Total marrow and lymphoid irradiation with helical tomotherapy: A practical implementation report

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*marrow and lymphoid irradiation, helical tomotherapy, TMLI, ABMT, allogenic bone marrow transplantation*
Abstract

Objective To standardize the technique and resources for total marrow and lymphoid irradiation (TMLI) as part of the conditioning regimen before allogenic bone marrow transplantation (ABMT) using helical tomotherapy.

Methods We used this technique in our first 5 patients requiring TMLI. Patients were immobilized using a mask and a whole-body vacuum cushion. CT scanning was performed in head first supine (HFS) and feet first supine (FFS) orientations with an overlap at mid-thigh. Target consisted of the entire skeleton, spleen, sanctuary sites and major lymphatics whereas lungs, kidneys, aero-digestive tract, bowel, parotids, heart and liver were defined as organs at risk (OAR). Treatment was performed in two parts based on 2 different plans generated in HFS and FFS orientations with an overlap at the mid thigh. Patients along with the immobilization device were manually rotated by 180° to change the orientation after the delivery of HFS plan. The dose at the junction was contributed by a complementary dose gradient from each of the plans. Plan was to deliver 95% of 12Gy to 98% of CTV with dose heterogeneity < 10% and pre-specified OAR dose constraints. Megavoltage-CT was used for position verification before each fraction. Patient specific quality assurance and an in-vivo film dosimetry to verify junction dose were performed in all patients.

Results Treatment was delivered in two daily fractions of 2Gy each for 3 days with at least 8-hours gap between each fraction. The target coverage goals were met in all the patients. The average person-hours per patient were 16.5, 21.5 and 25.75 for radiation oncologist, radiation therapist and medical physicist respectively. Average in-room time per patient was 9.25 hours with an average beam-on time of 3.32 hours for all the six fractions.

Conclusion This report comprehensively describes technique and resource requirements for TMLI and would serve as a practical guide for departments keen to start this service. Despite being time and labor intensive, it can be implemented safely and robustly. We will be using this methodology in a prospective phase II trial to study safety and feasibility of dose escalated TMLI as part of conditioning regimen before ABMT.

Introduction

The total body irradiation (TBI) with extended source-to-skin distance (SSD) is a simple and robust technique to deliver myeloablative treatment as part of the conditioning regimen for allogeneic bone marrow transplant (ABMT) for myeloid and lymphoid leukemia. However, this modality does not spare organs at risk (OAR) except lungs and results in large heterogeneities in radiation dosage across the body.

Total marrow irradiation (TMI) is emerging as an alternative to TBI as it has shown reasonable safety and efficacy in phase I/II trials [1–6]. Addition of lymphoidal irradiation to TMI (TMLI) has the potential to reduce the rejection against the lymphocytes in donor marrow. Currently several groups are evaluating its role in standard and high-risk acute leukemias [7]. TMLI targets the entire skeleton and lymphoid tissues while sparing the organs at risk such as parotids, oral cavity, lens, thyroid, lungs, heart, bowel, kidneys, liver, breast, etc. thereby significantly limiting potential toxicities associated with irradiation of these structures. Hereby, we report our initial experience with the detailed technique, resource and time requirements for TMLI using Helical Tomotherapy (HT) (Accuray Inc, USA) at our center.

Materials And Method

This report aimed to standardize the methodology for simulation, target delineation, treatment planning, optimization, patient-specific quality assurance, in-vivo dosimetry, pre-treatment image verification, setup and treatment. Patients were considered for this procedure after due discussions in the multi-disciplinary tumor board in close co-ordination with the haemato-oncology team. Feasibility for TMLI in these patients was based on
the ability and willingness to lie down on the treatment couch for at least 1.5 hours. All patients signed an informed consent document before the procedure. Our experience of treating the first five consecutive adult patients (age >18 years) has been used in this practical implementation report.

