

Evaluation of Dose Distribution in Optimized Stanford Total Skin Electron Therapy (TSET) Technique in Rando Anthropomorphic Phantom using EBT3 Gafchromatic Films

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ABSTRACT

Background: The Total Skin Electron Therapy (TSET) targets the whole of skin using 6 to 10 MeV electrons in large field size and large Source to Surface Distance (SSD). Treatment in sleeping position leads to a better distribution of dose and patient comfort.

Objective: This study aims to investigate the uniformity of absorbed dose in the sleeping Stanford technique on the Rando phantom using dosimetry.

Material and Methods: It is an experimental study which was performed using 6 MeV electron irradiation produced by Varian accelerator in the AP and PA positions with gantry angles of 318/3, 0 and 41/5 degrees, and RAO, LAO, RPO and LPO with 291/4 gantry angle and 45 degrees of collimator angle in the sleeping position.

Results: The results show that the dose uniformity achieved in this technique is in the range of $(100 \pm 25\%)$ and, the dose accuracy was 6%.

Conclusion: Total Skin Electron Therapy (TSET) technique in sleeping position is very suitable for elderly and disabled patients, and meets the required dose uniformity. Furthermore, the use of a flattening filter is recommended for the more dose distribution uniformity.

Keywords

TSET; Film Dosimeters; Phantom; Dosage Radiotherapy

Introduction

Non-Hodgkin's lymphoma accounts for 5% of cancers. Cutaneous Lymphoma (CTCL) is 19% of Non-Hodgkin's Lymphoma [1, 2]. The most common cutaneous lymphoma is mycosis fungoid with prevalence of 38% [3-5]. Besides, the Total Skin Electron Therapy (TSET) was initiated in 1950 for the treatment of T-cell skin lymphoma (CTCL), Kaposi's sarcoma, inflammation of breast cancer and scleroderma [6, 7]. 90% of people at the early stages of mycosis fungoid disease (MF) were recovered totally by TSET, while this cannot be achieved with chemotherapy and other methods [8, 9]. TSET targets the entire skin and acts at a depth of several millimeters using 6 -10

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MeV electrons with large field size and large SSD in order to provide a uniform dose to the total skin surface.

The first application of ionizing radiation in the treatment of mycosis fungoid was made by Scholts in 1902 [10]. By this method, the treatment of the entire skin was difficult due to geometric constraints such as large field size and field junctions [11]. In 1939, Summerville suggested an X-ray bath for the treatment, but this treatment was rejected because of the bone marrow suppression side effects [12] and thus, the use of X-rays has been limited in the treatment of non-Hodgkin's lymphoma [2, 11]. In addition, other treatments reduce the symptoms of the disease, but do not prevent the spread of the disease under the skin [13, 14]. One of the most effective treatment methods is the use of electrons in radiation therapy [2, 11]. Electrons are preferred to other ionizing radiation because of their sharp dose falloff on the surface. For this reason, local skin lesions, up to about 1 cm depth, can be treated with electrons by maintaining healthy organs [15].

The main aims of TSET are dose delivery to whole skin with high uniformity ($\pm 10\%$) and minimum dose to other organs [11, 16, 17]. X-ray contamination in the TSET should be 1 -4% of the maximum electron dose received on the body surface [18]. It should be noted that because of the differences in the curvature of the body surface and the unusual anatomy of some patients, there are some problems in prescribed dose delivery without having overdose and underdose areas. So the goal of uniform dose distribution cannot be easily achieved [17, 19]. According to the American Association Physics Medical, the uniformity of the field in the vertical direction should not be more than 8% in a field with dimensions of approximately 200 cm long in 80 cm wide, and the horizontal uniformity of the patient should not be more than 4% in the treatment area with dimensions of 160×160 cm² [19, 20]. Although the patient dose is expected to be less homogeneous and 15% dose

uniformity was reported on the skin surface of the patients [19]. TSET is a part of external beam radiotherapy, and there are various methods for its implementation in the clinic, which are performed at each center depending on the equipment, facilities, staff training and patients' conditions [15, 17].

