A Phantom Study on Feasibility of Manual Field-in-Field Clinical Implementation for Total Body Irradiation and Comparison of Midplane Dose with Different Bilateral TBI Techniques

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Abstract

Objective: The aim of this study is to implement a new treatment technique in total body irradiation (TBI) using the manual field-in-field-TBI (MFIF-TBI) technique and dosimetrically verifying its results with respect to compensator-based TBI (CB-TBI) and open field TBI technique. **Materials and Methods:** A rice flour phantom (RFP) was placed on TBI couch with knee bent position at 385 cm source to surface distance. Midplane depth (MPD) was calculated for skull, umbilicus, and calf regions by measuring separations. Three subfields were opened manually for different regions using the multi-leaf collimator and jaws. The treatment Monitor unit (MU) was calculated based on each subfield size. In the CB-TBI technique, Perspex was used as a compensator. Treatment MU was calculated using MPD of umbilicus region and the required compensator thickness was calculated. For open field TBI, treatment MU was calculated using MPD of umbilicus region, and the treatment was executed without placing compensator. The diodes were placed on the surface of RFP to measure the delivered dose and the results were compared. **Results:** The MFIF-TBI results showed that the deviation was within ± 3.0% for the different regions, except for the neck for which the deviation was 8.72%. In the CB-TBI delivery, the dose deviation was ± 3.0% for different regions in the RFP. The open field TBI results showed that the dose deviation was not within the limit ± 10.0%. **Conclusion:** The MFIF-TBI technique can be implemented for TBI treatment as no TPS is required, and laborious process of making a compensator can be avoided while ensuring that the dose uniformity in all the regions within the tolerance limit.

Keywords: Compensator-based total body irradiation, manual field-in-field total body irradiation, open field total body irradiation, total body irradiation

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Introduction

Total body irradiation (TBI) is a specialized form of magna field radiation therapy where a relatively homogeneous dose of radiation is delivered to the entire body as part of a conditioning regimen before hematopoietic stem cell transplant. TBI serves a dual purpose in a conditioning regimen; immunosuppression and cytotoxicity.[1-3] It aims to destroy all malignant cells in the host body, prepare niches in the bone marrow to receive the recipient stem cells and finally suppress the host immunity to prevent the immune system from rejecting the donor stem cells that are being transplanted.[4] The unique advantage of TBI over conditioning regimens based on cytotoxic chemotherapy is that it has better tissue penetration since it is not dependent on either blood supply or hepatic/renal parameters; hence, even sanctuary sites such as central nervous system and testes are not spared.[5-8] The disadvantages associated with TBI are risks associated with acute and late toxicities including second malignancy which contributes to increased morbidity and mortality, need for specialized equipment, and challenging logistics of administration.[9,10] Recent developments have been

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focusing on simplifying treatment delivery, decreasing the risk of toxicity while achieving better efficacy.

The target volume for the TBI treatment is the whole body including the skin, the skin can get an adequate dose using the beam spoiler kept at the distance from the 10–20 cm distance from the patient surface.[11] Many studies were done to achieve homogeneous dose distribution to the whole body.[12-14] TBI treatment can be delivered conventionally with different techniques such as extended source to surface distance (SSD) with anterior to posterior/posterior to anterior (AP/PA) technique and extended SSD with bilateral treatment technique, which can be either compensator-based (CB) TBI or field-in-field (FIF) TBI. The centers which do not have the facility to perform CB TBI or FIF TBI, deliver TBI through an open field. Problem with bilateral TBI technique is inhomogeneous dose distribution due to the varying thickness of the patient from the lateral view. To overcome this inhomogeneous dose distribution, CB bilateral TBI technique and FIF TBI technique was used. The disadvantage of CB TBI is that the treatment time will be more compared to FIF TBI technique due to placing the compensator in the appropriate place, calculating compensator thickness, and binding the compensators. *In vivo* dosimetry is the recommended procedure to check the dose at different regions of the patient during TBI treatment technique. Various *in vivo* dosimeters can be used to measure the dose received at different places in the patient; such as film, TLD chips, Metal–oxide–semiconductor-field-effect-transmitter (MOSFET), and silicon diodes.[15-17]

