Commissioning and Clinical Implementation of Total Skin Electron Irradiation Using a Standard TrueBeam Linear Accelerator

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ABSTRACT

Purpose:
To commission and clinically implement a modified Stanford technique for Total Skin Electron Irradiation (TSEI) using a standard TrueBeam linac, achieving consistent and high-quality skin dose coverage.

Methods:
Commissioning was performed on a TrueBeam linac using a 6 MeV electron beam at a dose rate of 1000 MU/min. A field size of 34 × 34 cm² was used with a phantom (solid water or Rando) positioned at a source-to-surface distance (SSD) of 400 cm behind a 4-mm beam degrader. Optimal dual-gantry angles and field uniformity were determined using Farmer chamber measurements along vertical and horizontal axes at SSD = 400 cm and verified with film dosimetry. Percent depth dose (PDD) curves were measured in solid water using a parallel-plate chamber at gantry angle=270° and at the optimized dual-gantry angles. Absolute dose calibration was performed using both parallel-plate and cylindrical chambers. Total treatment dose was determined using MOSFET dosimeters and a cylindrical phantom, accounting for dose contributions from adjacent dual fields. The B-factor was defined as the ratio of total treatment dose to calibration point dose. An end-to-end test was conducted to validate overall dosimetric accuracy.

Results:
Optimal dual-gantry angles were identified as 254° and 286°, achieving dose uniformity within ±10% over vertical distances from −100cm to 80cm and horizontal distances from −35cm to 35cm. PDD measurements yielded a reference depth (d_ref) of 0.9cm and a depth of maximum dose (d_max) of 0.6cm for both gantry configurations. The calibration point dose for a single dual-fields was 0.0487 cGy/MU at d_max, while the total treatment dose was 0.136 cGy/MU, resulting in a B-factor of 2.79. End-to-end testing with MOSFETs and TLDs confirmed dosimetric accuracy.

Conclusions:
The commissioned modified Stanford technique achieved clinically acceptable dose uniformity and provides a practical and effective TSEI option using a standard TrueBeam linac.

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INTRODUCTION

TSEI is an effective radiotherapy technique for treating malignant skin diseases, particularly mycosis fungoides. The Stanford technique and its variants are the most widely used TSEI approaches and often needs dedicated treatment capabilities, such as high-dose-rate (HDR) electron delivery. This work presents our commissioning experience for TSEI using a standard TrueBeam linear accelerator without using HDR electron mode, demonstrating its implementation for total skin irradiation.

METHODS AND MATERIALS

1. Determination of optimal dual gantry angles: Optimal dual gantry angles result in an acceptable uniform dose distribution across vertical and horizontal axes at the treatment distance of SSD=400cm. A farmer chamber was used to measure radiation signals. The setup is presented in Fig. 1.1 and Fig. 1.2. At optimal dual gantry angles of 254/286, radiation measurements were carried out along horizontal and vertical axis at the treatment distance (SSD=400cm). The measurements were obtained in a step of 10cm from -40cm to 40 cm along horizontal axis and -100cm to 80cm along vertical axis.
2. Cross calibration of parallel plate (pp) ion chamber. The pp chamber was cross-calibrated at 20MeV against the Farmer chamber traceable to ADCL at University of Wisconsin. The cross calibration of the pp chamber allowed us to accurately measure absolute dose in solid water at lower electron energy (<=6MeV).
3. Absolute dose calibration. The calibration point was set at the location of dmax for (a) the dual-field geometry (Gantry=254/286) and (b) Gantry=270 at SSD=400cm. Measurements were performed using the Markus pp chamber and solid water slabs. Percent depth ionization (PDI) was measured from surface to depth=1.4cm with reasonable spatial resolutions in between. The reference depth, dref, was determined to be 0.9cm from I50 (from PDI) and R50 formula.
4. Second check of absolute dose calibration using a farmer chamber. Farmer chamber was used to measure the absolute dose at the gantry pair (254/286) in solid water at treatment setup. Farmer chamber-based measurement served as a second check on the measurements from PP chamber. The dose calibration from PP ion chamber measurements were used for MU calculations in clinical plans.
5. The dose calibration determined in Section 3 was obtained from dose delivered from one dual-field. In actual treatment setup, dose at a particular location receives additional radiation contribution from adjacent dual-fields. The adjacent dual-field's contributions were determined using MOSFET dosimeters and a CT cylindrical phantom (Fig. 5.1). Two kinds of geometry were used. In the first kind of geometry, three dual-fields were delivered. In addition to the primary dual-field, two nearby dual fields were directed toward the CT phantom +/- 60 degrees away from the primary dual-field (which coincides with Z direction). In the second kind of geometry, four dual-fields were delivered. Two dual-fields were directed to the CT phantom +/-30 degrees away from the primary direction (Z direction). The remaining two dual-fields were directed to the CT phantom +/-90 degrees away from the primary direction (Z direction).
6. End-to-End (E2E) test using MOSFETs and TLDs. Rando was irradiated under treatment setup (SSD=400cm, Gantry angles were 254 and 286). 1000MUs were delivered for each single field. Rando was irradiated at the primary orientation facing toward the isocenter, followed by two irradiations where Rando was rotated +60 and -60 degrees relative to the primary orientation. MOSFETs were placed along the central line on the surface of the Rando at head (piece #2), neck (piece #9), chest (piece #14), abdo (piece #24), and pelvis (piece #31). See Fig. 6.1. For TLD measurements, the setup and procedures were the same as that for MOSFET measurements, except TLDs (from ADCL at University of Wisconsin) were used as dosimeters. 1000MUs were delivered for each single field.

