Original Article

Analysis of TLD-100 Calibration and Correction Factor in Different Field Sizes Under Low Dose Conditions Irradiated with Two Systems: Gamma Knife 4C and Theratron 780-C

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ABSTRACT

Purpose- In most current research, thermoluminescent dosimeters are used as a practical implement for dosimetry systems. In this study, we calibrated thermoluminescent dosimeters by Gamma Knife 4C and Theratron 780-C units as gamma emitters in low dose conditions. Moreover, we compared the response of both calibration curves to consider the possibility of using every device's calibration curves instead of the other instrument.

Materials and Methods- Calibration curves of Theratron 780-C machine and Gamma Knife 4C unit were measured and plotted in low dose conditions. In order to conduct individual calibration, TLDs were exposed with a dose of 100 cGy and through group calibration, dosimeters were divided into 7 groups and were exposed with doses of 0-12 cGy in both machines. To evaluate TLD response by changing the field size, TLDs were irradiated with different field sizes in Theratron 780-C and with different collimator sizes in Gamma Knife 4C. The best fitting curves were obtained with Excell and Matlab software.

Results- By complying with the best fitting curves for the TLD-100 and conforming to Fisher's test, the calculated p-value was 0.92, which was greater than 0.05, therefore the difference is not significant between two calibration curves.

Conclusions- Regardless of the differences in calibration conditions between Theratron 780-C machine and Gamma Knife 4C unit, the results showed that every one of these devices can be replaced and used to estimate the unknown dose both in stereotactic radiosurgery and radiotherapy.

Keywords:
TLD Dosimeter,
Calibration,
Gamma Knife 4C,
^{60}Co,
Correction Factor.

1. Introduction

The goal of calibration is to control the accuracy of the metrological principle of the measuring gauges under standard conditions to ensure the conformity of the measurement undertaken with international standards used [1].

Every measuring instrument should be calibrated periodically and repeatedly because of some criteria such as the passage of time, burnout and unpredictable events which cause their efficiency change and decrease. Therefore, the main purpose of the calibration performance is to ensure the gauges perform well and establish a traceability

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system to reference standards by determining the accuracy of readings from the device [1, 2].

In this study, the calibration process is used to perform by thermoluminescent dosimeters (TLD) whose responses do not give absorbed dose directly. This type of dosimeter measures the electrical charge in a special mass of material directly. Therefore, TLD dosimeters need calibration as an electrical charge measuring device. The most important objective in radiation therapy is to deliver a prescribed dose to the treatment lesion and reduce the minimum dose to the surrounding normal tissues. Thermoluminescent dosimeters were frequently used in order to estimate the absorbed dose to the normal tissues while the tumor is being irradiated by radiotherapy or radiosurgery instruments [3, 4].

Gamma Knife 4C unit and Theratron 780-C machine both produce gamma ray by ^{60}Co source which is one of the most practical radiations in radiotherapy and radiosurgery. ^{60}Co is a radioactive isotope of Cobalt which has some characteristics such as half-life of 5.2714 years, energies of 1.17 and 1.33 MeV, and an average energy of 1.25 MeV [5]. Theratron 780-C machine and Gamma Knife 4C unit are used for conventional radiotherapy and stereotactic radiosurgery (SRS). SRS was proposed by Leksell in 1951 and Gamma Knife system was manufactured by Elekta Company, which was developed for treating brain tumors such as blood vessel defects, Parkinson's disease, epilepsy [6, 7, 8]. In the SRS technique, multiple radiation beams focus and localize on a small volume such that the high dose will be delivered to the target, and the minimum dose will be received by the surrounding tissue. In Gamma Knife 4C unit, the photons are emitted from 201 sources of ^{60}Co and distributed to four different helmets with collimator sizes of 4, 8, 14 and 18 mm by focusing on a common volume under a source to focus a distance (SAD) of 400 mm [9].

