Volumetric Modulated Arc Therapy-based Total Body Irradiation (VMAT-TBI): 3-year Experience

Pam Lee, MS, Xuejun Gu, PhD
University of Texas, Southwestern Medical Center
2018 AAMD Meeting

Disclosure

Nothing to Disclose
UTSW Radiation Oncology – Most Advanced Technologies
Resources at UTSW  
Radiation Oncology Department

- Varian Linacs (8, 6 with IGRT and OBI)  
- Elekta Linacs (3) all with IGRT and OBI  
- Two Philips 4D Large Bore 16 Slice CT Scanners  
- Brainlab’s Airo Mobile CT  
- Three VisionRT systems  
- Brainlab’s Exactrac system  
- ICON Gamma Knife  
- M6 Cyberknife  
- Calypso  
- Xcision’s Gamma Pod  
- Two Varian Varisource iX HDR afterloaders

Resources at UTSW  
Radiation Oncology Department

- 20 Radiation Oncologists  
- 20 Medical Physicists  
- 11 Dosimetrist  
- 45 Therapists
**Outline**

- **Rationale of TBI**
- **Conventional TBI**
- **VMAT-TBI**
  - VMAT-TBI immobilization device
  - VMAT-TBI treatment workflow
    - Simulation
      - Treatment planning
    - Treatment QA
    - Treatment delivery
- **Conclusion**
Clinical Use of TBI

- Total body irradiation (TBI) has become an integral part of hematologic stem cell transplant or bone marrow transplant preparative regimens.
- Treating disease: leukemia, aplastic anemia, lymphoma, multiple myeloma, autoimmune diseases, etc.
- Purpose of TBI
  - Cytotoxicity: to contribute to the eradication of any residual tumor cells and recipient’s bone marrow.
  - Immuno-suppression: prevent host from rejecting donor stem cells.

Typical Treatment Regimen

- Low-dose TBI
  - A single fraction low-dose TBI (2 Gy) combined with various chemotherapy regimens has emerged as an effective form of immunosuppression prior to allogenic stem cell transplantation in non-myeloablative approaches.
  - Prescription: 200 cGy x 1

- High-dose TBI
  - Prepare for bone marrow transplantation in myeloablative approach.
  - High-dose TBI is potentially lethal without intensive medical support and stem cell backup. Also it is toxic if incorrect delivery.
  - Prescription: 150 cGy x 8 BID or 200 cGy x 6 BID
    - Homogenous dose distribution within +10%, skin dose 90% Rx*
    - Lower lung dose ~8-9 Gy to minimize pneumonitis
    - Lower dose rate 10 cGy/min to minimize pneumonitis

Conventional TBI Techniques

AAPM Report 17 (TG 29), Figure 1.

- four sources
- two horizontal beams
- head rotation
- two vertical beams
- source moves horizontally
- half body, adjacent direct fields
- patient moves horizontally
- half body, direct and oblique fields
- single source, extended SSD
Physics side bar

Dose Homogeneity AAPM Report 17 Figure 2

Conventional TBI (UTSW)

Compensator

Several meters
Conventional TBI: Standing (UTSW)

Conventional TBI: Floor (UTSW)
Conventional TBI

- Large dosimetric uncertainty;
- Treatment may not be comfortable
- Time consuming:
  - Treatment simulation time ~1 hr
  - Treatment delivery time: > 1 hr (mainly setup)

Modern Radiotherapy

IMRT  VMAT
Modulated ARC TBI (MATBI)

Dosimetric aspects of inverse-planned modulated-arc total-body irradiation

Mareike Held, Neil Kirby, Olivier Morin, and Jean Poulion
Department of Radiation Oncology, University of California San Francisco, California 94143-1708

Inverse-planned modulated-arc total-body irradiation

Neil Kirby, Mareike Held, Olivier Morin, Shannon Fogh, and Jean Poulion
Department of Radiation Oncology, University of California San Francisco, California 94143-1708

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Total Bone Marrow Irradiation (TMI)

Cite Cancer Res. 2011 January 1; 17(s): 174-182. doi:10.1158/1058-8402.CCR-10-1912.