FIF-TBI treatment planning is done with the help of treatment planning system (TPS). Using the computed tomography (CT) images and the TPS treatment planning will be done with FIF technique. Using computerized FIF technique, homogeneous dose distribution can be achieved within the tolerance limit Different studies have showed that the FIF technique can be successfully employed to achieve homogeneous distribution.[18-20] Many centers do not have high-end treatment machine to plan TBI with Tomotherapy or volumetric-modulated arc therapy (VMAT) treatment technique. The limitation of dose calculation at extended SSD using TPS is also another issue. At our center, we faced these issues. This novel technique of MFIF-TBI will be useful for centers with limited resources. The manual field-in-field TBI (MFIF-TBI) can be implemented using multi-leaf collimator (MLC) and jaws to overcome the TPS dose calculation limitation and to avoid time spent on the calculation of compensator thickness and for binding compensators of different regions for each patient. This study aims to implement a novel treatment approach for TBI using MFIF-TBI technique and its dosimetric results were compared with CB-TBI and open field TBI technique.

Materials and Methods

Measurement setup

The Elekta™ Synergy Platform treatment machine was used for the analysis of midplane dose for different methods used in the bilateral TBI techniques. The rice flour phantom (RFP) was prepared with the rice flour in the form of the human structure. The shape of the different human anatomy was created separately like skull was made using a single bag; the neck was made using another bag; and so on. All parts were then kept together to form the shape of a human body. Figure 1 depicts the photograph of RFP. The phantom was placed in the supine position with bent knees on the motorized treatment couch at the extended SSD of 385 cm from the source. The percentage depth dose (PDD), half value layer, and beam flatness were measured at 385 cm SSD using gantry angle 270°, field size 40 cm × 40 cm, collimator angle 45°, and 6 MV high energy X-ray.[11] While the MFIF TBI measurements were done with gantry angle 270°, field size 40 cm × 40 cm, collimator angle 0° and 6 MV high energy X-ray, the CB-TBI measurements were done with all parameters remaining the same except for the collimator, with a rotation of 45°to achieve a larger field size. However, using collimator angle 45° to create FIF will be very difficult and it cannot be manageable. To avoid this issue, the measurements were taken at 0° collimator angle for MFIF TBI. An acrylic sheet beam spoiler with 1 cm thickness was used between phantom surface and source.

In vivo dosimetry

In vivo dosimetry is necessary to measure the delivered dose to TBI treatment patients.[17,21-23] In this study, we used *in vivo* silicon diodes (ISORAD™ from Sun Nuclear Corporation) to measure the dose. The silicon diode detectors have a diameter of 10 mm with adequate electronic equilibrium to measure the dose. Before each measurement, the *in vivo* diodes were calibrated to measure accurately 1 monitor unit (MU) equal to 1 cGy at 100 cm SSD. Each diode was calibrated separately with gantry angle 0°, collimator angle 0°, 6 MV energy, and 10 cm × 10 cm field size at 98.5 cm SSD. During calibration, 10 cm thickness of polymethyl methacrylate phantom was placed below the diodes to account for backscatter and the diodes were placed perpendicular to the central axis of the beam. The calibration factor for each diode is stored separately in the software system. During the dose measurement, the calibration factor was included by the software for that particular diode.

Manual field-in-field total body irradiation delivery

The RFP was placed on the TBI couch with the knee bent position at 385 cm SSD. The length of the RFP,

Figure 1: The photograph of RFP. RFP: Rice flour phantom

umbilicus (isocenter) to skull, umbilicus (isocenter) to feet end distances were measured. The machine isocenter to umbilicus distance, machine isocenter to RFP Knee distance, machine isocenter to RFP ankle distance and machine isocenter to RFP skull distance were measured. The separation was measured using caliper at different places in the RFP such as skull, umbilicus, and calf. Using the above separation, the midplane depth (MPD) was calculated for skull, umbilicus and calf regions. Figure 2 shows the number of sub-fields used in the MFIF-TBI technique. There are three fields – one primary field and two subfields. The different subfield size was opened for different regions using the MLC and jaws.

To calculate the projected field size at extended SSD 385 cm, the required field size at standard SSD was calculated using the following formula:

$$r_d = r \, x \frac{f + d}{f} \quad (1)$$

where,

r_d is the projected Field size at the extended SSD,

r is the field size at the standard SSD 100 cm,

f is the standard SSD,

d is the distance from isocenter to the patient surface at extended SSD.