Some studies of the thermoluminescent dosimeter that have been considered include: the analysis of dose response curves for several photon energies or for two different particles (photon and electron), comparison of dose response curves of the EBT3 film in external radiotherapy and SRS. A research analyzing the dose response curve by TLD in SRS and external radiotherapy has not been undertaken. In this project, the TLD-100 dosimeters were calibrated by Theratron 780-C machine and Gamma Knife 4C as gamma ray emitters. However, different calibration conditions may affect the calibration curve such as SSD, SAD, the number of sources, the form of phantom and field size. Consequently, these factors were considered. Our main and principal concern is to compare the response of the TLDs irradiated with the gamma ray in these two systems.

2. Materials and methods

In this project, irradiation in conventional radiotherapy and stereotactic radiosurgery was performed by Theratron 780C and Leksell Gamma Knife 4C respectively. Ionization chamber (PTW-TM30013-0.6 cm^3, Freiburg, Germany) and (PTW-M31010-0.125 cm^3, Freiburg, Germany), electrometer (PTW, UNIDOS type T10001, Freiburg, Germany) were used to estimate the dose rate by AAPM's TG-51 and TRS-398 protocol [10].

GR100M (TLD) was manufactured by Harshaw Chemical Company, Germany, with the following characteristics of Lithium Fluoride (LiF) crystals doped with Titanium (Ti) and Magnesium (Mg), sizes of 3.2×3.2×0.9 mm^3 and energy range of 50 µGy to 500 Gy.

Initially, TLDs were annealed at 285°C for 30 min, followed by fast cooling and for typical annealing heating at 400°C for 1h. After irradiation, the TLDs should be stored for 24h at room temperature (20°C) before reading to clear the low energy traps [11, 12, 13, 14]. Individual calibrations should be done to compensate the inherent differences among TLDs because every TLD has a random response for the same amount of irradiation. Therefore, we did individual calibration to reduce this effect by measuring a correction coefficient for every detector. In order to do individual calibration by Theratron 780C machine, TLDs were placed in a thin perspex slab with conditions of SSD=80 cm, field size=10×10 cm^2, depth=5 cm, and exposed 100 cGy uniformly in the isocenter of the cobalt's source (Figure 1) [7, 14, 15, 16].

During individual calibration by Gamma Knife 4C unit, TLDs have been placed in a flat perspex cassette which was located in a special spherical phantom of the Gamma Knife and were exposed with SAD=40 cm uniformly by 18 mm collimator size (Figure 2) [17, 18].

Figure 1. a) Theratron 780-C machine, b) Perspex sheets in the field of radiation.

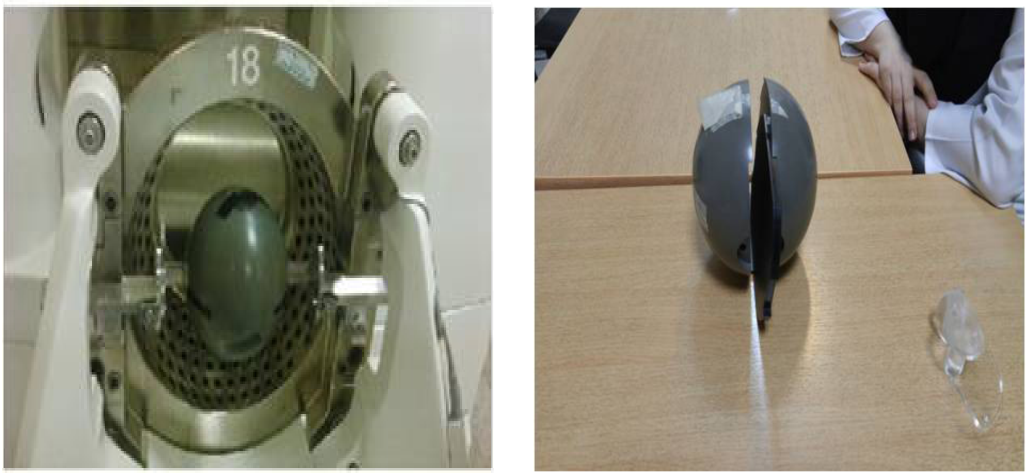

Figure 2. a) Leksell Gamma Knife system with collimator 18 mm , b) Special cassette in the middle of spherical phantom for calibration of TLDs.