For example, at one of the TSET techniques, anterior, posterior, and each sides of the patient are irradiated called the four field technique [21]. However, TSET dose are typically given using the Stanford six dual-field method or the Mc Jill rotation technique. Most centers prefer the Stanford technique [7]. The Stanford six dual-field method was defined by Karzmark at Stanford University in 1970 [22], which the patient stands in 6 positions of anterior posterior (AP), posterior anterior (PA), right posterior oblique (RPO), left posterior oblique (LPO), right anterior oblique (RAO) and left anterior oblique (LAO) with 60 degrees' rotation relative to each other [4, 6, 7, 9, 11, 23]. The dual electron fields are given with a symmetric angle about ± 20 degrees from the horizontal plate to the patient's head and the other to the foot in a large SSD (greater than 300 cm) to produce large and uniform fields [6, 7].

Over the years, various modifications have been made in the configuration of TSET techniques to improve the uniformity and homogeneity of skin dose distribution, which is the goal of this treatment. These modifications include the use of a beam spoiler or disperser, a flattening filter and a sleeping position for weak patients in a standing technique [17]. Because in Stanford and Mcjill techniques, patients need to stand for 10 to 30 minutes during treatment, and this is difficult for patients who are weak or elderly, the six-field sleeping technique was recommended by Wu et al. for those patients, who cannot stand safely and properly in a given position for a long time during radiation. In addition, according to studies, the sleeping technique leads to the vertex of scalp and foots receive adequate and uniform dose

without additional boost. It should be noted that in the sleeping position, the pressure of the patient weight is also reduced and patients do not suffer from pain in their arms, which affects the patient's positioning and is an important advantage for patients, who need TSET [20]. Therefore, there is a need for designing the technique that does not have Stanford's standing position problems and the patient is treated as lying on the floor (modified Stanford in lying on the floor).

Considering the features of this kind of treatment, the importance of complete dosimetry under clinical conditions is clear. However, due to the unusual body form, which makes the non-uniform dose distribution on the skin surface leading considering TSET technique as a complicated and difficult technique, various tools and equipment were needed for dosimetry measurements.

According to the studies, great clinical centers in the world are currently treating patients with TSET techniques, but in Iran, despite the interest of specialist oncologists, TSET has not been performed until now due to dosimetric problems, lack of facilities and equipment for delivering correct and uniform dose to patient and problems in implementation of the technique. It is hoped with this study, TSET will be done in Iranian clinical centers, as in other countries.

Material and Methods

This experimental study was conducted in the radiotherapy department of Cancer Institute of Imam Khomeini Hospital in Tehran during 1395-1396. In this study, an electron with 6 MeV energy was used to irradiate the Rando anthropomorphic phantom dedicated to total body irradiations [24]. Since direct dose measurement is not feasible in patients treated, most data related to dose distribution are obtained through measurements in tissue equivalent phantoms. To measure some of the basic parameters such as percent depth dose and dose rate, cube water homogeneous

phantom with $50 \times 50 \times 50$ cm³ dimensions was used. Moreover, in this study, RW3 slab phantom layers with different thicknesses of 1, 2, 5 and 10 mm were used. These layers are water equivalent, and used to determine the buildup dose, film calibration, and percent depth dose (PDD). In addition, two cylindrical phantoms with a diameter of 30 cm and a height of 10 cm made of polyethylene were used to simulate the head and feet of the human body for the first measurement in a homogeneous environment. The dosimetry of this study was done by EBT3 Gafchromic films.

EBT3 Film calibration

22 film pieces, which were in 5×5 cm² size in 11 different dose levels, including 5, 8, 11, 25, 33, 50, 75, 100, 125, 150, 170 cGy, were irradiated with 2100 C/D Varian accelerator in electron mode with 6 MeV energy and dose rate of 300 MU/min at a 0-degree gantry angle in TSET clinical condition (40×40 cm² field size and SSD = 206.5 cm). Film calibration was performed in the presence of a beam spoiler made of Plexiglas in 1220×1830 mm² diameters with 5 mm thickness located at 6.5 cm from the slab phantom surface [25].

Percent Depth Dose (PDD)

In this study, the PDD was measured using 0.055 cc PTW-Freiburg Markus parallel plate chamber. The Markus chamber was irradiated with a Varian accelerator with a 6 MeV electron in TSET condition. By adding 1 and 2 mm layers, the chamber readings were obtained at different depths from surface to 24 cm depth, and the dose changes with depth were measured [25]. The most probable energy $E_{p,0}$ and the mean energy \bar{E}_0 were obtained using following equations:

$$E_{p,0} = C_1 + C_2 Rp + C_3 Rp^2 \quad (1)$$

$$\bar{E}_0 = c_4 R_{50} \quad (2)$$

Photon contamination

The PDD curve was used to measure the photon contamination and the single-field

photon contamination was obtained using the following equation:

$$\gamma_{1-field} = \frac{D(d=5)}{D(d=0)} \quad (3)$$

Since the surface dose is the same for each of the 6 therapeutic fields in the normal incidence, that is $D_{AP}(d=0) = D_{Oblique}(d=0)$, thus the cumulative photon contamination $\gamma_{6-field}$ was determined as follows:

$$\gamma_{6-field} = \frac{\sum Fields \gamma_{1-field}}{Body\ factor} \quad (4)$$

