Total Body Irradiation (TBI)

by Adam Melancon

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### Special Procedures at MDACC (June 2014)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>FY10</th>
<th>FY11</th>
<th>FY12</th>
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<td>43</td>
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<td>26</td>
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<td>20 to date</td>
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<tr>
<td>IORT</td>
<td>30</td>
<td>26</td>
<td>58</td>
<td>12</td>
<td>?</td>
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</table>
Total Body Irradiation (TBI)

- Clinical Basis For TBI
- AAPM Report 17 (Task Group 25) Recommendations
- Current MD Anderson Technique
Primary Purposes of TBI

• **Immunosuppression:**
  – For BMT (To kill lymphocyte cells to allow engraftment of donor stem cells)

• **Cytoreduction:**
  – Eradication of malignant cells (Leukemias, Lymphomas, etc)
  – Eradication of cell populations with genetic disorders (Fanconi’s anemia)
Uses of Total Body Irradiation

High Dose TBI

- To destroy host’s bone marrow and kill residual cancer cells
- To immunosuppress pt prior to Bone Marrow Transplant (BMT)
- Usually adjuvant Chemotherapy +/- TBI prior to BMT transplant
Uses of Total Body Irradiation

High Dose TBI

Tx regimen:

✓ 4 – 10 Gy Single fraction (LD$_{50}$ ~ 4 Gy)
✓ 6 Gy 3 Gy x 2, BID
✓ 10 – 14 Gy Fractionated
  12 Gy in 1.5 Gy x 8 fx BID or 2~3 Gy daily fx
  14 Gy in 1.75 Gy x 8 fx BID
  12 Gy in 2.0 Gy x 6 fx BID (Europe)

Dose Rate: Between 5 and 25 cGy/min
Uses of Total Body Irradiation

High Dose TBI:

- Unlike most other treatment delivered by a radiation oncologist, high-dose TBI is potentially lethal without intensive medical support and stem cell backup.
- Incorrectly delivered TBI may result in fatal toxicity as well.
Clinical Complications - Sequelae

High Dose TBI

Lung Toxicity is most concerned
Early Side effects: Nausea, Vomiting, Diarrhea
Within 10 days - Dry mouth, sore throat, reduced tear formation
Hepatic enlargement, gonad failure, poor renal function
Single fraction ~ 26% pt pop: interstitial pneumonitis may be avoided using fractionation
Cataract formation (85% / 11 years)
Risk of re-development of second tumor (chemo-irradiation + BMT) ~ 20%
Uses of Total Body Irradiation

Low Dose TBI

Why: To reduce risk and serious complications

For: Lymphocytic Leukemia, Lymphomas, and Neuroblastoma

Dose: 10–15 cGy/day for 10–15 days

2 Gy single fraction
Low Dose TBI

- Recently, a single fraction low-dose TBI (2 Gy) combined with various chemotherapy regimens has emerged as an effective form of immuno-suppression prior to allogenic stem cell transplantation in non-myeloablative approaches.
- Some trials reported only minor acute treatment-related toxicities and faster hematopoietic engraftment.
MDACC cases from Jan-June 2014

- 37 pts received TBI, including 18 pedi and 19 adults
- Adults Prescription
  - 2.0 Gy x 1 (18 cases)
  - 3.0 Gy x 4 (1 case)
- Pedi Prescription:
  - 1.50 Gy x 8 BID (5 cases)
  - 1.65 Gy x 8 BID (1 case)
  - 1.75 Gy x 8 BID (5 cases)
  - 3 Gy x 2, 2Gy x 2, 4Gy x 2
  - 2Gy x 1, 3Gy x 1, 4.50 Gy x 1
- Dependent on transplant protocols and patient conditions (lung, kidney, heart functions)
State of the Art — 1938

Heublin ~1932, USA

Lead lined ward,

4 beds at one end, Coolidge tube at other end

Beds 5 and 7m from tube

Tx all 4 pts at one time!

20 Hrs, 185Kvp, 3mA, 2mm Cu

0.68 ~ 1.26 R/Hr as a % of erythema dose.

(Bird cage!)
State of the Art? – 2000

Shielded treatment room
4 - 18 MV beams
Bed 4 to 5m from target
One patient a time
Custom blocks/bolus/MU
Uniform Dose (±10%?)
State of the Art? – 2000

Typical Rx Note:
BID with 6 hrs apart
Setup Note:
1. SAD 380 cm
2. Lucite scatter plate
3. Rice bags at neck
4. Dose rate 300 mu/min
5. Lung blocks 4, 6, 8 fx
6. Dose calc to midplane level of umbilicus
Purpose of AAPM Report #17

- Review methods for producing large fields for TBI, HBI, and other large field procedures

- Make recommendations regarding dosimetric measurements required for large fields

- Consider the practical problems of specifying and delivering radiation doses for such large fields
  - Cost vs Benefit
  - Small enough room to minimize cost + Shielding + space
  - Simple procedure fewer sources
TBI Methods
AAPM Report 17, figure 1.