The treatment MU was calculated for three different fields using the MPD of skull, calf, and umbilicus. The primary open field for the entire length of the patient and MU was calculated using MPD of skull. The primary field treatment MU (PFT MU) was calculated using the following formula.

$$\text{PFT MU} = \frac{\textit{Priscription Dose / Side}}{\textit{PDD of skull x output}} \quad (2)$$

where,

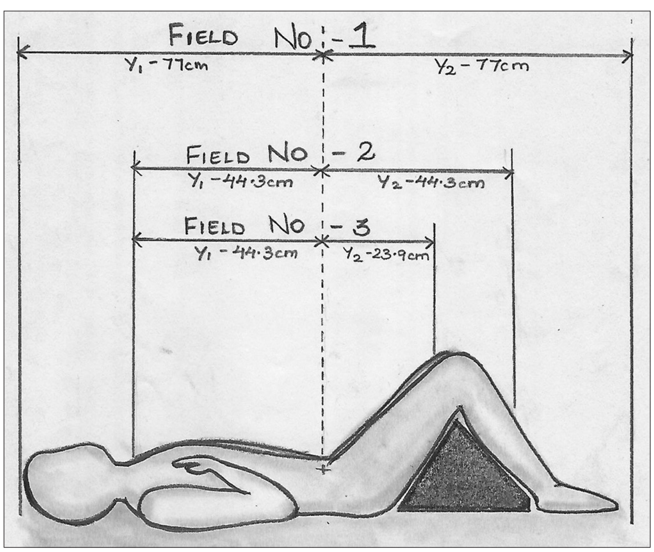

Figure 2: The number of sub-fields used in the MFIF-TBI technique. MFIF-TBI: Manual field in field-Total body irradiation

output is the dose in cGy/MU at the depth of maximum dose for a field size of 40 × 40 cm^2 and PDD is the percentage depth dose at mid-plane depth at the skull level.

The first subfield cranial border starts at lower neck and its caudal border ends at covering full calf region. The field size length of the patient from isocenter (umbilicus) to lower neck distance and isocenter (umbilicus) to the end of the calf region was measured. To project the field size at extended SSD, the standard field size was calculated using the formula (1). The treatment MU for first subfield was calculated using MPD of calf. The first subfield treatment MU (FST MU) was calculated using the following formula.

$$\text{FST MU} = \left(\frac{\textit{Priscription Dose / Side}}{\textit{PDD of calf x output}}\right) - (\text{PFT MU}) \quad (3)$$

where,

PDD is the percentage depth dose at calf depth.

PFT MU is the primary field treatment MU calculated with skull depth.

The second subfield cranial border starts at lower neck and its caudal border ends at the thigh. The field size length of the patient from isocenter (umbilicus) to lower neck distance and isocenter (umbilicus) to end of the thigh region was measured. To project the field size at extended SSD, the standard field size was calculated using the formula (1). The treatment MU for the second subfield was calculated using MPD of umbilicus. The second subfield treatment MU (SST MU) was calculated using the following formula.

$$\text{SST MU} = \left(\frac{\textit{Priscription Dose / Side}}{\textit{PDD of umbilicus x output}}\right) - (\text{PFT MU}) - (\text{FST MU}) \quad (4)$$

where,

PDD is the percentage depth dose at umbilicus depth.

PFT MU is the primary field treatment MU calculated with skull depth.

FST MU is the first subfield treatment MU calculated with calf depth.

The RFP was irradiated with the calculated MU for different field sizes by MFIF-TBI technique. The prescribed dose for this study was 200 cGy in 1 fraction with each side receiving 100 cGy to the midplane of the RFP. The *in vivo* diodes were placed on the surface of different regions of RFP such as skull, umbilicus, thigh, calf, knee, neck, and ankle to measure the irradiated dose at Dmax. Using the measured Dmax dose the midplane dose for different regions was calculated.

To calculate the midplane dose the following formula was used:[24]

$$\text{PDD} = \frac{\textit{Dose at any depth x} 100}{\textit{Dose at Dmax}}$$

This formula was modified as following

$$\text{Dose at any depth} = \frac{PDD\ x\ Dose\ at\ Dmax}{100}$$

Midplane dose of given region

$$= \frac{Dose\ at\ Dmax\ x\ PDD\ of\ the\ given\ region}{100} \quad (5)$$

Using the above formula the midplane dose of different regions was calculated. The calculated midplane dose was compared with the planned midplane dose at different regions. Similarly, the couch was rotated to irradiate opposite side of the RFP with the calculated MU and field size. To show diode measurement accuracy, the same was repeated 5 times and the diode readings were noted. To measure the reproducibility of MFIF measurements using RFP, each rice flour bags were removed and the RFP bags were repositioned and realigned along with diodes, and the measurements was repeated. The entire process was repeated twice.