Simulation

Simulation was done after the insertion of all catheters or venous access as deemed fit by the hemato-oncology team. Patients were positioned supine in a large vacuum bag encompassing the entire body in a neutral position and a 3-clamp thermoplastic mask on a standard neck support was made to immobilize the head and shoulder. The arm, forearm and hands were placed closely touching the lateral aspect of the body. The knees were placed in a comfortable position and the height was adjusted on the vacuum bag. In males, the scrotum was strapped to the lower abdomen and marked. The firm impression of heel and toes on the vacuum bag was captured. Before acquiring CT imaging, a thin copper wire was placed over the mid-thigh bilaterally. Lines were drawn horizontally over upper and lower limbs with corresponding lines over the vacuum bag to aid reproducibility. As HT unit can treat till a maximum length of 135cm, two sets of CT scans (on AcquilonLB, Toshiba, Japan) of 5mm slice thickness in free breathing were acquired for each patient. The first scan was acquired from vertex to distal thigh (at least 5cm beyond the wire placed over mid-thigh) in the headfirst supine (HFS) position. Then the patient along with the immobilization was rotated by 180° and a second CT scan was acquired from toes (entire vacuum bag to be included) to the upper thigh (at least 5cm beyond the wire placed over mid-thigh) in feet first supine (FFS) position. Both scans encompassed the entire thigh to aid in registration for the evaluation of the summated plan. For the HFS scan the CT reference point was marked over the chin and for the FFS scan over the knee.

Target Delineation:

CT images were transferred to RayStation Treatment Planning System (TPS, V7.0, RaySearch labs, Stockholm), which is the preferred system for target delineation in our department. Clinical target volume (CTV) included entire bony skeleton, brain, testes splen and major lymphatics. CTV defined on HFS and FFS scan included bones auto-segmented based on grey level (Hounsfield units-HU) thresholding ranging between 250-1700 HU and edited appropriately. Bony CTV was split into multiple segments (skull, chest, upper/lower limbs, vertebra, and pelvis) to enable differential planning target volume (PTV) margins. Mandible, hyoid bone, patella and larynx were excluded from CTV. PTV margin of 3mm, 5mm, 7mm, 10mm, 5mm were given to CTV skull, vertebra, chest/spleen, upper limb (and lower limb for FFS scan), and pelvis (and scrotum) respectively. For patients with maximum lateral separation exceeding 45cm, an additional margin was created for PTV upper limbs since the field of view (FOV) of megavoltage CT (MVCT) was limited to 40cm. Lymphatics delineated included cervical, supraclavicular, mediastinal, axillary, entire para-aortic chain, external and internal iliac, andinguinal nodes. A uniform PTV margin of 5mm was applied to generate lymph nodal PTV. Individual PTV’s generated were summated to create PTV. Organs at risk (OAR) delineated were eyes, lens, midline mucosa (oral, pharyngeal, laryngeal, tracheal and esophageal mucosa), lungs, heart, liver, bowel, kidneys, parotids, thyroid, breast, and ovaries. Dose Prescription and dose constraints have been summarized in table-1.

Treatment planning, plan evaluation and patient-specific quality assurance (PSQA):

We used the Precision planning system (iDMS version 1.1.1.1, Accuray Inc, USA) for optimization and dose calculation purposes. For planning and optimization, the entire target volume contoured in HFS & FFS images series was divided into three parts namely PTV-upper, PTV-lower and PTV-Junction [Fig-1]. The length of the junction volume was kept at 10cm (typically located between the upper thigh corresponding to the distal end of the fingers and knee) and it was divided into five sub-volumes in each CT image series to create a dose gradient. They were labeled as PhyUG2Gy, PhyUG4Gy, PhyUG6Gy, PhyUG8Gy, PhyUG10Gy, PhyLG2Gy, PhyLG4Gy, PhyLG6Gy, PhyLG8Gy, and PhyLG10Gy. The copper wires placed on the left and right mid-thigh were used as common reference markers to correlate the axial positions from both HFS & FFS CT image series. Using this common reference marker the extension and location of the three PTV’s were verified in both the CT image series.

