Dosimetry of Esophageal radiotherapy: a phantom study

Zohreh Hoseinpour[1], Alireza Nikoofar[2], Seied Rabi Mahdavi[3], Hadi Hasanzadeh[1,*], Saeid Zavareh[4]

[1]Department of Medical Physics, Semnan University of Medical Sciences, Semnan, Iran
[2]Department of Radiation Oncology, Iran University of Medical Sciences, Tehran, Iran
[3]Department of Medical Physics, Iran University of Medical Sciences, Tehran, Iran
[4]School of Biology, Damghan University, Damghan, Iran.

*Corresponding Author: email address: Hasanzadeh.h@semums.ac.ir (H. Hasanzadeh)

ABSTRACT

Esophageal cancer is the eighth most ordinary cancer and the sixth most common cancer between the males and ninth for females in the world; its major and effective treatment is external radiotherapy. This type of cancer can be found in different areas of esophagus including cervical, upper, middle and lower esophagus. In this treatment, healthy tissues such as the trachea, spine and sternum and even thyroid receive dose and it is important that the absorbed doses by these organs be in their tolerance dose levels. We measured the surface and depth doses in an anthropomorphic phantom using thermoluminescent dosimeters. To do so, a target volume was considered in the phantom as a primary esophageal tumor with margins of 5 cm in the distal and proximal, and 3 cm in lateral. Phantom was CT planned and treatment was performed according to patient treatment. The considered measurement locations were Eye, right and left Parotid, left and right Submandibular, left and right Thyroid, Trachea, Manubrium of Sternum and Spine. Our results show that in places located further to primary beam such as Thyroid (phase one), Trachea, Spine and Sternum, the difference between dose from *TPS* and *TLD* measurements is observed. In organs which have placed within scattered radiation, the difference is insignificant (P-value≥0.05), although some differences might cause by *TLD* limitations. In conclusion, the TPS calculated and TL measured doses distinguish significantly at the spine (depth), trachea (depth) and manubrium of sternum especially in phase 1 which might be due to the calculation algorithm used by the planning system which is reliable in homogeneous medium, but TL measurements were performed in the heterogeneous anthropomorphic phantom.

Key Words: Esophageal cancer; Radiotherapy; Anthropomorphic Phantom; TLD dosimetry

INTRODUCTION

Esophageal cancer is one of the gastrointestinal cancers which plays a vital role in human life, because it's the pathway to transfer foods. It is the eighth most ordinary cancer in the world [1] and the sixth most common cancer between the males and ninth for females in the world [2]. This cancer happens most often in the thorax [1]. Epidemiological studies show that the age of 60 or older, is the main risk factor for esophageal cancer [3]. It is considered to be one of the most important cancers in developing countries [4]. There exist several treatments for this type of cancer, but among them, the major and effective treatment is external radiotherapy [5]. This type of cancer can be found in different areas of esophagus including: cervical, upper, middle and lower esophagus. Although radiotherapy is an effective treatment, but if not done properly it might bring damages to surrounding healthy tissues. In treating this type of cancer, healthy tissues such as the trachea, spine and sternum and even thyroid are within the radiation field and will receive dose, but it is important that the absorbed doses by these organs be in permissible dose levels and not greater than the values specified by treatment planning system (TPS). Excessive doses cause problems such as dry mouth and salivary and thyroid disorders and in addition, it causes respiratory problems and burning in the chest. In radiotherapy, the depth dose distribution in a phantom which simulates

human body [6-8] must be obtained to assure that the prescribed dose is delivered to the target volume in the patient. An acceptable phantom with similar tissues and anatomy of the body was presented by Hasanzadeh et al that is useful for internal and surface dosimetry [8]. For dosimetric aims we need a suitable dosimeter with appropriate size and accuracy. Some dosimeters have been reported for in vivo dosimetry such as metal oxide semiconductor field effect transistors, alanine, plastic scintillators, radiochromic films, conventional portal films or electronic portal imaging devices and gels [9]. Also calculational technique such as: Monte Carlo simulation methods, thermoluminescent (TL), diode and ionization chamber have wide application in dosimetry [10, 11]. Among all of dosimeters, thermoluminescent dosimeter (TLD) is acceptable for internal measurements because its size permits easily fit inside the phantom and could be used several times without any damages. Thermoluminescent dosimetry is mostly used for in vivo dosimetry. TLDs have many advantages; the most important features can be noted as their tissue equivalency. So given the above mentioned reasons and the need to assure the quality control programs, we decided to measure the surface and depth doses in an anthropomorphic phantom using thermoluminescent dosimeters.