Patient setup and output calibration

Output changes with field size dimensions vary from one accelerator to the other. Therefore, for any electron energy and any applicator with any field size, the output must be measured. The output for an applicator with usually 10×10 cm² field size is considered as standard and the other fields are measured against it. Since the 6-field Stanford technique has been used in this study, thus the output was measured in TSET conditions at each AP and oblique set up, separately. The Marcus ion chamber was placed on the surface of the slab layer phantom and irradiated with Varian accelerator in 40×40 cm² with a 6 MeV electron (at 0 degree gantry angle and 0 degree colli-

mator angle in SSD = 206.5 cm, 318.5° gantry angle and 0 collimator angle in SSD = 95 cm, 42.5° gantry angle and 0 collimator angle in SSD = 95 cm). (Figure 1). The beam spoiler was placed at a distance of 6.5 cm from the surface of the slab phantom. The output measurements in the oblique position were performed at the same condition with 291.4° gantry angle and 45° collimator angle in SSD = 238.5 cm. The spoiler was placed at 5 cm from the slab phantom.

Absorbed dose uniformity

Twelve EBT3 films were clamped on the surface of Rando phantom at umbilical region (the dose prescription point), the left and right lateral relative to the umbilicus on the transverse axis, vertex of scalp, forehead, sternum, axillary area, iliac crest, knees and ankles. The films were irradiated in TSET condition as AP, and anterior and posterior oblique of the right and left. Since the umbilicus is the dose prescription point according to the protocol, thus the dose uniformity of the other points relative to the umbilicus was examined according to the equation 5:

$$\text{Homogeneity Percent} = \frac{D_{point} - D_{umbilicus}}{D_{umbilicus}} \times 100 \quad (5)$$

In this regard, the D_{point} is the dose of the

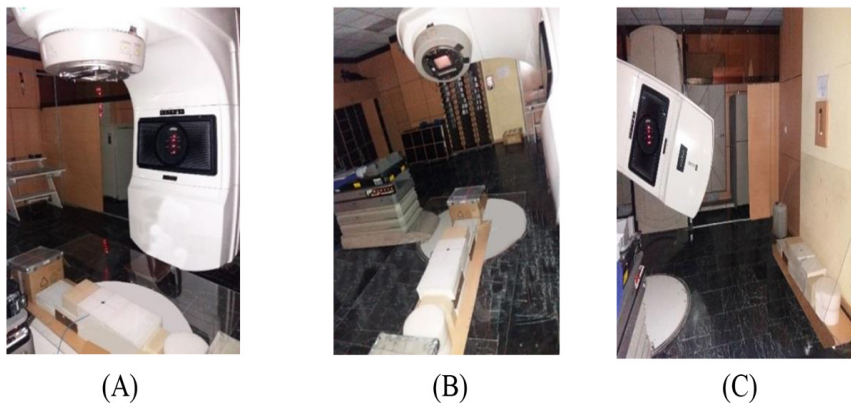


Figure 1: Total Skin Electron Therapy (TSET), sleeping Stanford technique. (A) Anterior Posterior (AP) treatment set up with 0° gantry and collimator angle. (B) AP with 318.5° gantry angle and 0° collimator angle. (C) Oblique with 291.4° gantry angle and 45° collimator angle.

study point and $D_{\text{umbilicus}}$ is the received dose at the umbilicus surface [15, 26].

Dose Accuracy

Since there is no standard therapeutic technique in TSET and the radiation conditions and treatment setup varies from center to center, thus the dose distribution is also different. The best way is the use of a point as the reference point and considering the upper and lower limit for other point's dose and limit organ at risk dose. In this study, a prescriptive dose was delivered to the umbilicus surface in six fractions similar to other studies and equal to 1 Gy. The upper and lower limit for other points was considered $\pm 10\%$ of prescribed dose.