As a standard protocol CT tabletop in the image series was replaced by the Radixact couch model. The patient position was set using a green laser in such a way that the entire body was fit within the field of view. Two
separate treatment plans were generated on each of the scans (HFS and FFS) to cover the entire target including the junction between the two plans [Fig-2a and 2b].
Plan setup parameters were chosen to meet the clinical goals of the target. Pitch from 0.3 – 0.43, field width of 5cm, modulation factor of 2.5 – 3.5 for HFS orientation and 2.15- 2.5 for FFS were used. A higher heterogeneity was accepted near the upper limbs especially near the forearm and hands. Pitch values were optimized to have minimal thread effect and good target coverage. Higher modulation factors were used for initial iterations and subsequently modified to have efficient beam delivery time. The final plans generated on both the CT's were summated [Fig-3a] and the dose profile across the junction [Fig-3b] was evaluated on RayStation TPS (due to limitation in summating plans generated on two differently referenced CT’s on Precision TPS). As part of the PSQA, we measured the dose using a cylindrical cheese phantom (Accuray Inc, USA) with the A1SL ion chamber (Sun Nuclear, USA). Since the target volume exceeded 120cm, multiple point doses (3 for HFS plan and 2 for FFS plan) were measured to cover the entire target. Each point dose measurement was associated with a specific QA plan and a laser position co-ordinate for phantom placement. Before each measurement phantom position was verified using MVCT image registration with planning CT.

Treatment delivery and In-vivo dosimetry:

Pre-treatment imaging and treatment delivery were divided as the patient was treated in both HFS and FFS positions as described in the pictogram [Fig-4]. Treatment was interrupted each time after a pre-specified time. In HFS treatment, the first MVCT scan was obtained from mid-chest to upper abdomen level to correct any significant longitudinal and yaw errors manually. The 2nd MVCT was acquired from the vertex to the mid-chest level. After applying the necessary lateral and vertical corrections, patient was treated up to the upper abdomen. The third MVCT scan was obtained encompassing the entire abdomen up to mid-thigh, the position of scrotum was verified and the rest of the patient treatment was completed for HFS plan. Subsequently, the patient was rotated by 180 degrees (in yaw plane) with the same immobilization and alignment in place for FFS treatment plan. The fourth MVCT was acquired from ankle to thigh, couch corrections were applied (including the longitudinal corrections since the patient was moved manually) and treatment was delivered with FFS plan. The dosimetric accuracy of the junction was verified using GafChromatic ebt3 film placed over the junction during the first treatment fraction.

Results

Five patients (3 males; 2 females) with a median age of 36 years (range 25-49 years) underwent this procedure from the 7th-5th day before ABMT. The median patient height was 167cm (range 160-178cm).

All patients received two daily fractions of 2Gy each for 3 days with a minimum gap of 7 hours between each fraction. The mean beam-on-time per fraction was 33.25 minutes with a dose rate of 1051MU/minute. The resources and time requirements for the treatment planning and delivery procedure have been summarized in table-2.
The desired target coverage and OAR sparing was satisfactorily achieved in all patients. The dose-volume parameters achieved have been summarized in table-3. The dose homogeneity was acceptable with a mean homogeneity index of 0.170 (range 0.147-190) for the combined PTV (PTV-upper + PTV-lower + PTV-junction). A higher inhomogeneity was accepted only for PTV upper limbs (mean HI=0.327, range 0.197-0.441). The mean of lung D50, kidney D50, heart D50, liver D50 and max dose to mucosal structures achieved were 8.15Gy, 7.5Gy, 8.17Gy, 7.41Gy and 12.48Gy respectively. The liver was included in the target volume for the patient-2, which led to a higher lung D50. For the calculation of average D50 for liver, this patient was excluded (Table 3).

Setup errors were minimal in all patients based on MVCT verification [table 4]. After the initial verification with the first MVCT and manual re-positioning if required, none of the patients required additional re-positioning since most of the errors noted were corrected by necessary couch translations.