MATERIALS AND METHODS

External Radiation Therapy technique (ERT)

The target volume considered in the phantom was a primary esophageal tumor with margins of 5 cm in the distal and proximal, and 3 cm in lateral. Phantom was CT planned and treatment was performed according to patient treatment; this was usually followed by a two-or three-field technique over 5–6 weeks. Irradiation was performed initially with a dose of 45-50 Gy in 1.8 or 2 Gy/fraction, 5 days a week, by an anterior and posterior port in 25 fractions then one anterior and bilateral field with total dose 900 cGy in 1.8-2 Gy in 5 fractions with 6-25 MV photons [12, 13]. It is notable that in this treatment, the fields covered supraclavicular for treatment of supraclavicular nodes [14-16], but lunges were shielded with Cerrobend blocks to prevent extra doses to them. In phase two, we applied three fields, one anterior and bi-oblique. In phase two spinal cord was shielded and the dose to the spinal cord was kept below 45 Gy [13, 15]. All doses were prescribed at the isocentre.

Calibration of dosimeters

The dosimeters used in this study were *LiF:Mg,Ti* (*TLD-100*) thermoluminescent dosimeters that are in the form of square (3.1×3.1×0.9 mm) chips (Harshaw, USA). Thermoluminescent readouts were performed using a commercial TLD reader (Harshaw Model 3500, USA). Dosimeters were annealed using a laboratory oven (Atash 1200 Exiton Crop, Iran). The annealing procedure used consists of two subsequent annealing: 1 h at 400˚C and 24 h at 80˚C [9]. To prevent the initial steep dose gradient in the depth dose curve, TLD measurements were carried out near the depth of maximum dose d_{max} [17].

Before irradiation, all TLD batches were annealed and then irradiated to equal doses and were readout; the procedure was repeated two times to increase accuracy. Elemental calibration coefficients (*ECC*) for each TLD were determined by putting TLDs between the entrance of a Perspex phantom and delivering them a dose of 200 cGy with 6 MV photons which was chosen in the linear region of TL response (100 cm Source Axis Distance (*SAD*) ,10×10 cm field size). Then the calibration curve of *TLD*s was obtained by exposing *TLD*s to several doses in Plexiglas phantom (depth of 3 cm and distance of 97 cm) (Figure 1).

Phantom structure

Phantom used in this study was an anthropomorphic phantom corresponds to an average adult body constructed from natural bone and mixture of paraffin wax with *NaCl* as impurity for soft tissue, which effective atomic number and electron density were 6.57 and 3.36×10^{23} *electrons/g*, respectively. Tissue substitute for lungs were two spongy woods with similar dimensions and density to lungs. Several applicators were provided to locate *TLD* in several depths and an esophageal lumen was considered for entrance of esophagus applicator [8, 18] (Figure 2).

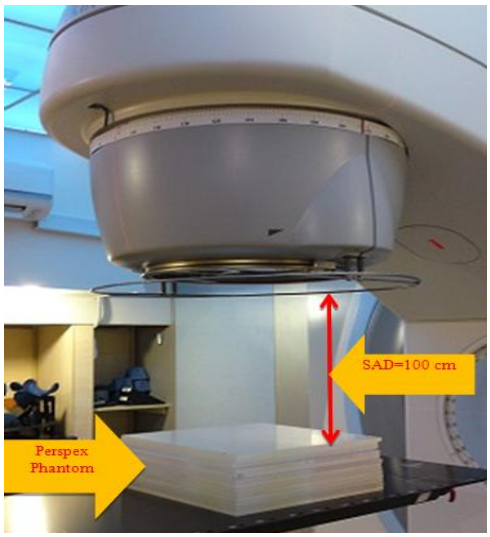

Figure 1. Setup of thermoluminescence dosimeter (TLD) calibration.

Figure 2. Anthropomorphic phantom with the depth TLD applicators.

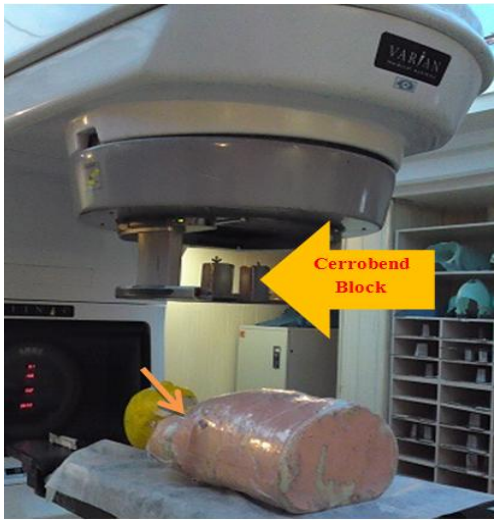

Figure 3. Set up of anthropomorphic phantom on the treatment couch and TLDs placed in arbitrary positions (Arrow shows the external marker).