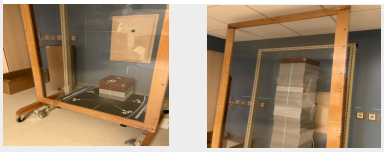


Fig. 1.1 and 1.2 ; the setup for determining optimal dual gantry angles

RESULTS

1. Determination of optimal dual gantry angles. Measurements were obtained at the center (X=0, Y=0) and at the extreme locations (Y=80cm and/or -80cm) for 5 dual gantry angle pairs. The results from Fig. 1.3 showed that a gantry angle pair of 254 and 286 yielded minimal radiation signal differences from Y=80cm to Y=-80cm. The measurements (Fig. 1.4) were obtained in a step of 10cm from -40cm to 40 cm along horizontal axis and -100cm to 80cm along vertical axis. The results indicated that radiation signals were within 8% from X =-30cm to 30cm and from Y=-100cm to 80cm at the gantry angle pair 254 and 286.

SSD=400cm

SSD=100						
X (cm)	Y (cm)	Z (cm)	G251 (nC)	G269 (nC)	G251 and G269 (nC)	
0	0	300	2.037	2.058	4.095	0
0	-40	300	0.1871	3.343	3.5301	0.365452
0	80	300			0	-1
X (cm)	Y (cm)	Z (cm)	G252 (nC)	G286 (nC)	G252 and G286 (nC)	
0	0	300	2.286	2.319	4.607	0
0	-40	300	0.2213	5.428	5.6473	0.225809
0	80	300			0	-1
X (cm)	Y (cm)	Z (cm)	G253 (nC)	G287 (nC)	G253 and G287 (nC)	
0	0	300	2.574	2.596	5.17	0
0	-40	300	0.2634	5.492	5.7554	0.11323
0	80	300			0	-1
X (cm)	Y (cm)	Z (cm)	G254 (nC)	G286 (nC)	G254 and G286 (nC)	
0	0	300	2.82	2.848	5.668	0
0	-40	300	0.374	5.541	5.855	0.032992
0	80	300	5.428	0.3404	5.7684	0.017713
X (cm)	Y (cm)	Z (cm)	G255 (nC)	G285 (nC)	G255 and G285 (nC)	
0	0	300	3.063	3.129	6.212	0
0	-40	300	5.562	0.375	5.937	-0.04427
0	80	300	5.452	0.4023	5.8543	-0.05758