Total Marrow Irradiation: A New Ablative Regimen as Part of Tandem Autologous Stem Cell Transplantation for Patients with Multiple Myeloma

1Department of Medical Oncology & Therapeutics Research, City of Hope Cancer Center, Duarte, CA
2Department of Hematology and Hematopoietic Cell Transplantation, City of Hope Cancer Center, Duarte, CA
3Department of Bioinformatics, City of Hope Cancer Center, Duarte, CA
4Department of Radiation Oncology and Radiation Research, City of Hope Cancer Center, Duarte, CA
Southern California Kaiser Permanente, Los Angeles, CA
VMAT-TBI at UTSW

- **Goal**: Achieving a high-quality comfortable treatment in standard treatment room:
  - A high quality treatment plan
    Planning at the current advanced TPS system
  - A patient-comfortable treatment
    Treatment at supine position
  - A treatment without requiring special vault
    Treatment at standard distance on couch

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VMAT-TBI

- A multi-iso VMAT treatment with the aid of home-developed body frame
A Lazy-susan body frame

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VMAT-TBI Treatment Workflow

A. Treatment Simulation  B. Treatment Planning  C. Treatment QA  D. Treatment Delivery

A. Treatment Simulation

A. Treatment Simulation

HFS Upper-Body

FFS Lower-Body
Simulation Protocol

- Field of view (FOV):
  - Consistent between HFS and FFS
  - FOV should include entire TBI body frame

- CT Slice thickness
  - Using 5mm to reduce total CT image size

- kVp and mAs
  - Using Pelvic protocol (120kVp and 80mAs) to generate image with good quality in both H&N and Pelvic region.

- CT marker placement
  - One BB is placed on the patient sternum aligned with BBs on TBI frame, which generate a reference point for patient setup
  - Additional two BBs are placed on the abdomen and pelvis to ensure the body straightness along Z axis

B. Treatment Planning

1. Image concatenation
2. Beam placement
3. Contour
4. Plan optimization
B.1. Treatment Planning – Image Concatenation

Calculate Mean HU for each CT cross section in overlap region.
B.1. Treatment Planning – Image Concatenation

HFS Upper-body  FFS Lower-body

RMSE = \sqrt{\frac{1}{n} \sum_{j=1}^{n} (y_j - \bar{y}_j)^2}

Best match

RMSE = \sqrt{\frac{1}{n} \sum_{j=1}^{n} (y_j - \bar{y}_j)^2}
B.2. Treatment Planning – Beam Placement

- Generally the whole body is divided into 6-7 sections
  - 3-4 in upper body using VMAT (Head, Chest, Abdomen, and Pelvic)
  - 2-3 in legs using AP-PA fields (Upper, Middle and Lower Legs)

- Balancing dose coverage and treatment delivery time
  - Shorten treatment delivery --- fewer arcs
  - Minimizing cold/hot spots --- optimal field overlap

Beam Setup from Pinnacle to Eclipse

- One right Chest ISO/Arc
- One left Chest ISO/Arc
- Same beam arrangement applied to the pelvis
- Chest/Pelvic isos < 4cm away from center to avoid couch collision
**Beam Setup Steps**

- Place AP beams to check coverage
- Rotate upper body beams to Lt-Lat to check coverage
- Rotate upper body beams to Rt-Lat to check coverage
- Change Upper body beams to Arcs
- Leg beams remain AP/PA with collimators 90° to prepare for FIF

**B.2. Treatment Planning – Beam placement**

**Automatic beam placement engine**

- All isos are set along patient middle line
- **Set head arc beam (first)**
  - Make sure beam covers the head but no lung
- **Set chest arc beams (second)**
  - Three arcs, with one arc 90° collimator rotation
  - Simultaneously rotating head & lung arcs to make sure head & lung arcs have at least 2 cm overlapping at skin in 360 rotation
- **Set abdomen arc beam (third) and pelvic arc beams (fourth)**
  - 1-2 arcs per sections depending on pt. size
  - Following the same overlapping rule at skin in 360 rotation
- **Set Legs AP-PA beams**
  - 1 large open beam with junction at skin
  - 1-2 sub fields mimicking the FIF concept to block the hot spot
B.3. Treatment Planning - Contouring

- **Normal structure:**
  - Body+TBI Frame
  - Body
  - Body-0.5cm

- **PTVs - based on (Body-0.5cm):**
  - PTVbody=(Body-0.5cm) excluding lungs
  - PTVarc
    - pPTVhead
    - pPTVchest excluding lungs
    - pPTVabdomen
    - pPTVpelvis
  - PTVleg
  - PTVlung (lung-1cm)