Compensator-based total body irradiation delivery

The RFP was placed on the TBI couch with the knee bent position at 385 cm SSD. The separation was measured using caliper at different places in the RFP such as skull, neck, umbilicus, calf, chest, knee, shoulder, thigh, and ankle. Using the above separation, the MPD was calculated for all the regions. Using the MPD of the different regions the required Perspex compensator thickness was calculated to compensate the irregular thickness of the patient separation in different regions such as skull, neck, knee, calf, and ankle.[11,25] Calculated compensator thickness was positioned at the appropriate places. Figure 3 shows the CB TBI treatment setup. The treatment MU for CB-TBI was calculated using the MPD of umbilicus region.

$$\text{Treatment MU} = \frac{Priscription\ Dose\ /\ Side}{PDD\ of\ Umbilicus\ x\ output} \quad (6)$$

where,

output is the dose in cGy/MU at depth of Dmax for a field size of 40 cm × 40 cm and PDD is the percentage depth dose at the umbilicus level.

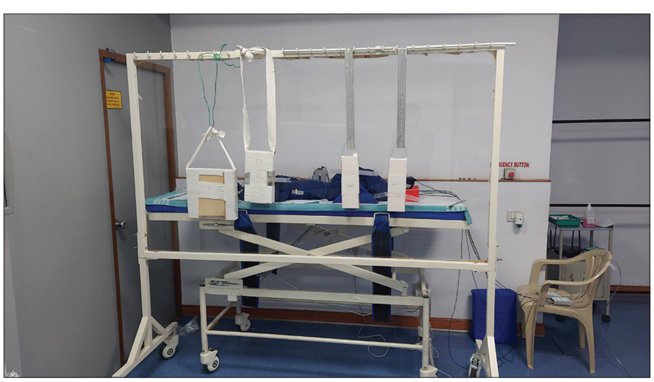

Figure 3: The compensator-based TBI treatment setup. TBI: Total body irradiation

The prescribed dose for CB-TBI study was 200 cGy in 1 fraction. Each side of the RFP was irradiated with the calculated MU for 100 cGy to the midplane of the RFP and the Dmax dose was measured at different regions using *in vivo* diodes. Using the measured Dmax dose, the mid-plane dose for different regions was calculated for CB-TBI technique using the formula (5). The calculated mid-plane dose was compared with the planned mid-plane dose at different region. Similarly, the couch was rotated to irradiate opposite side of the phantom with CB-TBI technique.

Open field total body irradiation delivery

The RFP was placed on the TBI couch with the knee bent position at 385 cm SSD. The separation was measured using caliper at different places in the RFP such as skull, neck, umbilicus, calf, chest, knee, shoulder, thigh, and ankle. Using the above separation, the MPD was calculated for the umbilicus region. Using the MPD of umbilicus region the treatment MU for open field TBI was calculated with the formula (6). The prescribed dose for open field TBI study was 200 cGy in 1 fraction. Each side of the RFP was irradiated with the calculated MU for 100 cGy to the midplane of the RFP and the Dmax dose was measured at different regions using *in vivo* diodes. Using the measured Dmax dose the mid-plane dose for different regions was calculated for open field TBI technique using the formula (5). The calculated mid-plane dose was compared with the planned mid-plane dose for different region. Similarly, the couch was rotated to irradiate opposite side of the phantom with open field TBI technique.

Results

Manual field-in-field total body irradiation results

The length of the RFP with knee bent position, umbilicus (isocenter) to skull, umbilicus (isocenter) to feet end distances were verified with the measured distance. The machine isocenter to umbilicus, machine isocenter to RFP knee, machine isocenter to RFP ankle distance, and machine isocenter to RFP skull distances were verified with the measured distance. Verification of these distances will reduce the positional errors and MLC and jaw accuracy in the MFIF technique. The time taken for RFP position and verification of distance was 6 min for each side. The field sizes of the three subfields of MFIF TBI were measured on RFP at extended SSD and the actual field sizes at standard SSD were calculated using the formula (1). Table 1 shows the standard field size at isocenter and calculated field size (projected field size) at extended SSD. The RFP was irradiated with the calculated MU for different subfields. Table 2 shows the diode measurement and percentage of deviation for MFIF technique. The deviations from the prescribed dose for umbilicus, skull, neck, thigh, knee, calf, and ankle were − 2.22%, −1.64%, +8.72%, −0.28%, −1.26%, −1.85%, −0.99%, respectively, for MFIF TBI. Figure 4 shows the percentage of deviation for different regions of the