A. Measurement

In order to determine the dose delivery accuracy, the Rando anthropomorphic phantom and EBT3 radiochromic films were used. A single film was placed on the isocenter of the umbilicus surface, and the dose delivered to the umbilicus surface was measured after irradiation in AP and left and right posterior oblique (for the same dose level).

B. Dose Calculation

The dose that should be given in a single AP field or oblique field was calculated using the following relationship:

$$\sum_{6 \text{ position}} \text{Dose position} = \text{Dose AP position} \times \text{Body Factor} \quad (6)$$

According to this equation, the total dose is equal to the product of the single AP or oblique field dose by the body factor [19]. Body factor is a factor that correlates the reference dose to the dose from total 6 therapeutic fields at a suitable gantry angle. The body factor is applied where different therapeutic fields were overlapped together and each point on the surface receives dose from more than one field [27]. In this study, the body factor was measured experimentally.

C) Comparison of measured and calculated dose

The dose accuracy was determined from the equation 7 as:

$$\text{Accuracy} = \frac{\text{Calculated Dose} - \text{Measured Dose}}{\text{Measured Dose}} \times 100 \quad (7)$$

Results

The EBT3 film calibration curve

The pixel value for each film was obtained using the ImageJ software after scanning the films 48 hours from the irradiation and fixing the changes on the film. Since the EBT3 film response at 0-10 Gy is appropriate in the red channel, the analysis was done in the red channel. Figure 2 shows the calibration curve as a function of the dose. It is observed that by increasing the dose, the optical density also

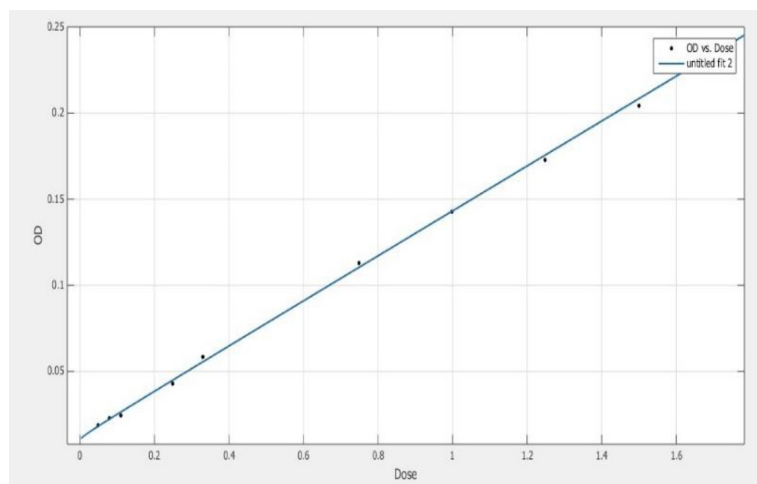


Figure 2: The best curve fitted on the EBT3 film data in MATLAB.

increased.

By applying Levenberg-Marquardt algorithm [28] with the formula of $D_{fit} = b.net OD + c.net OD^n$ on calibrating curve in Figure 2, the results of fitting curves were as following:

$$f(x)=(0.0113 \times x^{0.0469})+(0.1300 \times x) \quad (8)$$

Where the matching parameters b and c are 0.1300 and 0.0113. Also the power of nonlinear word (n), and the regression coefficient in the curve function matching to the EBT3 film data acquired as 0.04697 and 0.9989 respectively.

Results of basic parameters measurement

Results of Percentage Depth Dose (PDD) measurements using a parallel plate chamber

The results of direct PDD measurements in TSET conditions using a Marcos parallel plate chamber were plotted in the form of a PDD curve using MATLAB. The buildup dose depth was obtained equal to 7 mm. The results of the measurement show that the surface dose is 87.52% of the maximum depth dose (buildup dose). Furthermore, the practical range is 2.2 cm and therefore the most probable energy equivalent to 4.37 MeV, R50 is 1.7 cm and the

mean energy is 3.961 MeV. The percentage of depth dose curve is shown in Figure 3.

Results of photon contamination measurement

The single-field and total photon contamination were obtained 1.12 and 2.18, respectively.

The results of the accelerator output calibration using Marcus parallel plate chamber

The electrometer reading values and the dose in MU = 50 and dose rate = 300 MU/min for the AP and oblique positions are presented in Table 1.