SSD=400cm

SSD=100						
position	X (cm)	Y (cm)	Z (cm)	G254 (nC)	G286 (nC)	G254 and G286 (nC)
1	0	0	300	2.820	2.848	5.668
2	0	-40	300	0.374	5.541	5.855
3	0	80	300	5.428	0.3404	5.7684
4	-30	0	300	2.642	2.704	5.346
5	40	0	300	2.479	2.527	5.006
6	10	0	300	2.813	2.881	5.694
7	20	0	300	2.758	2.822	5.58
8	-10	0	300	2.773	2.792	5.565
9	-20	0	300	2.701	2.722	5.423
10	-30	0	300	2.633	2.643	5.276
11	-40	0	300	2.464	2.447	4.911
12	0	10	300	3.356	2.320	5.676
13	0	20	300	3.892	1.814	5.706
14	0	30	300	4.316	1.426	5.742
15	0	40	300	4.890	1.079	5.769
16	0	50	300	5.208	0.829	6.037
17	0	60	300	5.358	0.633	5.9177
18	0	70	300	5.358	0.455	5.8133
19	0	-10	300	2.330	3.369	5.699
20	0	-20	300	1.667	3.856	5.523
21	0	-30	300	1.435	4.341	5.776
22	0	-40	300	1.096	4.738	5.834
23	0	-50	300	0.8148	5.024	5.8388
24	0	-60	300	0.5749	5.369	5.9429
25	0	-70	300	0.4258	5.464	5.8898
26	0	-80	300	0.314	5.541	5.855
27	0	-90	300	0.2314	5.536	5.7674
28	0	-100	300	0.1638	5.177	5.3408

Fig. 1.3 and 1.4: radiation uniformity measurements at dual gantry angles of 254 and 286

2. Cross calibration of parallel plate chamber: the cross-calibration value: $k_{ecal} N_{D,W}^{C060} = 13.879 \times 10^9 Gy/C$

3. Absolute dose calibration. The absolute dose calibrations were slightly different between the dual-field geometry (G=254/286) and the single gantry geometry (G=270). We used the dose calibration from the dual-field geometry. Dose/MU at dref=0.04625cGy/MU. Dose/MU at dmax=0.04871cGy/MU, calculated from PDD.

4. 2nd check of the absolute dose calibration using a farmer chamber. The measured absolute dose was 0.0474cGy/MU at dref. The measured absolute dose from pp chamber was 0.04625cGy/MU at dref. They agreed within 2.4%. The dose calibration from pp chamber, not from the farmer chamber, was used for commissioning and clinical treatment..

5. Determination of cGy/MU at treatment setup: The final dose rate (cGy/MU) at dmax=0.6cm was 0.1362cGy/MU. See Fig. 5.1. This was obtained by averaging the measurements from two kinds of geometry.

Fig. 5.1 the phantom usede to determine cGy/MU at treatment seeup.

6. End-to-End (E2E) test using MOSFETs and TLDs:

expected dose (cGy)	136.2				
	head	neck	chest	abdo	pelvis
MOSFET (cGy)	135.4	141.9	137.3	140.7	134.6
MOSFET % diff	-0.6	4.2	0.8	3.3	-1.2
TLD (cGy)	136.8	135.5	137.8	138.8	133.4
TLD % diff	0.4	-0.5	1.2	1.9	-2.1

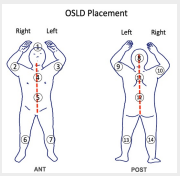
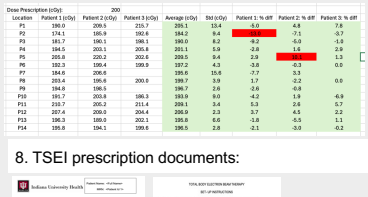


Fig. 7.1 TLD measurement locations

Fig. 6.1 dosimeter locations for E2E test

7. In vivo TLD measurement results. All measurement were within 10% except P2 for patient 1 and P5 for patient 2. This was likely due to uncertainty in patient standing position. P7 and P9 were excluded due to TLD misplacement during treatment.



8. TSEI prescription documents:

CONCLUSIONS

The commissioned modified Stanford technique achieved clinically acceptable dose uniformity and provides a practical and effective TSEI option using a standard TrueBeam linac.

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