The PSQA results achieved for all the patients were satisfactory as per our institutional thresholds and have been summarized in table-5. On qualitative comparison of TPS calculated dose profile and measured dose profile (in-vivo film dosimetry) at the same level no abnormal spikes in dose were observed in all the patients [Fig-5].
All patients completed their treatment with no Grade 2+ acute toxicities (CTCAE V5). Subsequently, all patients were successfully engrafted and no late toxicities were observed at a median follow-up of 7 months (range 2.5-8 months).

Discussion

After a considerable experience with extended SSD TBI for last several years, we evaluated this methodology of TMLI, with an aim to eventually study the feasibility and safety of dose escalation in selected patients. Our objective with this study was to standardize the procedure, plan resources and time requirements for this procedure in our department. We preferred HT for magna-field irradiation as it offers a high degree of conformity, homogeneity of target coverage dose and significant sparing of OAR with optimal treatment efficiency, without the need for multiple junctions. This is possibly the reason why several groups have extensively evaluated it for TBI and TMI/TMLI [8–14]. Recently VMAT has also been evaluated in this setting to a reasonable success [15,16]. Although we have used HT to treat our patients, the same principles can be broadly applied for VMAT as well.

The target delineation for both TMI and TMLI has been varied in literature. Exclusion of mandible, maxilla, bones in the forearm, small bones of the hands and feet from the target has been diverse [1–6]. We have included the entire skeletal system excluding mandible, hyoid, laryngeal cartilage and patella. Similarly inclusion of nodal groups varied with some authors not explicitly mentioning the nodal groups that are intentionally irradiated [8–10]. We have included cervical, mediastinal, para-aortic, pelvic and inguinal nodal chains and have excluded Waldeyer’s ring and porta-hepatic nodal groups in order to limit the doses to oropharyngeal mucosa and liver/bowel respectively. There is also a discrepancy when it came to inclusion of liver, which was part of the target in some and was an OAR in a few series [8–10,17]. Patients will be followed up to validate the appropriateness of our approach.

We have used two sets of CT scans and plans with complementary dose gradient across the junction similar to the one described by Haraldsson, et al [18] for TMI. Planning and optimization processes were similar except that we allowed a lengthier junction to ensure plan robustness. The target delineation, final plan summation and evaluation were performed on one TPS, whereas the optimization and dose calculation were carried out on another TPS. The dose coverage and homogeneity met our pre-specified dose constraints except in upper limbs where the inhomogeneity exceeded our thresholds. This is expected with HT delivery for peripherally located targets due to increased thread effect and limited beamlet views for this region.

Lung D50 achieved in our patients was relatively higher compared to other published series of TMLI [8–10,17] and this is possibly due to differences in target delineation, margins and differences in target coverage goals. Varying margins to the chest wall target have been used by investigators which were based either on geometric expansion ranging from 0-10 mm [9,18] or based on chest wall motion [18]. Our coverage goal of 95% of dose to 98% of CTV was higher than the 85% set by others (9) possibly explaining higher lung D50. However, lung D50 achieved for TMLI in our cohort was comparable to that achieved by Haraldsson, et al for TMI. We intend to aggressively limit lung D50 in future, especially when we escalate TMLI doses by relaxing the target coverage goals in the upper chest (our current mean CTV chest D98 was 99.6%). We already have reduced our mean lung D50 constraint from 8.5Gy to 7Gy for our last patient.

We have used MVCT alone as a guide for patient setup verification, which mandated diligent patient immobilization and systematic imaging protocol to minimize patient repositioning. The first MVCT (lower neck to chest) in our imaging protocol was done to manually correct any longitudinal and yaw errors before proceeding with the rest of the procedure. This step significantly reduced the magnitude of couch corrections and the need for repositioning. Special attention was given to extremities and scrotal position during immobilization and daily set up to minimize the repeated image verifications. The robustness of the dose at the junction was reaffirmed with the help of film dosimetry.

