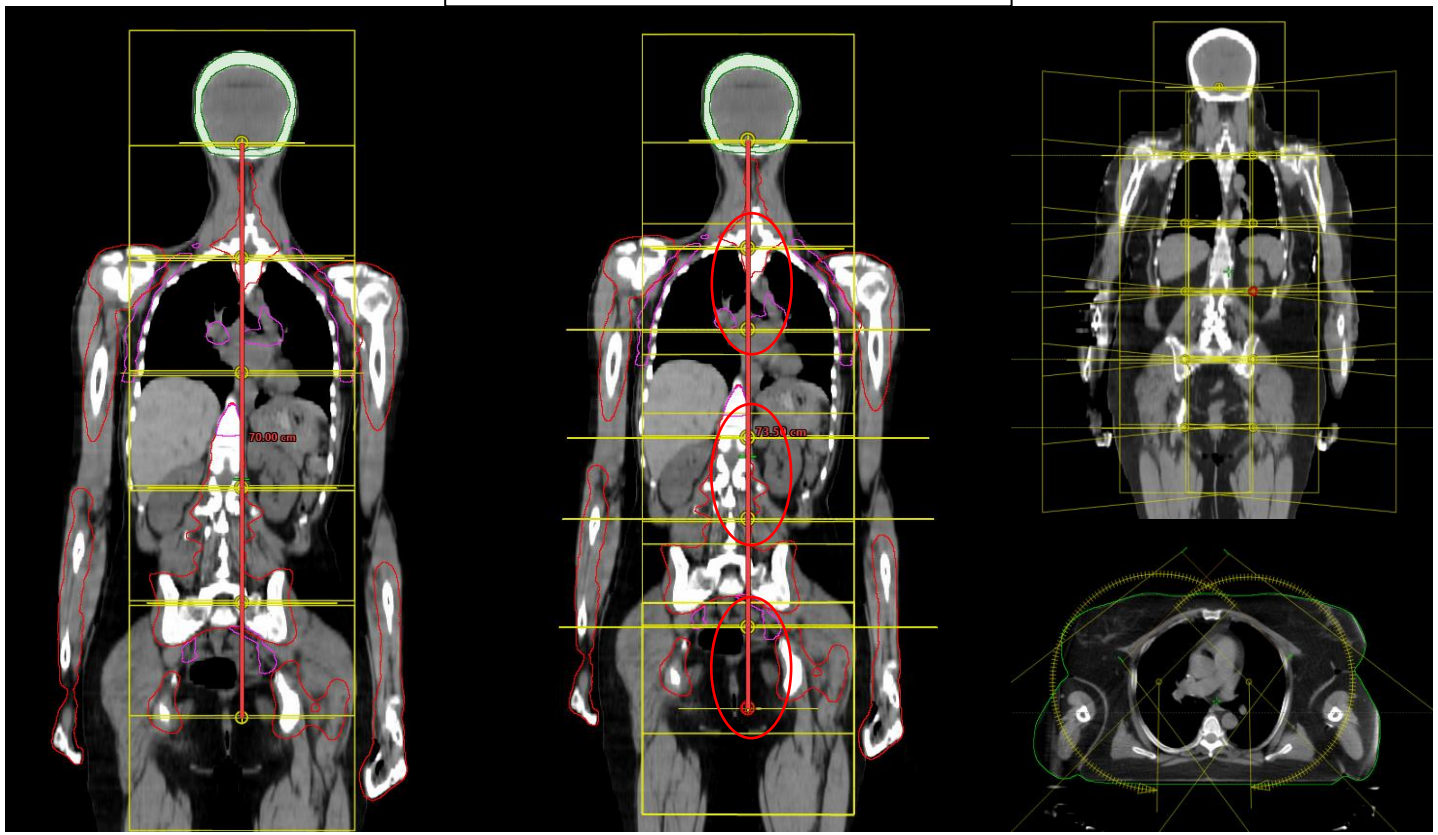
TrueBeam VMAT TMLI



COH method

VMA method

Halcyon/Ethos VMAT TMLI

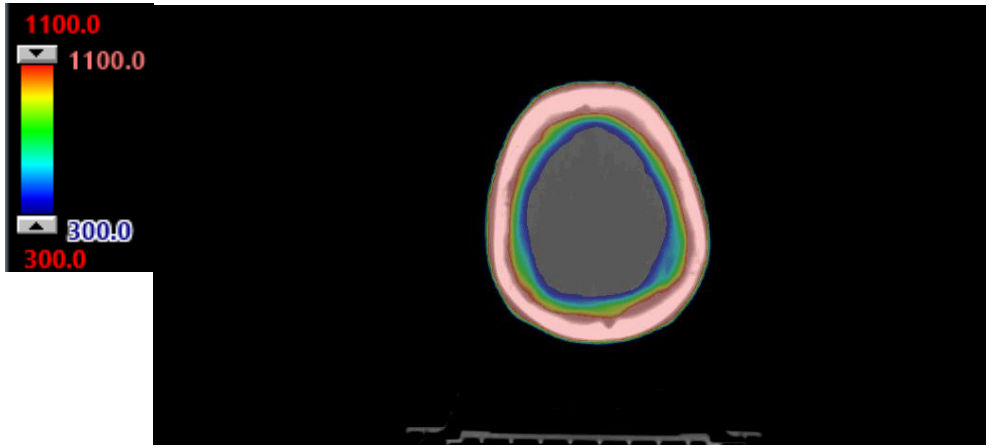


Equidistant iso placement More subplans for tx	Tandem iso placement More efficient delivery	Isos with lateral offset for large patients

Study supported by Varian Medical Systems, Inc.

