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Original Research Article

In-vivo dosimetric analysis in total skin electron beam therapy

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ABSTRACT

Background and purpose: Thermoluminescent dosimetry (TLD) is an important element of total skin electron beam therapy (TSEBT). In this study, we compare radiation dose distributions to provide data for dose variation across anatomic sites.

Materials and methods: Retrospectively collected data on 85 patients with cutaneous lymphoma or leukemia underwent TSEBT were reviewed. Patients were irradiated on two linear accelerators, in one of two positions (standing, n = 77; reclined, n = 8) and 1830 in vivo TLD measurements were obtained for various locations on 76 patients.

Results: The TLD results showed that the two TSEBT techniques were dosimetrically heterogeneous. At several sites, the dose administered correlated with height, weight, and gender. After the first TLD measurement, fourteen patients (18%) required MU modification, with a mean 10% reduction (range, −25 to +35). Individual TLD results allowed us to customize the boost treatment for each patient. For patients who were evaluated in the standing position, the most common underdosed sites were the axilla, perineum/perianal folds, and soles (each receiving 69%, 20%, and 34% of the prescribed dose, respectively). For patients evaluated in a reclining position, surface dose distribution was more heterogeneous. The sites underdosed most commonly were the axilla and perineum/perianal folds (receiving less than one third of prescribed dose). Significant variables were detected with model building.

Conclusion: TLD measurements were integral to quality assurance for TSEBT. Dose distribution at several anatomical sites correlated significantly with gender, height, and weight of the treated individual and might be predicted.

1. Introduction

Total skin electron beam therapy (TSEBT) is a radiation modality for patients with diffuse cutaneous lymphoma and skin manifestations of leukemia [1,2]. The use of TSEBT for cutaneous lymphoma differs widely among treatment centers. The most commonly used technique for radiation treatment is performed with the patient standing [3,4]. Patients who are unable to stand during treatment receive treatment in a reclining position [5,6]. Though several reports on dose variation have been published, no previous study has included a systematic evaluation of dosimetric differences among techniques [7–9]. Due to anatomical or technical variations, certain areas of the body may be "shadowed" or underdosed during TSEBT [10–12]. In vivo dosimetry allows for the identification of areas that should receive significantly less radiation. A thermoluminescent dosimeter (TLD) is typically used for in vivo dosimetry during TSEBT. Areas that often receive boosts include the top of the scalp, perineum/perianal region, upper inner thighs, and soles of the feet [4,8,9,13]. Additionally, inframammary folds in women and other skin folds (e.g., panniculus in obese patients) must be considered [8,11].

Currently, low-dose TSEBT is commonly used because this approach involves a short course of radiation, and patients report superior tolerability [14–17]. While TSEBT is one of the most effective modalities for treatment of cutaneous lymphoma, measuring TLD is time consuming and limits the availability of TSEBT at many institutions.

In this study, we compare patient dose distributions as a quality assurance check for patients receiving TSEBT in order to provide dose recommendations for boosts in the era of low-dose TSEBT.

2. Materials and methods

2.1. Radiation technique

From January 2000 to June 2017, eighty-five courses of TSEBT

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radiation for cutaneous lymphoma (T-cell, n = 74; B-cell, n = 7) and leukemia cutis (n = 4) have been completed. For this study, 68% of those who participated were male. We used modified Stanford technique to deliver TSEBT to 77 patients (91%) [3,18,19]. The remaining eight patients (9%) were not able to stand during the course of radiation; they underwent TSEBT for multiple segmental fields in a reclining position. The high dose rate electron beams with 6 or 9 MeV electron energy from a Siemens primus (n = 44) or Varian truebeam linear accelerator (n = 41) were used. External eye shields were routinely used during wide-field skin irradiation to protect the cornea and lens. Nails of the hands and feet, other than the shielded regions involved with lymphoma manifestations, were usually shielded to preserve nail growth.

2.2. In-vivo dosimetry

TLDs are considered the most appropriate dosimeters due to their small size, reusability, and nearly tissue equivalent density. In this study, TLD-100 rods (LiF:Mg.Ti; diameter: 1 × 6 mm) were used for TSEBT measurements. The readout was done using a Harshaw 5500 automated TLD-Reader. To double-check the evaluation, ten TLDs from the same batch were used as control dosimeters. They exposed to a single dose of 2 Gy with the same energy. Reading of first group of the control dosimeters was done at the beginning and the second group at the end of the cycle. This enabled us to determine if fading or other unexpected changes applied to the batch. The thermal treatments of the TLDs were done for bleaching of the previous dose information in TLD PTW annealing oven heats on 400 °C for 10 min.