RFP in MFIF technique. The total time taken for MFIF TBI delivery was 30 min. The same measurements were repeated five times to show the accuracy of diode measurements. The accuracy of diode measurements was within ±2% deviation. Table 3 shows the accuracy of diode measurement repeated over five times with the MFIF TBI technique. Figure 5 shows the diode measurement uncertainty error bar obtained by repeating the irradiation with MFIF-TBI technique. To measure the uncertainty of the measurement, the RFP was repositioned two times. The percentage of deviation between each repositioning was within ± 2% deviation. Table 4 shows the measurement uncertainty after repositioning of RFP in the MFIF TBI technique. Figure 6 shows the measurement uncertainty error bar obtained by repositioning the RFP in the MFIF-TBI technique.

Compensator-based-total body irradiation results

The initial measurements of RFP were taken and verified similarly to the MFIF-TBI. Verification of these distances will reduce the positional error of compensator placing in the CB-TBI technique. Based on the separation of different regions, the Perspex compensator thickness was calculated.[11] The calculated compensator thickness was placed at the appropriate places. Time taken for this CB-TBI treatment positioning including initial measurements, verification of distance and compensator positioning was 10 min for each side. Table 5 shows the compensator thickness, diode measurement, and percentage of deviation for CB-TBI technique. The deviations from the prescribed dose for umbilicus, skull, neck, thigh, knee, calf, and ankle were -1.86, +1.92, +0.50, +0.09, +1.26, +1.69, -1.32, respectively, for CB-TBI. Figure 4 shows the percentage of deviation for different regions of the RFP in CB-TBI technique. The total time taken for CB-TBI delivery was 45 min.

Open field total body irradiation results

The initial measurements of RFP were taken and verified similarly to the MFIF-TBI. The time taken for open field-TBI treatment positioning including initial measurements, verification of distance, and beam spoiler positioning was 6 min. The treatment MU was calculated using the MPD of umbilicus region. The calculated treatment MU was delivered

Table 1: The standard field size at isocenter and calculated field size (projected field size) at extended source to surface distance

Field number	Field size at isocenter (standard field size at isocenter) (cm)	Field size at extended SSD (projected field size at RFP) $rd = r \times \frac{f+d}{f}$ (cm)	Delivered MUs
1	40×40	154×154	1624
	X1-20.0, x2-20.0	X1-77.0, x2-77.0	
	Y1-20.0, y2-20.0	Y1-77.0, y2-77.0	
2	23×23	88.6×88.6	82
	X1-11.5, x2-11.5	X1-44.3, x2-44.3	
	Y1-11.5, y2-11.5	Y1-44.3, y2-44.3	
3	23×17.7	88.6×68.2	176
	X1-11.5, x2-11.5	X1-44.3, x2-44.3	
	Y1-11.5, y2-6.2	Y1-44.3, y2-23.9	

SSD: Source to surface distance, RFP: Rice flour phantom, MUs: Monitor units

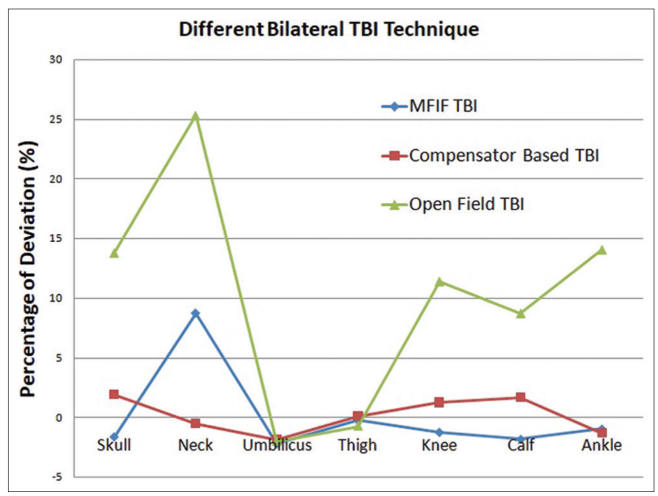

Figure 4: The percentage of deviation for different regions of the RFP with respect to different techniques in bilateral TBI. TBI: Total body irradiation. RFP: Rice flour phantom

Table 2: The diode measurement and percentage of deviation for the manual field in field technique