The results of the dose uniformity of total body with Rando anthropomorphic phantom

The results of dose uniformity are presented in Table 2. It can be seen that achieved dose uniformity was within the range of $100 \pm 25\%$ by considering the umbilicus as the reference point.

The results of the dose accuracy

The results of the measurements showed that the absorbed dose at the umbilicus level is equal to 1.06 Gy. Therefore, dose accuracy was 6%.

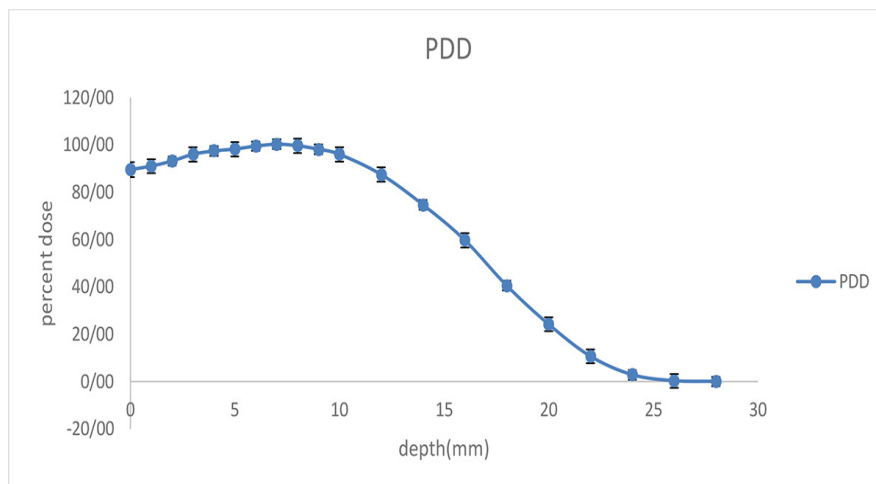


Figure 3: The 6 MeV Percentage Depth Dose (PDD) curve in Total Skin Electron Therapy (TSET) conditions by Marcus ion chamber.

Table 1: Chambers readings values (Pico colon) and absorbed dose (cGy) in the irradiation of Anterior Posterior (AP) and oblique techniques.

Absorbed dose (cGy)	Chamber reading (pc)	Correction (P,T) factor	Pressure (hPa)	Temperature	SSD (cm)	Collimator angle	Gantry angle
8.76	59.5	2.162	876	22	206.5	0°	AP 0°
6.95	47.2	2.162	876	22	95	0°	AP 318.5°
6.95	47.2	2.162	876	22	95	0°	AP 42.5°
2.03	13.8	2.162	876	22	238.5	45°	Oblique 291.4°

SSD: Source to Surface Distance, AP: Anterior Posterior

Table 2: Average surface dose of different areas of the Rando phantom in the Total Skin Electron Therapy (TSET) technique irradiation.

Normalized dose (%) in Oblique technique (cGy)	Normalized dose (%) in AP technique (cGy)	Area name on the Rando phantom
100±12	100±8	umbilicus (dose prescription point)
70±5	85±4	Right and left laterals relative to umbilicus
110±10	125±6	sternum
85±4	75±4	forehead
60±6	55±5	Right and left axillary
33±9	30±12	Scalp of vertex
105±4	96±10	knees
38±8	45±8	pelvis
6±4	5±3	foot

AP: Anterior Posterior

Discussion

Dosimetry at large distances and large field size that is important for the implementation of the TSET techniques is difficult and has its own problems. Therefore, most institutions and centers try to use measured data in standard conditions of SSD = 100 cm instead of direct measurement of some of the basic parameters of TSET (such as field size and large SSD), and attempt to obtain the information and required data in TSET through computational formulas. In general, it can be said that there is no theoretical agreement on a variety of dosimetric methods for TSET techniques whether the measured data in TSET conditions should be used or computational data. There-

fore, each institution has its own method.

Measuring the buildup dose was performed by Reynard in 2008 with 6 MeV electron and flattening filter placed at the head of 21EX LINAC accelerator at 380 cm SSD and 40 cm × 40 cm field size [29]. According to his report, buildup depth was 9 mm. The differences in our study with Reynard can be explained because of the difference in SSD and type of accelerator used and also implementation an extra flattening filter. The maximum depth calculated by Platoni in 2012 with a 6 MeV electron of Varian 2100C in 380 cm SSD and field size of 36 × 36 cm² was obtained as 7 mm [30]. The results of our study are similar to Platoni.