Phantom dosimetric measurements

The phantom was CT-Planned during which external markers were placed on its surface to avoid any mismatch between planned and treated sites. All *CT* slices were sent to the *Core Plan TPS* (Pars radiotherapy center, Tehran, Iran). Target volume was considered as *CTV* with 5 cm distal and proximal and 3 cm lateral margins. Phase one was planned with 18 MV photons in two parallel opposed field technique (anterior and posterior) in which supraclavicular nodes were irradiated, too.

Lungs were blocked with Cerrobend to prevent any unnecessary irradiation. The three field technique was planned for phase two; it composed an anterior and bi-oblique beams. After planning each phase, phantom was placed on the treatment couch (Fig. 3) and TLDs were placed at the pre-selected locations at the surface and some depth in the phantom (10 surfaces and 6 depths). The considered locations for *TLD*s were Eye, right Parotid (skin surface &1cm depth), left Parotid (skin surface &1 cm depth), left Submandibular, right Submandibular, left Thyroid (skin surface & 1 cm depth), right Thyroid (skin surface & 1 cm depth), Trachea (skin surface & 4 cm depth), Manubrium of Sternum, Spine (inside the phantom & skin surface).

Each TLD measurement point on a phantom consisted of at least two chips in a thin plastic pack.

RESULTS

The calibration curve with its linear regression equation which relates the collected charge in TLDs to radiation absorbed dose is brought in Figure 4. Radiation doses received by organs at risk and organs near radiation field in the phantom were measured with calibrated *TLD*s and are presented in cGy in table 1 & 2. In this table, dose obtained from TLDs were compared to the doses calculated by the treatment planning system.

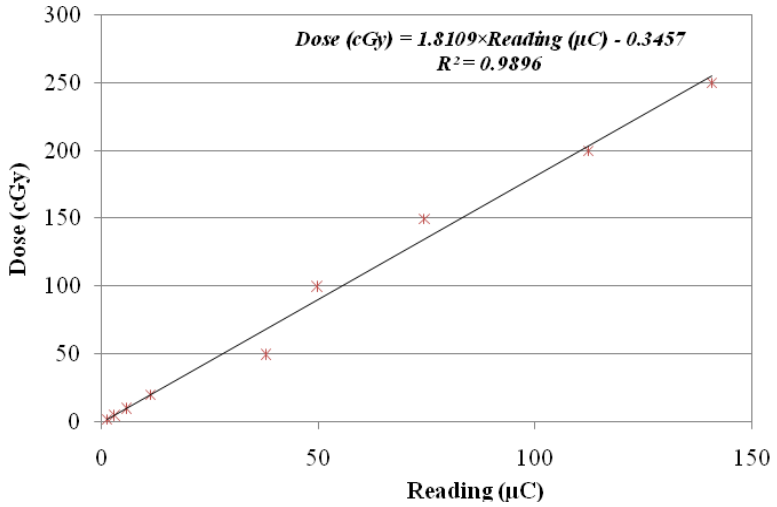

Figure 4. Calibration curve for thermoluminescent dosimeters

Table 1. Measured and calculated dose to considered organs in phantom (phase one)

Organ		Absorbed dose (cGy)	
		Measured	Calculated
		Mean±SD	Mean
Eye		4.96±0.08	N.A.*
Parotid	depth	2.88±0.31	0
	surface	1.2±0.05	0
Submandibular		5.16±0.15	0
Thyroid	depth	34.97±0.76	54
	surface	30.84 ±0.88	20
Trachea	depth	173.2±11.93	190
	surface	120.17±0.47	120
Spine	depth	126.66±27.33	190
	surface	100.75±30.37	80
Manubrium of Sternum		104.56±0.7	124.8

* **not available from TPS.**

Table 2. Measured and calculated dose to considered organs in phantom (phase two)