As compared to TBI, TMLI is a time and resource-intensive procedure. We observed that for one patient to be
successfully treated, the department would have to allocate nearly 27 physicist-hours, 21.5 therapist-hours and 16.25 radiation oncologist-hours (table-2). Significantly higher person-hours and in-room time as compared to other magna-field irradiations can potentially lead to stress on work-timings for all the personnel involved especially in busy radiation oncology departments. The mean in-room time of 9.25hrs per patient over 3 days, could potentially lead to significant changes in treatment schedules for other patients. We chose weekends and public holidays to treat our patients to minimize interruptions to the department’s routine. Our beam-on time was higher compared to that reported for TMI using HT and VMAT [16], but comparable to others for TMLI using HT [8-10,17]. Our time for target delineation, treatment planning and QA was comparable to that reported by others for TBI [19]. We believe that further optimization of total in-room time can be achieved with growing experience.

Since the aim of the study was to standardize our methodology and plan resource requirements, we chose to publish this report after treating the initial 5 patients. However, the dosimetric data is limited due to the small sample size and hence we may have to optimize the target and OAR dose constraints in the future on a case to case basis. All our patients were young and had healthy lung volumes enabling us to achieve desirable lung D50, however this could be challenging in patients with poor lung volumes. The robust set-up and minimal couch corrections noted in our study may not be possible to achieve in more challenging patients and hence may either require a more liberal margin recipe or a compromise on dose constraints. Our average beam-on-time of 9.25hrs per patient may pose a significant challenge while treating pediatric patients, although the need for junction would not arise in such patients (<135cm).

### Conclusion

TMLI results in significant sparing of OAR and provides an opportunity for safe dose escalation despite being a time and resource-intensive procedure. Our comprehensive report on the detailed methodology, resource and time requirements to implement TMLI would help departments planning to commission this procedure and plan their resources. We will be using this methodology in a prospective phase II trial to study the safety and feasibility of dose-escalated TMLI as part of the conditioning regimen before ABMT.

### List Of Abbreviations

TMLI: Total marrow and lymphoid irradiation
ABMT: allogeneic bone marrow transplantation
OAR: Organs at risk
SSD: Source to skin distance
HFS: Head first supine
FFS: Feet first supine
FOV: Field of view
CT: Computed Tomography
CTV: Clinical target volume
PTV: Planning target volume
TBI: Total Body Irradiation
PSQA: Patient specific quality assurance
TPS: Treatment planning system

MVCT: Megavoltage-CT

**Declarations**

**Ethics approval and consent to participate**

Voluntary written informed consent was obtained from the patients to study and publish their clinical data anonymously

**Consent for publication**

Voluntary written informed consent was obtained from the patients to study and publish their clinical data anonymously

**Availability of data and materials**

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

**Competing interests**

The authors declare that they have no competing interests

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Not applicable

**Authors’ contributions**

SC was the chief treating radiation oncologist and was involved in the entire treatment, analysis and manuscript preparation; SS was the senior registrar involved in entire treatment, analysis and manuscript preparation; RT was the medical physicist involved in treatment planning and dosimetry; JE was the Chief Haemato-Oncologist involved during the treatment; MS was the associate medical physicist involved during treatment planning and collection of data; GK was the medical physicist involved in patient specific quality assurance (PSQA) tests; PKP was involved in data collection, analysis and manuscript preparation; DS is the head of medical physics department and has significantly contributed for the treatment planning, PSQA and dosimetry analysis; RJ has contributed significantly during treatment planning and manuscript writing.

All authors read and approved the final manuscript

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Tables

Table-1: Dose volume constraints and planning goals.
| Structure                        | Planning Objective                                                                 |
|---------------------------------|-----------------------------------------------------------------------------------|
| CTV                             | 98% of CTV to receive at least 95% of 12Gy                                         |
|                                 | Dose to 2% < 110% of prescription dose                                            |
|                                 | Dose to 98% > 90% of prescription dose                                            |
| PTV                             | 95% of PTV to receive 95% of prescription dose                                     |
| Lungs                           | Mean dose < 8.5 Gy                                                                |
| Kidneys                         | Mean dose to each kidney < 8.5 Gy                                                |
| Heart                           | Mean dose < 8.5 Gy                                                                |
| Liver                           | Mean dose < 8.5 Gy                                                                |
| Lens                            | Mean dose < 3 Gy                                                                  |
| Mucosal structures, Esophagus, Bowel | Max dose < 105% of prescription dose                                           |