Prescribed dose at mid-plane region (100 cGy from each side)					
MFIF-TBI technique					
Position	Separation (cm)	PDD (%)	Diode reading MFIF TBI (Dmax dose)	Midplane dose with MFIF D=(Dmax×PDD)/100	Percentage of deviation (%)
Skull	14.7	84.58	116.3	98.36	−1.64
Neck	7.5	93.65	116.1	108.72	+8.72
Umbilicus	24.0	72.97	134.0	97.78	2.22
Thigh	23.1	73.98	134.8	99.72	−0.28
Knee	15.0	84.32	117.1	98.73	−1.26
Calf	18.0	80.52	121.9	98.15	−1.85
Ankle	14.1	85.36	116.0	99.01	−0.99

TBI: Total body irradiation, MFIF-TBI: Manual field in field-TBI, PDD: Percentage depth dose

Table 3: The accuracy of diode measurement repeated over five times with the manual field in field total body irradiation technique

Prescribed dose at midplane region (100 cGy from each side)												
MFIF-TBI technique												
Position	Separation (cm)	PDD (%)	Diode reading MFIF-TBI (Dmax dose) (cGy)					Mid plane dose with MFIF D=(Dmax×PDD)/100 (cGy)				
			Repeat 1	Repeat 2	Repeat 3	Repeat 4	Repeat 5	Repeat 1	Repeat 2	Repeat 3	Repeat 4	Repeat 5
Skull	14.7	84.58	116.3	116.4	116.3	116.2	116.4	98.36	98.37	98.36	98.28	98.45
Neck	7.5	93.65	116.1	116.0	116.2	116.1	116.2	108.72	108.63	108.82	108.72	108.82
Umbilicus	24.0	72.97	134.0	134.2	134.1	134.4	134.0	97.78	97.92	97.85	98.07	97.78
Thigh	23.1	73.98	134.8	134.8	134.9	134.7	134.8	99.72	99.72	99.79	99.65	99.72
Knee	15.0	84.32	117.1	117.1	117.2	117.1	117.0	98.73	98.73	98.82	98.73	98.65
Calf	18.0	80.52	121.9	121.8	121.9	121.9	121.9	98.15	98.07	98.15	98.15	98.15
Ankle	14.1	85.36	116.0	116.2	116.0	116.0	116.1	99.01	99.18	99.01	99.01	99.10

TBI: Total body irradiation, MFIF-TBI: Manual field in field-TBI, PDD: Percentage depth dose

Table 4: The measurement uncertainty after repositioning of rice flour phantom in the manual field in field-total body irradiation technique

Prescribed dose at mid plane region (100 cGy from each side)								
MFIF-TBI technique								
Position	Separation (cm)	PDD (%)	Diode reading MFIF-TBI (Dmax Dose) (cGy)			Mid plane dose with MFIF D=(Dmax×PDD)/100 (cGy)		
			Reposition 1	Reposition 2	Reposition 3	Reposition 1	Reposition 2	Reposition 3
Skull	14.7	84.58	116.3	115.4	113.3	98.36	97.60	95.82
Neck	7.5	93.65	116.1	113.5	117.2	108.72	106.29	109.75
Umbilicus	24.0	72.97	134.0	132.7	135.2	97.78	98.65	99.02
Thigh	23.1	73.98	134.8	132.6	132.5	99.72	98.09	98.02
Knee	15.0	84.32	117.1	116.5	115.4	98.73	98.23	97.30
Calf	18.0	80.52	121.9	119.8	118.8	98.15	96.46	95.65
Ankle	14.1	85.36	116.0	114.2	114.1	99.01	97.48	97.39

TBI: Total body irradiation, MFIF-TBI: Manual field in field-TBI, PDD: Percentage depth dose

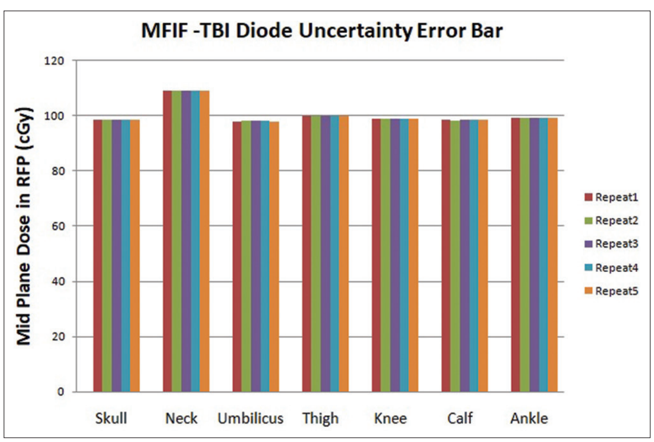

Figure 5: The diode measurement uncertainty error bar obtained by repeating irradiation with MFIF-TBI technique. MFIF-TBI: Manual field-in-field-Total body irradiation