Organ		Absorbed dose (cGy)	
		Measured	Calculated
		Mean±SD	Mean
Eye		1.13±0.12	N.A.*
Parotid	depth	4.87±0.01	0
	surface	4.88±0.02	0
Submandibular		5.22±0.36	0
Thyroid	depth	5.64±0.87	9.7
	surface	5.04 ±0.11	5.9
Trachea	depth	94.51±8.84	120.4
	surface	41.39±1.58	60
Spine	depth	151.62±7.88	166
	surface	37.93±2.5	50
Manubrium of Sternum		42.38±2.99	33.6

* **not available from TPS.**

DISCUSSION

In this study, the appropriate external radiotherapy planning was performed to measure the absorbed dose to selected organs and besides compare those to values obtained from TPS. We used 18 MV photons in this study while some studies have suggested 6 MV photons or 6–18 MV photons [19] or 6– 25 MV [13]. The major disadvantage of 6 MV photons is the existence of many cold points in the plan that prevents delivering a suitable dose to tumor and treatment area and also hot points at the surface. According to Ahmad et al, in phase one (AP/PA), d_{max} doses (hot spot of 2 cm) for 6 and 18 MV photons are 110 and 105% respectively and cause hot spots; in other words the integral dose to surrounding tissue would be less with the 18 MV photons and in phase two (AP- LPO, RPO) there was no difference between 6 and 18 MV photons [20]. Among different types of TLDs such as: LiF:Mg,Ti, (*TLD*-100), LiF:Mg,Cu,P (*TLD*-700H), CaF_2:Dy (*TLD*-200), CaF_2:Mn Al_2O_3 (*TLD*-500) and $CaSO_4$:Dy (*TLD*-900), LiF:Mg,Ti (*TLD*-100) was selected because of its tissue equivalency, flat energy response and high sensitivity which make it suitable for entrance and skin surface [21].

The selection of the above mentioned anthropomorphic phantom in this investigation (because it similarity in design and material to

human body) helps similar absorption and scattering effects to human body [8]. Most of phantom dosimetric studies were done with PMMA phantoms in which they didn't consider heterogeneities like human body [22, 23].

There are some differences between results of *TPS* and *TLD* measurements which might be due to the tissue inhomogeneity which has not considered in *TPS* calculation algorithm, but existed in phantom. According to the ICRU [7] the accuracy in the dose determination should be within ± 5%, or even lower, in the conventional radiotherapy. Some places such as Trachea, spine and sternum are in the treatment field in both phases, but thyroid is at the edge of field in phase one and received primary radiation but in phase two it was out of field and didn't receive any primary photons and it just receives scattered radiation. In places that locate further to primary beam such as Thyroid (phase one), Trachea, Spine and Sternum, the difference between dose from *TPS* and *TLD* measurements is observed. In organs which have placed within scattered radiation, the difference is insignificant (P-value≥0.05), although some differences might cause by *TLD* limitations. According to our results, by increasing distance from isocenter or treatment area, the dose decrease rapidly. TL dosimeters were placed between T2 and T3 for spine and in front of T1 and T2 for trachea.

The measured dose at parotid, submandibular glands and eye are due to scattered radiation. Our results show that there is no difference between depth and surface doses in the out of field organs; this is only possible the absorbed dose to these organs is due to scattered radiation.

CONCLUSION

This study showed that the absorbed dose at points out of field is due to scattered radiation which causes relatively similar depth and surface, but in points in field of treatment, there exist primary radiation and depth and surface doses are different. The TPS calculated and TL measured doses distinguish significantly at the spine (depth), trachea (depth) and manubrium of sternum especially in phase 1. Differences might be due to the calculation algorithm used by the planning system which is reliable in homogeneous medium, but TL measurements were performed in the heterogeneous anthropomorphic phantom.

ACKNOWLEDGMENTS

This work was a part of Miss Hoseinpour thesis for the degree of M.Sc. in Medical Physics supported by Semnan University of Medical Sciences. The work was made possible with kindly collaboration of Pars radiotherapy center and Radiology department of Iran University of Medical Sciences.

REFERENCES

1. Chen J, Zhu J, Pan J, Zhu K, Zheng X, Chen M, et al. Postoperative Radiotherapy Improved Survival of Poor Prognostic Squamous Cell Carcinoma Esophagus. Ann Thorac Surg. 2010;90(2):435-42.

2. Rosenblatt E, Jones G, Sur R, Donde B, Salvajoli J, Ghosh-Laskar S, et al. Adding external beam to intra-luminal brachytherapy improves palliation in obstructive squamous cell oesophageal cancer: A prospective multi-centre randomized trial of the International Atomic Energy Agency. Radiother Oncol. 2010;97(3):488-94.