Table-2: Time, resource requirements for the TMLI. (as per local practice)
| Process                                      | Time (Median)                          | Resource                                                                 |
|---------------------------------------------|----------------------------------------|--------------------------------------------------------------------------|
| Simulation and image acquisition            | 1.5 hrs                                | 2 Radiation therapists
|                                             |                                        | Verified by Medical Physicist and Radiation oncologist                   |
| Target Delineation                          | 6 hrs                                  | 1 Radiation Oncologist                                                  |
| Optimization and dose calculation           | 44 hrs
|                                             | (effective working hours spent by physicist- 12 hrs)                     | Medical Physicist 1 hr verification by second medical physicist
|                                             |                                        | (partially shared time with other activities)                          |
| Plan evaluation                             | 1 hr                                   | Medical Physicist
|                                             |                                        | Radiation Oncologist                                                   |
| Patient specific Quality assurance         | 1.5 hr                                 | 2 medical Physicists                                                   |
| Treatment delivery fraction1               | 1.75 hrs                               | 2 Radiation therapists Medical Physicist
|                                             |                                        | Radiation Oncologist                                                   |
| Treatment Delivery subsequent fractions     | 1.5 hrs                                | 2 Radiation therapists, Medical Physicist
| (5#)and In vivo dosimetry                   |                                        | Radiation Oncologist                                                   |

**Summary of person hours**

| Therapist                           | 21.5 hrs |
|-------------------------------------|----------|
| Medical Physicist                   | 26.75 hrs|
| Radiation Oncologist                | 16.25 hrs|

**In-room time for all fractions**

| 9.25 hrs per patient* |

*This excludes the treatment room preparation time which is about 15 min before each fraction

Table-3: Dose volume parameters achieved in the first 4 patients treated
| Structure          | Parameters | Patient 1 (Gy) | Patient 2 (Gy) | Patient 3 (Gy) | Patient 4 (Gy) | Patient 5 (Gy) |
|-------------------|------------|----------------|----------------|----------------|----------------|----------------|
| CTV Skull         | D98        | 11.96          | 11.79          | 11.62          | 11.93          | 11.88          |
|                   | D2         | 12.59          | 12.89          | 12.98          | 12.68          | 12.56          |
| CTV chest         | D98        | 11.95          | 11.9           | 12.17          | 11.75          | 11.95          |
|                   | D2         | 12.57          | 12.7           | 12.83          | 12.74          | 12.63          |
| CTV Trunk         | D98        | 11.76          | 11.73          | 12.11          | 11.81          | 11.98          |
|                   | D2         | 12.97          | 12.89          | 13.68          | 12.74          | 12.66          |
| CTV Upper limb    | D98        | 12.02          | 10.82          | 10.72          | 11.49          | 11.52          |
|                   | D2         | 13.76          | 13.99          | 13.95          | 12.89          | 13.11          |
| CTV Lower limb    | D98        | 11.77          | 11.81          | 11.73          | 11.9           | 11.45          |
|                   | D2         | 12.57          | 13.02          | 12.7           | 13             | 12.70          |
| **Planning Target Volume** |          |                |                |                |                |                |
| PTV Upper         | D95        | 11.79          | 11.65          | 11.12          | 11.67          | 11.8          |
| PTV Junction      | D95        | 11.22          | 11.44          | 11.05          | 11.42          | 11.43          |
| PTV Lower         | D95        | 11.88          | 12.03          | 11.94          | 11.94          | 11.94          |
| **Organs at risk** |            |                |                |                |                |                |
| Eyes              | D50        | 8.92           | 7.1            | 6              | 4.5            | 9.53           |
| Lens              | D50        | 3.1            | 3.3            | 2.65           | 2.8            | 2.61           |
| Midline mucosa    | D50        | 9              | 10.8           | 10             | 11.58          | 8.76           |
| Lungs             | D50        | 8.15           | 8.75           | 8.4            | 8.45           | 6.99           |
| Heart             | D50        | 8.18           | 9.69           | 7.24           | 7.1            | 8.65           |
| Bowel bag         | D50        | 6.72           | 7.6            | 7.12           | 7.48           | 7.29           |
| Liver             | D50        | 5.31           | 11.7           | 6              | 4.65           | 8.19           |
| Kidneys           | D50        | 6.1            | 9.5            | 5.8            | 8.65           | 7.45           |