- four sources
- two vertical beams
- single source, short SSD
- two horizontal beams
- head rotation
TBI Methods
AAPM Report 17, figure 1.

source moves horizontally

single source, long SSD

patient moves horizontally

half body, direct and oblique fields

half body, adjacent direct fields
Parallel-opposed Lateral Fields
Dose Homogeneity AAPM Report 17, figure 2.

A=AP
B=Lats
Possible Dose Homogeneity
AAPM Report 17, figure 2.

• The ratio of peak dose to midline dose decreases:
  – As patient thickness decreases
  – With increasing beam energy
  – With increasing SSD

• This implies better techniques use *High energy, long SSD, and AP-PA beam* orientations.

• If High Energies are used, consideration must be given to effects of low doses in BU (buildup) region. Dose in BU may be increased by adding a beam spoiler (plastic plate) near pt skin.
TBI Dose Distributions

- AAPM Report 17, Figure 9, $^{60}$Co parallel opposed beams
- $\pm 10\%$ dose uniformity is possible for AP-PA beam orientation only

Figure 9: Dose distributions for large parallel opposed fields of cobalt-60 radiation.
TBI Dose Distributions

- AAPM Report 17, Figure 10, 25 MV parallel opposed beams
- ±10% uniformity is possible for both lateral and AP-PA beam orientations
Boosting Skin Dose

10 MV X-rays  400 cm SSD

- 10 cm beyond surface
  \( K_2 = 0.200 \quad M_w = 1.770 \)

- 15 cm beyond surface
  \( K_2 = 0.280 \quad M_w = 2.070 \)

- 20 cm beyond surface
  \( K_2 = 0.320 \quad M_w = 2.240 \)

- No 6 mm sheet
  \( K_2 = 0.410 \quad M_w = 1.880 \)

% Ionization vs. Depth (gm/cm-sq)
Summary—Choice of Energy & SSD

• Preferred
  – Higher energy
  – Longer SSD
  – AP/PA beam orientation
  – Scatter plate close to the patient
Basic Phantom Dosimetry

- **Water is the material of choice**
  - Plastic phantom need corrections to convert to water dose

- **Minimum size, 30x30x30 cm³**
  - Larger size preferred, use additional buildup material

- **Need to correct for lack of full scatter**
  - Depends on phantom size, field size and energy

- **Dosimeter should be energy independent**

- **Stem and cable effects should be minimized**
MDACC Technique(s)

Classic Technique
Chair Technique
Pediatric Technique

Lateral Fields—Compensators
MDACC TBI AP/PA “Classic Technique”

Varian 2108 18MV

380 cm SAD

collimator 45°, Gantry 90°

AP view

Umbilicus

scatter plate

Midline Laser

PA view

Umbilicus

40 x 40 cm
MDACC TBI Setup
MDACC TBI – Lung blocks

- Lungs fully shielded for 4, 6, 8 fractions
- Block shadows are aligned on patient in treatment position
- Port film (40 MU) taken
- Blocks adjusted (if necessary) and port film retaken (if necessary)
- MU for port film(s) subtracted from treatment MU
MDACC TBI—Lung Blocks
In-Vivo TLD Measurements
MDACC TBI – Setup Notes

• Lateral decubitus position, patient lying on styrofoam (lifts patient off gurney)

• Scatter plate close to patient

• Rice bags for neck bolus

• Laser on calves for AP, on ankle for PA

• Legs bent to fit patient in light field
TBI dose uniformity
(TLD, RANDO phantom, Therac 20, no bolus)
Fig. 37-4  Stand for total body irradiation designed by Mick-Radio Nuclear, New York, NY, and used at the Medical College of Wisconsin. Note the partial transmission blocks.
SCOT-TBI

- Chair Technique, AP/PA
- Beam Energy $\geq$ 6 MV
- Dose = 4 x 200 cGy/Fraction
- Dose to Lung & Kidney = 50 cGy/Fraction
- Dose Uniformity(Points 1-5): $\pm$10% of 200cGy/fraction
Lung and Kidney

Shielding (shaded area)

Lung

Kidney
If CT alone (no U-sound)

SCOT blocks
## Dose Points

Dose Prescribed: Umbilicus (mid plane)