3. American Cancer Society. Cancer Treatment & Suvivorship Facts & Figures 2012-2013. American Cancer Society. 2012.

4. Nag S, Dally M, de la Torre M, Tatsuzaki H, Kizilbash N, Kurusun S, et al. Recommendations for implementation of high dose rate 192Ir brachytherapy in developing countries by the Advisory Group of International Atomic Energy Agency. Radiol Oncol. 2002;64(3):297-308.

5. Berger B, Belka C. Evidence-based radiation oncology: oesophagus. Radiol Oncol. 2009;92(2):276-90.

6. Lindskoug BA. Clinical applications of thermoluminescent dosimetry. Strahlentherapie. 1985;161(2):91-5.

7. Aschan C. Applicability of thermoluminescent dosimeters in X-ray organ dose determination and in the dosimetry of systemic and boron neutron capture radiotherapy. Helsinki: University of Helsinki; 1999.

8. Hasanzadeh H, Abedelahi A. Introducing a simple tissue equivalent anthropomorphic phantom for radiation dosimetry in diagnostic radiology and radiotherapy. Journal of Paramedical Sciences (JPS) 2011;2(4):25-9.
9. Costa AM, Barbi GL, Bertucci EC, Ferreira H, Sansavino SZ, Colenci B, et al. In vivo dosimetry with thermoluminescent dosimeters in external photon beam radiotherapy. Appl Radiat Isot. 2010;68(4):760-2.
10. Gambarini G, Borroni M, Grisotto S, Maucione A, Cerrotta A, Fallai C, et al. Solid state TL detectors for in vivo dosimetry in brachytherapy. Appl Radiat Isot. 2012;71:48-51.
11. Uniyal SC, Sharma SD, Naithani UC. A dosimetry method in the transverse plane of HDR Ir-192 brachytherapy source using gafchromic EBT2 film. Phys Med. 2012;28(2):129-33.
12. Kumar S, Dimri K, Balachandran P, Kumar A, Lal P, Sikora S, et al. An audit of postoperative radiotherapy after non-curative resection for cancer of the oesophagus. Clin Oncol. 2005;17(5):352-7.
13. Pasquier D, Mirabel X, Adenis A, Rezvoy N, Hecquet G, Fournier C, et al. External beam radiation therapy followed by high-dose-rate brachytherapy for inoperable superficial esophageal carcinoma. Int J Radiat Oncol Biol Phys. 2006;65(5):1456-61.
14. Halperin EC, Brady LW, Wazer DE, Perez CA. Perez and Brady's principles and practice of radiation oncology. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2013.
15. Khan FM. Treatment planning in radiation oncology. [S.l.]: Lippincott Williams & Wilkins; 2011.
16. Okawa T, Tanaka M, Kita M, Kaneyasu Y, Karasawa K, Ide H, et al. Radiotherapy for superficial esophageal cancer. Int J Radiat Oncol Biol Phys. 1994;30(4):959-64.
17. Swinnen A, Verstraete J, Huyskens DP. Feasibility study of entrance in vivo dose measurements with mailed thermoluminescence detectors. Radiol Oncol. 2004;73(1):89-96.
18. Hasanzadeh H, Sharafi A, Allah Verdi M, Nikoofar A. Assessment of absorbed dose to thyroid, parotid and ovaries in patients undergoing Gamma Knife radiosurgery. Phys Med Biol. 2006;51(17):4375-83.
19. Zhao K-L, Shi X-H, Jiang G-L, Wang Y. Late-course accelerated hyperfractionated radiotherapy for localized esophageal carcinoma. Int J Radiat Oncol Biol Phys. 2004;60(1):123-9.
20. Ahmad M, Nath R. Three-dimensional radiotherapy of head and neck and esophageal carcinomas: A monoisocentric treatment technique to achieve improved dose distributions. Int J Canc. 2001;96(1):55-65.
21. Rivera T. Thermoluminescence in medical dosimetry. ARI Applied Radiation and Isotopes: Supplement. 2012;71:30-4.
22. Kinhikar RA, Tambe CM, Upreti RR, Patkar S, Patil K, Deshpande DD. Phantom dosimetric study of nondivergent aluminum tissue compensator using ion chamber, TLD, and gafchromic film. Med Dosim. 2009;33(4):286-92.
23. Constantinou C, Attix F, Paliwal BR. A solid water phantom material for radiotherapy x-ray and γ-ray beam calibrations. Med Phys. 1982;9(3):436-41.