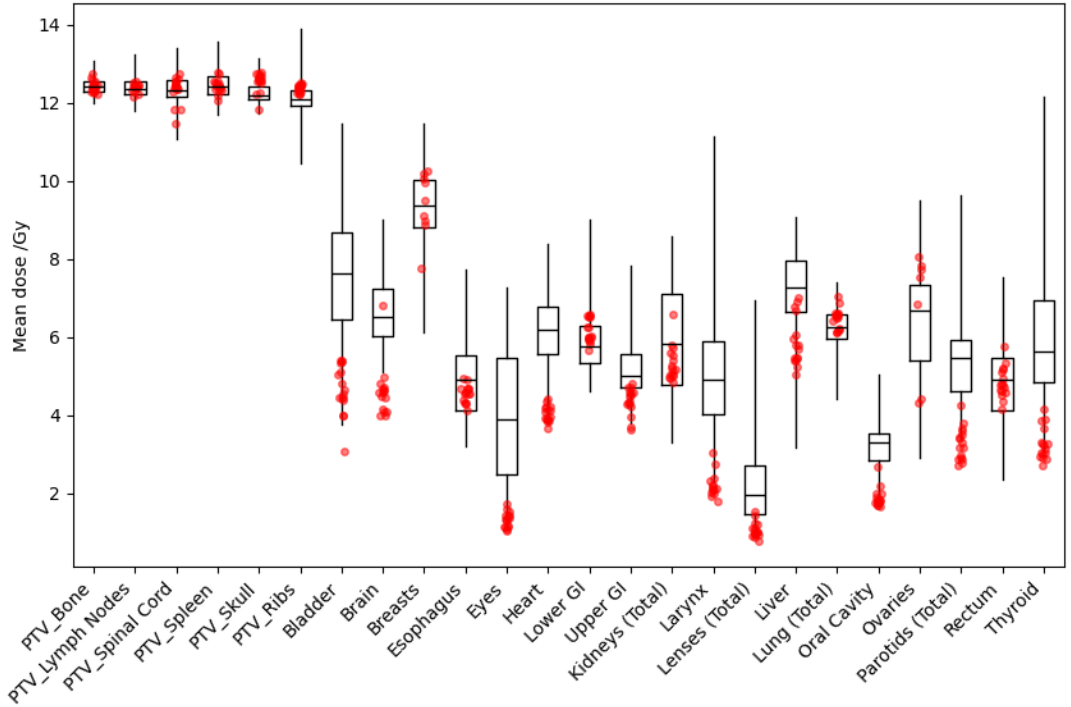
Evaluating the KBP technique

- 16 previous TMLI patients were selected as a test dataset.
- An Ethos TMLI plan was created for each patient and was optimized by the KBP technique.
  - If the patient width is > 52 cm, isocenters in the torso are placed with a 7-cm offset from the midline.
  - Plan optimization was performed with little human intervention. It took 12 to 17 hours to complete optimization and dose calculation of a plan.



Plan optimized with the RapidPlan model.

Gender	8 male / 8 female
Patient width /cm	51.5±5.7 (43 – 62)
PTV length /cm	97.8±6.0 (90.8 – 109.0)
Isos @midline?	Yes: 8 / No: 8



Study supported by Varian Medical Systems, Inc.

Suggestions on starting IM-TBI/TM(L)I

- Do planning exercise well ahead of time to identify any issue with your TPS.
  - Be patient since planning (contouring, field setup, and optimization) may take a lot of time.
- Make use of recent guidelines from SIOPE, COG, AAPM, etc.:
  - AAPM TG-379 report is in advanced internal review and may be published soon.
- Practice with an anthropormorphic phantom and map out the “flight envelope” of your machine.

AAPM Grand Challenge

- Subsequent to recent completion of a AAPM TG-379 report draft, the Working Group on Grand Challenges and TG-379 are organizing a grand challenge on TBI/TM(L)I treatment plan optimization.
- You can generate plans with any TPS with your favorite modality for your favorite machine.
- We designed the challenge as a learning experience: in the first phase of the Grand Challenge (learning phase), we will provide less-challenging cases for people to learn and improve planning skills.
- Registration is open!

For more Info & to register:

AMERICAN ASSOCIATION *of* PHYSICISTS IN MEDICINE

GRACE CHALLENGE