<table>
<thead>
<tr>
<th># 1</th>
<th>Head</th>
<th># 6</th>
<th>Hip</th>
</tr>
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<tbody>
<tr>
<td># 2</td>
<td>Neck</td>
<td># 7</td>
<td>Rt Knee</td>
</tr>
<tr>
<td># 3</td>
<td>Rt Shoulder</td>
<td># 8</td>
<td>Rt Ankle</td>
</tr>
<tr>
<td># 4</td>
<td>Mid Mediastinum</td>
<td># 9</td>
<td>Rt Lung</td>
</tr>
<tr>
<td># 5</td>
<td>Lumbar Spine</td>
<td>#10</td>
<td>Rt Kidney</td>
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MDACC Total Body Irradiation Commissioning
Varian 21EX SN 2349 (2108)

TBI Geometry
- TBI X Insert
- Collimator Setting: 40 X 40
- Collimator Angle: 45 Degrees
- Gantry Angle: 90 degrees

Instrumentation
- PTW N23333 SN 747 Farmer Chamber
- CNMC 206 SN 3659204 Electrometer

Measurement Phantom(s):
- Plastic-Water Block
  - 30 x 30 x 30 cm

Measurement / Calculation Point: at d max

Irradiation Geometry

Reference-Point Distance = 551 - 30 = 521 cm

"Output" is defined at d max in full-scatter, 521 cm source-point-distance, 40 x 40 field, gantry 90° through scattering plate

18 MV: 0.0422 cGy / MU
6 MV: 0.0400 cGy / MU
Output calc:

Dose = Dose @Ext SSD / Dose @ Std Geometry

ISQ = [ (100 + dmax) / Ext SSD] ^ 2

Calc = Sc. Sp. ISQ. TF

Output calc:

Dose = Dose @Ext SSD / Dose @ Std Geometry

ISQ = [ (100 + dmax) / Ext SSD] ^ 2

Calc = Sc. Sp. ISQ. TF
**Total Body Irradiation (MDACC 'CHAIR') Calculation Worksheet**

**Patient:** TEST  
**Protocol:**  
**MR Number:** 492877  
**Treatment Date:**  
**Rx:** Total Dose: 450 cGy  
**RX Point:** umbilicus  
**Dose per Fraction:** 450 cGy per fraction  
**Number of Fractions:** 1  
**Number of Fields:** 2  

<table>
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<tr>
<th>No.</th>
<th>Calculation Point</th>
<th>Distance Off-Axis</th>
<th>Separation (Sep)</th>
<th>Mid Depth</th>
<th>TMR</th>
<th>OAF</th>
<th>Output @ Calc Pt</th>
<th>Dose at Cx</th>
<th>Percent of Cx</th>
<th>Difference &gt; 10 % ?</th>
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<tr>
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<td>80</td>
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<td>0.0411</td>
<td>269.6</td>
<td>119.8%</td>
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<tr>
<td>2</td>
<td>Neck</td>
<td>60</td>
<td>10</td>
<td>5.00</td>
<td>0.976</td>
<td>1.071</td>
<td>0.0441</td>
<td>289.6</td>
<td>128.7%</td>
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<td>3</td>
<td>SSN</td>
<td>40</td>
<td>30</td>
<td>15.00</td>
<td>0.809</td>
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<td>0.0355</td>
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<td>50</td>
<td>25.00</td>
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<td>0.0272</td>
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<td>5.00</td>
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<td>9</td>
<td>Lower Leg</td>
<td>70</td>
<td>8</td>
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<td>0.993</td>
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<td>Ankle/Foot</td>
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<td>1.000</td>
<td>1.091</td>
<td>0.0461</td>
<td>302.3</td>
<td>134.4%</td>
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**MU = 6565**

| TBI Parameters / Equations: | Computed By / Date:  
---|--------------------------|
| Ref Output: 0.0422 cGy/MU | Initial Check By / Date:  
---|--------------------------|
| Output_{calc} = O_{ref} x TMR x OAF | Final Check By / Date:  
---|--------------------------|
| MU = Rx Dose / (Output_{calc}) | Approved by Attending M.D.:  
---|--------------------------|
Pediatric TBI - Single Fx
MDACC “Pediatric” TBI:
Lung / Kidney Blocks
MDACC “Pediatric” TBI: Lung / Kidney Blocks
QA–Annual Calibration

- Check setup laser
- Measure beam profile
  - Ion chamber in air and plastic, compare to previous data
- Measure PDD in water @ Ext SSD
- Dose calibration @ Ext SAD, 10 cm depth
  - Relative to $d_{\text{max}}$ dose at 100 cm SSD, 10×10 cm² field
Summary Current MDACC TBI

- 18 MV, AP-PA positions
  - good homogeneity
- Custom Lung Blocks
  - no special compensators needed
- Uses \(40 \times 40\) (100 cm SAD) TMR data
  - measured TMR @ Ext SAD is only slightly different than standard TMR data
  - RANDO phantom and in-vivo measurements confirm accurate dose delivery
- No extra daily or weekly QA needed
ACKNOWLEDGEMENTS

• Melinda Chi
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