Furthermore, the results of the Platoni study, which was carried out in 2012 in TSET condition for 6 MeV electrons, estimated $R_{50} = 1.5$ cm and $R_p = 2.1$ cm and $E_{p,0} = 4.4$ MeV and $E_0 = 3.4$ MeV [28]; thus, increasing distance and reducing the size of the field have caused the values of R_{50} and R_p to decrease compared to our study. Therefore, the effect of SSD was dominant over field size. In the study of Zhe Chen in 2004, the values of $R_p = 2.3$ cm, $E_{p,0} = 4.5$ MeV, $\bar{E}_0 = 3.98$ MeV in SSD of 380 cm and 36×36 cm² field size were obtained for 6 MeV electron [16]. In 2008, Reynard also obtained values of $R_{50} = 1.8$ cm, $R_p = 2.8$ cm, $E_{p,0} = 5.56$ MeV and $\bar{E}_0 = 4.19$ MeV in the TSET technique with 6 MeV electron [29]. The results of this study are closer to Platoni and Zhe Chen. The difference in SSD, type of accelerator and flattening filter were caused difference with Reynard study.

The single-photon field contamination and the total photon contamination were 1.12 and 2.18, respectively. Since the rate of photon contamination should be about 1-4% of the average total dose received by d_{max} [18], the photon contamination of this study is acceptable. The rate of photon contamination in the Platoni study was 2.1% and in the Deufel study was 1.13% [19, 30]. The results of our study are in good agreement with Deufel and Platoni, and this is quite logical because photon contamination depends on the energy of the beam.

In most standard radiotherapy centers, a prescriptive dose (single number) can easily be used due to the uniform distribution of the dose. Since, TSET does not have a standard technique and the conditions and treatment setups vary from center to center, the dose distribution is also different. It is impossible to achieve a completely uniform dose distribution during total body irradiation. Our results indicated a dose uniformity of $100 \pm 25\%$ in AP and oblique techniques.

Absorbed doses in the vertex of the scalp and forehead regions are less than the absorbed

dose at the umbilicus point due to the distance from the central axis of the beam and the radiation attenuation. The axillary areas received less absorption dose due to its lateral positioning relative to the dose prescription point and the distance from the central axis. The right and left sides are located in the lateral position relative to the umbilicus. Therefore, the assessment of these area's dose is important. Because of their higher thickness, these two areas receive less absorption dose than the umbilical region, while the proximity to the central axis of the beam increases their absorption dose. Eventually, the absorbed dose in these areas is in acceptable range. Besides, the perineal, right, and left iliac crest areas, due to the increased tissue thickness, require fewer doses. The absorption dose in the lower limbs on the ankle region is relatively low due to the distance from the central axis of radiation, but the total absorption dose of the various parts of the lower limb is within acceptable limits. Therefore, the non-uniformity of dose distribution occurs frequently in some areas of the body such as the head, arms, and legs and the dose distribution in the trunk, pelvis, chest and abdomen is almost uniform. The areas of the body, such as the head, palm and leg, perine and axillary area receive fewer doses, thus additional field (boost) is used for these areas. According to the various studies, the level of dose uniformity at the phantom surface was obtained $\pm 4\%$ to $\pm 10\%$ [31-33]. When the flattening filter is installed on the head of the accelerator in addition to the electron TBI applicator and the beam spoiler is located near the phantom surface, the best uniformity is achieved. Platoni achieved 2% dose uniformity in the longitudinal axis and 4% in the transverse axis [30]. Dufel reported uniformity in accordance with the standard AAPM protocol, $\pm 8\%$ vertical uniformity and $\pm 4\%$ horizontal uniformity at the center of the treatment area with dimensions 160×160 cm² [19]. Fuzz and Suzuki designed a modified Stanford technique to achieve skin dose uniformity and ob-

tained uniformity of less than 11% [34]. The difference in the dose uniformity in our study in comparison to other studies can be due to flattening filter. However, in other studies, the flattening filter was used, the flattening filter has not been used in the present study. Evaluation the accuracy of dose delivery indicates that the dose accuracy is $\pm 6\%$, which can be attributed to errors in the device output, contour change error, setup error, and error in using dosimeters.

Conclusion

It can be concluded that TSET technique in sleeping position is very suitable for elderly and disabled patients, and meets the required dose uniformity. Furthermore, the use of a flattening filter is recommended for the more dose distribution uniformity.

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Conflict of Interest

None

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