TLD measurements of the prescribed skin dose were obtained for 76 patients (89%). To document dose measurements, TLD rods were taped to the surface of the patient's skin at various locations on the body. All TLDs were affixed and measured by the same physicist. Each TL dosimeter was heated by hot nitrogen gas stream to 135 °C for 15 s – this minimize the fading effect of the dosimeters. After the temperature increased to 240 °C with a heating ramp of 10 °C/s with a 33 s hold. During this time the light emission was measured, which is related to the absorbed dose by the TLD (Fig. 1). TLDs were typically measured on the first or second day of treatment, and all results were reported as a percentage of the prescribed dose. The reference point for the given dose was located at the anterior abdominal wall. Variation in TLD measurements was analyzed to determine the dose variation during TSEBT for various areas of the body. Several areas were underdosed according to EORTC criteria [20]. Scatter plots of measured dose vs. patient height, weight, and body mass index (BMI) were generated, and correlation coefficients were calculated. Dosimeters were placed symmetrically when applicable. For female patients, extra dosimeters were placed in the inframammary region when needed. Various other locations were measured individually, as determined by clinical situation and physical characteristics.

2.3. Patients characteristics

Median age of the patients was 64 yr (range, 26–87). Heights ranged from 154 to 192 cm; weights ranged from 51 to 130 kg. Male patients had greater median height [176 (IQR: 10) vs. 160 cm (IQR: 6), P < 0.001] and median weight (78 vs. 70 kg, P = 0.003). Median BMI was 26 (range, 19–39; IQR, 4.4), without significant difference between males and females (25 vs. 27, P = 0.14). Median surface dose was 30 Gy (range, 6–40 Gy). The entire wide-field skin surface received a median fraction dose of 1.6 Gy (range, 0.5–2 Gy) in a given day. All patients treated after 2011 (n = 41) received low-dose regimens (median dose: 12 Gy; median fraction dose: 1.5 Gy). Median monitor unit calculation was 575/Gy (range, 396–867). Boost or supplemental radiation was delivered to 70/85 patients (82%) to compensate for underdosing in shadowed body areas or for treatment of large lymph nodes/tumorous lesions. Dose required to deliver a full prescribed TSEBT dose was calculated from TLD measurements and delivered using daily median fraction dose of 2 Gy (range, 1–4). Fifteen patients (18%) did not receive additional radiation due to non-compliance or poor clinical conditions.

Median follow-up was 16 mo (range, 1–185). Three months after completion of radiotherapy, palliation was achieved in 71 patients (83%). A clinically complete response was documented in 47 patients (55%); partial response was documented in 24 patients (28%). Median time to skin progression (duration of clinical benefit) was 16 mo (95% CI: 10–22). After completion of TSEB, median overall survival (OS) was 23 mo (95%-CI: 0.7–45). Clinical outcomes are presented in Table 1.

2.4. Statistics

All statistical analyses were conducted with IBM SPSS Statistics 24.0 software. Mean change is reported with standard deviation (SD). Spearman's rank correlation coefficient (r) values were calculated to analyze TLD measurements. A χ^2 or Fisher exact test was performed to probe relationships between categorical variables. Two-sample *U* test was used to study the relationship between categorical and continuous variables. *T*-tests were used to analyze differences between paired samples. Differences were considered statistically significant at $p < 0.05$.

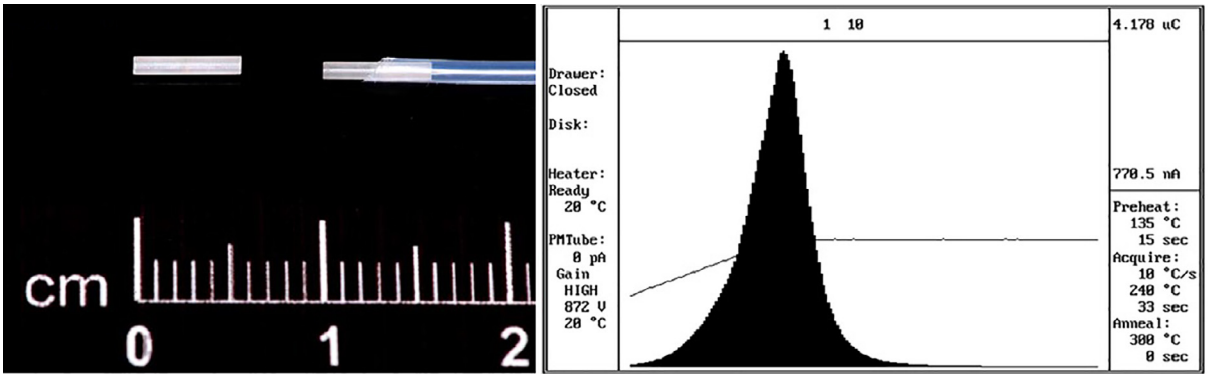

Fig. 1. The left picture points the TLD-100 size: a diameter of 1 mm and a length of 6 mm. The right side shows a typical glow curve of the TLD-100 during the evaluation of the light signal. Downright is written the thermal handling of the TLDs. The intensity of the emitted light is related to the dose absorbed by the TLD.