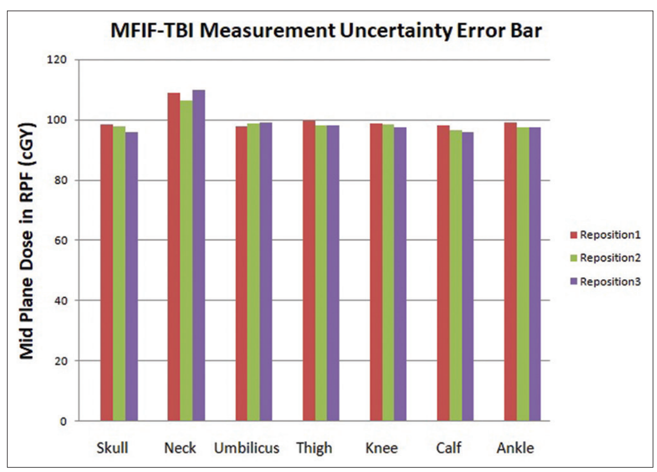

Figure 6: The measurement uncertainty error bar obtained by repositioning the RFP in the MFIF- TBI technique. MFIF-TBI: Manual field in field-Total body irradiation, RFP: Rice flour phantom

only with beam spoiler. Table 6 shows the diode measurement reading for different regions and percentage of deviation for the open field-TBI technique. The deviations from the prescribed dose for umbilicus, skull, neck, thigh, knee, calf, and ankle were −2.01%, +13.76%, +25.30%, −0.72%, +11.38%, +8.7%, +14.04%, respectively, for Open field TBI. Figure 4 shows the percentage of deviation for different regions of the RFP in

Table 5: The compensator thickness, diode measurement and percentage of deviation for calculated based-total body irradiation technique

Prescribed dose at mid plane region (100 cGy from each side)						
CB-TBI technique						
Position	Separation (cm)	PDD (%)	Perspex compensator thickness (cm)	Diode reading with compensator TBI (Dmax dose)	Mid plane dose with compensatorD=(Dmax×PDD)/100	Percentage of deviation (%)
Skull	14.7	84.58	3.6	120.5	101.92	+1.92
Neck	7.5	93.65	5.8	107.7	99.50	−0.50
Umbilicus	24.0	72.97	0.0	134.5	98.14	−1.86
Thigh	23.1	73.98	0.0	135.3	100.09	+0.09
Knee	15.0	84.32	2.0	120.1	101.26	+1.26
Calf	18.0	80.52	2.4	126.3	101.69	+1.69
Ankle	14.1	85.36	3.8	115.6	98.67	−1.32

TBI: Total body irradiation, CB: Calculated based-TBI, PDD: Percentage depth dose

Table 6: The diode measurement reading for different regions and percentage of deviation for open field-total body irradiation technique

Prescribed dose at mid plane region (100 cGy from each side)					
Open field TBI technique					
Position	Separation (cm)	PDD (%)	Diode reading open field TBI (Dmax Dose)	Mid plane dose with open field D=(Dmax×PDD)/100	Percentage of deviation (%)
Skull	14.7	84.58	134.5	113.76	+13.76
Neck	7.5	93.65	133.8	125.30	+25.30
Umbilicus	24.0	72.97	134.3	97.99	−2.01
Thigh	23.1	73.98	134.2	99.28	−0.72
Knee	15.0	84.32	132.1	111.38	+11.38
Calf	18.0	80.52	135.0	108.70	+8.7
Ankle	14.1	85.36	133.6	114.04	+14.04

TBI: Total body irradiation, PDD: Percentage depth dose

open filed-TBI technique. The total time taken for open field TBI delivery was 25 min.

Discussion

TBI plays a major role as a conditioning regimen in stem cell transplantation. The target volume for TBI treatment is the whole body. Due to the field size limitation, the extended SSD treatment was introduced for TBI treatment. Using extended SSD, TBI treatment can be delivered conventionally with AP/PA TBI technique and bilateral TBI technique. Various bilateral TBI techniques were studied and different techniques were implemented using RFP and these were dosimetrically verified.