The Grace Kim Memorial Grand Challenge:
Advancing Total Body, Marrow,
and Lymphoid Irradiation Treatment Planning

Grace Gwe-Ya Kim, PhD, FAAPM

- May 31, 1969 – Jun 26, 2025.
- PhD at Yonsei University in 2001.
- Post doctoral fellowship at Stanford University 2006.
- Sixteen years in the Division of Medical Physics, Dept of Radiation Medicine & Applied Sciences, UCSD School of Medicine.
    - Deputy director, Division of Medical Physics in 2023.
    - “Backbone of our radiaton therapy programs at RMAS”.
- Serving on both the AAPM and RSS Board of Directors.
- Member of numerous AAPM committes, authored 7 AAPM reports, and former Chair of TG-379.

Tips for participating in this Grand Challenge

- The total score consists of two parts:
  - Dosimetric score: Target coverage, OAR sparing, etc.
  - Planning & delivery efficiency score.
- You get extra points for using optimization techniques that improves planning efficiency!
- There are existing tools that are freely available at this moment:
  - A RapidPlan model for TMLI planning at 12 Gy Rx dose.
  - An open source ESAPI application that automates image concatenation, isocenter & beam placement, and creation of delivery plans.

TMLI RapidPlan model:

ESAPI code repository:

Summary

- Thanks to technological advancement in recent decades, IM-TBI/TM(L)I is now feasible on many linac models, including C-arm and ring-gantry linacs.
- TMLI addresses an unmet need for certain leukemia patients and expands the use of RT. Multi-institutional trials are needed to demonstrate clinical benefits of TMLI.
- Modern planning techniques including KBP could achieve consistent TMLI plan quality and help automate plan optimization.
- The ongoing AAPM Grand Challenge is a great way to jump start your IM-TBI/TM(L)I planning skills!

Thank you!

City of Hope®