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B.3. Treatment Planning - Contouring

**OARs:**
- Brain
- OralCavity
- BowelSpace
- Kidneys
- SpinalCanal
B.3. Treatment Planning – Auto-Contouring

Auto-Contour Engine

B.4. Treatment Planning – Plan Optimization

- Pinnacle: 2D + Smart Arc/VMAT
- Multiple prescriptions under one plan
  - VMAT for the arc
  - Upper leg
  - Middle leg
  - Lower leg
B.4. Treatment Planning – Plan Optimization

**Eclipse: 2D + RapidArc/VMAT**
- Plan upper leg first
- Use upper leg plan as the base dose plan for VMAT planning
- Plan the rest of leg plans
- Create a plan sum with all the plans
- Use the plan sum to create FIF to block hot spots in the junction area as much as you can.

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### Target Coverage:

<table>
<thead>
<tr>
<th>Target Volume</th>
<th>Dosimetric Parameter</th>
<th>Limit</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTVbody</td>
<td>D90%</td>
<td>100%</td>
<td>100% of prescribed dose</td>
</tr>
<tr>
<td>PTVlung</td>
<td>Dmax</td>
<td>16Gy</td>
<td>As homogenous as possible</td>
</tr>
</tbody>
</table>

### OARs Dose Constrain:

<table>
<thead>
<tr>
<th>Name of Structure</th>
<th>DVH Metric</th>
<th>Objective</th>
<th>Updated Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal Cord</td>
<td>Dmax</td>
<td>15Gy (as homogenous as possible)</td>
<td>0.125cc</td>
</tr>
<tr>
<td>Oral Cavity</td>
<td>Dmax</td>
<td>15Gy</td>
<td>0.125cc</td>
</tr>
<tr>
<td>Bowel</td>
<td>Dmax</td>
<td>15Gy</td>
<td>0.125cc</td>
</tr>
<tr>
<td>Kidney</td>
<td>Dmean Dmax</td>
<td>&lt; 130Gy</td>
<td></td>
</tr>
<tr>
<td>Whole Brain</td>
<td>Dmax</td>
<td>15Gy</td>
<td>0.125cc</td>
</tr>
</tbody>
</table>
B.4. Treatment Planning - Plan optimization

Manual towards automatic

Script

```java
public void decision(String context, String content) {
    if (context == null || content == null) {
        MessageBox.Show("Please select a plan");
        return;
    }
    string filename = string.Format("{0}_{1}.plan", content.Patient.LastName, content.Patient.Name);
    var patientPlan = context.PlanSetup.PatientPlan;
    if (context.PlanSetup.PatientPlan != null) {
        var script = context.PlanSetupPatientPlan;
        var esapi = context.Esapi;
        esapi.GenerateWorkfile(script);
        esapi.GenerateScript(Patient patient, plan, string filename);
    }
}
```

API

Eclipse

Eclipse Scripting API: ESAPI

Sample Patient Plan Quality

12Gy

PTVlung

PTVbody

90%
C. Treatment QA

1. QA with solid water phantom
   - Point dose measurement (<5%)
   - Film measurement (>90%, 5%/3mm)

2. Each Arc ISO has a QA plan of its own.

D. Treatment Delivery

1. Position verification: kV imaging or CBCT
D. Treatment Delivery

1. Position verification: CBCT or kV imaging
2. Beam delivery with low dose rate

Dose Rate Table:

<table>
<thead>
<tr>
<th>Beams</th>
<th>Adult</th>
<th>Pedi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>40MU/min</td>
<td>20MU/min</td>
</tr>
<tr>
<td>Lung</td>
<td>40MU/min</td>
<td>20MU/min</td>
</tr>
<tr>
<td>Abdomen/Pelvis</td>
<td>40MU/min</td>
<td>20MU/min</td>
</tr>
<tr>
<td>Legs</td>
<td>600MU/min</td>
<td>600MU/min</td>
</tr>
</tbody>
</table>

Setup: 15-35 mins + Beam-on: ~35-55mins = Total treatment time: ~50-90mins

2. Beam delivery with low dose rate
VMAT-TBI Conclusions

- Treatment at standard-size room
- Accurate treatment planning
- Accurate patient positioning
- We have treated 20 patients since 2015.
  - Follow-up data show no outcome difference compared to conventional TBI
  - Achieving high patient satisfaction

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Questions?