The patient separation will not be uniform in bilateral TBI treatment from the lateral view. Due to nonuniform separation, dose received in different regions will not be uniform. To deliver a uniform dose to the nonuniform patient body, FIF technique and compensator was used in the recent studies.[18,20] A novel TBI treatment technique with simple and possible method using MFIF-TBI technique was implemented. Some centers have opted for open field TBI technique due to various reasons, one of which can be a the limitation of dose calculation in TPS for extended SSD as seen with Monaco TPS (version 5.51.10). In this study, we have performed the manual FIF-TBI without TPS, CB-TBI, and open-filed TBI. For MFIF-TBI, we calculated the standard field size needed to project the measured field size at extended SSD for different subfields. The treatment MU was calculated based on the separation of different MPD and the treatment was executed. The dose deviation in the different regions was well within acceptable limits using the MFIF-TBI technique. After repositioning the RFP, measurement uncertainty showed the percentage of deviation to be very less when compared with the initial measurements. The overall treatment time for MFIF-TBI was less compared with CB-TBI technique. The CB-TBI was performed after placing the compensator in the appropriate regions.[11] The results showed that the deviation was within the acceptable limit of ± 10% for CB-TBI as per the AAPM report no 17.[21] The advantages of treating MFIF-TBI technique are less patient set up time, calculation of compensator thickness and binding the compensator for each patient can be avoided, placement of compensator in the correct regions, and achieving dose deviation within the limit without TPS. The open field TBI treatment was executed without using compensator and FIF technique. The results were compared with planned dose at plane of the RFP. The percentage of deviation for open field TBI was not within ± 10% for skull, neck, ankle, and knee regions due to variation in separation of the human anatomy in the lateral view. The dose was prescribed to a point in the umbilicus region along the midplane of the body. While the umbilicus region receives 100% dose, it will vary for the other regions according to their separation. Therefore the dose deposited will not be uniform along the length of the body in open field TBI. The percentage of deviation for different regions of the RFP with respect to different technique in bilateral TBI. This study shows that without using TPS and compensators, homogeneous dose can be achieved with the help of MLC and jaw using MFIF-TBI technique.[19]

The disadvantage of this technique is the image verification of patient position. Imaging is not possible with extended SSD-based techniques. The accuracy of dose distribution in various organs and normal structures cannot be determined with this type of treatment technique. The lung shielding is an important part of the extended SSD TBI treatment technique. Whenever lung dose increases beyond the tolerance limit, the lung toxicity will also increase. Pandu *et al*. showed that the lung compensator thickness can be calculated to reduce the lung dose within the tolerance limit.[11] The same lung compensators calculation can be used in MFIF-TBI technique.[11] The dose received by different organs can be known with FIF TBI treatment delivery planned using TPS.[20] The dose distribution can be improved with the help of a TPS using FIF-TBI. Lately, to deliver a homogeneous dose, different techniques were tried to treat the TBI patients. Using VMAT and IMRT technology uniform dose can be achieved and other normal structure doses can also be reduced.[26-28] Limitation of using the standard SSD VMAT technique includes multiple overlapping of arcs, three to four isocenters, long duration of contouring, treatment planning, and treatment delivery (1.5 h or nearly 2 h during the first fraction) when compared with MFIF technique.[28] If the immobilization is not properly used, the patient will move during the treatment due to longer treatment time which will impact the dose distribution. The dose rate used to treat VMAT, IMRT, and tomotherapy technique is high compared to extended SSD Technique. Using low-dose rate for TBI treatment will reduce the serious complication and better patient outcome.[21] The AAPM report no 17 guidelines state that *in vivo* dosimetry is recommended for all the TBI patients to measure the accurate dose delivered. The *in vivo* dosimetry can be performed with MOSFET and diodes.[17,21,29] In this study, we used *in vivo* diodes for accurate dose measurement.

Conclusion

This study concludes that novel MFIF-TBI treatment delivery is an effective method in terms of less treatment time, proper *in vivo* dosimetry, easy to implement, and able to maintain uniform dose distribution under tolerance limit without TPS and compensator. The advantages of this technique are no TPS is required, can avoid the laborious process of making compensators. Furthermore, study results ensured that both the MFIF and CB-TBI method can be implemented for TBI treatment. Using VMAT and IMRT technology, the uniform dose can be achieved and other normal structure doses can also be reduced. The disadvantage of this type of technique includes patient immobilization, field junction between the different isocenters and increase in time taken for contouring, planning, and treatment execution when compared with MFIF technique. The center which does not have the facility to plan patient treatment with TPS can use MFIF-TBI technique as the conditioning regime for stem cell transplant.

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Conflicts of interest

There are no conflicts of interest.

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