Table 4: Mean setup corrections (with standard deviations) in mm
| Site           | Lateral (x)     | Longitudinal (y) | Vertical (z)     |
|---------------|-----------------|------------------|------------------|
| Head and Neck | -0.98 ± 3.68    | -1.9 ± 2.67      | -0.69 ± 2.5      |
| Thorax        | 0.11 ± 3.86     | 0                | 1.32 ± 3.42      |
| Abdomen       | 1.40 ± 3.91     | 0                | 2.26 ± 2.94      |
| Legs          | 0.08 ± 3.99     | -0.4 ± 2.3       | -0.11 ± 2.17     |

Table-5: Patient Specific Quality Assurance results
| Patient | Location   | TPSCalc Dose (cheese) (cGy) | Measured Dose (cheese) (cGy) | Dose difference | % Dose difference |
|---------|------------|-----------------------------|-----------------------------|-----------------|-------------------|
| 1       | Brain      | 164                         | 163.91                      | -0.09           | -0.05             |
|         | Thorax     | 177                         | 177.02                      | 0.02            | 0.01              |
|         | Pelvis     | 191                         | 190.77                      | -0.23           | -0.12             |
|         | Upper leg  | 149                         | 149.34                      | 0.34            | 0.22              |
|         | Lower leg  | 141                         | 141.26                      | 0.26            | 0.18              |
| 2       | Brain      | 165                         | 166.47                      | 1.47            | 0.88              |
|         | Thorax     | 193                         | 193.86                      | 0.86            | 0.44              |
|         | Pelvis     | 205                         | 205.31                      | 0.31            | 0.15              |
|         | Upper leg  | 172                         | 172.54                      | 0.54            | 0.31              |
|         | Lower leg  | 153                         | 153.42                      | 0.42            | 0.27              |
| 3       | Brain      | 162                         | 163.12                      | 1.12            | 0.69              |
|         | Thorax     | 198                         | 198.87                      | 0.87            | 0.44              |
|         | Pelvis     | 201                         | 202.23                      | 1.23            | 0.61              |
|         | Upper leg  | 151                         | 151.33                      | 0.33            | 0.22              |
|         | Lower leg  | 149                         | 149.48                      | 0.48            | 0.32              |
| 4       | Brain      | 164                         | 162.09                      | 1.91            | -1.17             |
|         | Thorax     | 169                         | 168.5                       | 0.5             | -0.30             |
|         | Pelvis     | 174                         | 173.5                       | 0.5             | -0.29             |
|         | Upper leg  | 152                         | 151.69                      | 0.31            | -0.20             |
|         | Lower leg  | 149                         | 148.03                      | 0.97            | -0.66             |
| 5       | Brain      | 166                         | 165.66                      | 0.34            | 0.20              |
|         | Thorax     | 184                         | 182.69                      | 1.31            | 0.712             |
|         | Pelvis     | 191                         | 193.34                      | -2.34           | -1.22             |
|         | Upper leg  | 162                         | 160.27                      | 1.73            | 1.07              |
|         | Lower leg  | 150                         | 149.67                      | 0.33            | 0.22              |
Figure 1
Figure displaying Planning PTV sub volumes
Figure 2

Figure displaying HFS and FFS plan
Figure 3
a: Figure displaying combined plan at the junction  b: Figure displaying the dose profile across the junction after combining HFS and FFS plans

Figure 4
Figure displaying the sequence of pre-treatment imaging and the position of the film on thigh
Figure 5

Figure displaying in-vivo junction dosimetry in a patient.