The dosimetry of the Theratron 780-C machine and Gamma Knife 4C were performed by using an ionization chamber (PTW-TM30013, Vol. 0.6 cc), (PTW-M31010, Vol. 0.125 cm^3) and electrometer (PTW, UNIDOS, T10001) made in Germany.

In the next step, efficient correction coefficients (ECC) were obtained according to equation (1) to achieve the sensitivity of each irradiated TLD individually.

$$ECCj = \frac{< TLD >}{TLDj} \qquad (1)$$

Where ECC_j is the efficient correction coefficient of each TLD, <TLD> and TLD_j are the average reading of the total TLDs and individual reading, respectively [7, 14, 19, 20].

After the individual calibration of every system, TLDs were read by TLD reader (Fimel LTM, HF15001 model) which was manufactured in Germany. After the reading, each TLD was considered and numbered separately and then were stored inside the numbered capsules. In the following step, the standard deviation (SD) and average values have been measured. Ultimately, TLDs were omitted which were out of the range of readings higher or lower than the subtraction of mean and standard deviation (mean ± SD).

In order to convert the read number which is in terms of nano Coulomb (nC) to the delivered dose, a group calibration should be executed. On the part of group calibration of remaining TLDs after individual calibration, they were divided into 7 groups and exposed respectively with doses of 0, 1, 3, 5, 7, 9.5 and 12 cGy in Theratron 750-C machine and with doses of 0, 5, 7, 9, 10, 11 and 12 cGy in Gamma Knife 4C unit [3, 21, 22]. After exposing the dosimeters by both devices, they were stored in specified capsules which were numbered before and then read by TLD reader.

According to formula (2), the calibration curve was drawn where Y axis values will be obtained [7].

$$Yi =< \sum Rj \times ECCj > - < \sum B > \qquad (2)$$

Where Rj is TLD reading and B is background TLD reading.

When patient clinical conditions are not identical to reference (dosimetry) conditions, we should consider dose response differences. In order to evaluate TLD response by changing the field size, TLDs were irradiated with different field sizes (8×8 cm^2, 10×10 cm^2, 12×12 cm^2 and 15×15 cm^2) in Theratron 780-C and with different collimator sizes (4 mm, 8 mm, 14 mm and 18 mm) in Gamma Knife 4C. In this step, dose of 5 cGy was delivered to dosimeters in all determined field sizes by both machines.

The correction factor (C) for TLD detector as a function of the length of square field size (L) can be written by the following equation. (equation3)

$$C(L) = \alpha L^2 + \beta L + \gamma \qquad (3)$$

Where the characters of are constant depending on the kind of detector [23].

3. Results

According to formula (1), the ECC of each irradiated TLD by Theratron 780-C and Gamma Knife 4C systems are shown in Table1 and Table 2, respectively.

Table 1. ECC of each irradiated TLD by Theratron 780-C machine.

TLD number	TLD reading (nC)	ECC	TLD number	TLD reading (nC)	ECC
1	1.340e+06	1.147e+00	12	1.058e+06	1.452e+00
2	1.245e+06	1.254e+00	13	1.647e+06	9.917e-01
3	1.540e+06	9.998e-01	14	1.727e+06	8.898e-01
4	1.514e+06	1.015e+00	15	1.581e+06	9.719e-01
5	1.555e+06	9.882e-01	16	1.578e+06	9.750e-01
6	1.709e+06	8.991e-01	17	1.594e+06	9.750e-01
7	1.480e+06	1.038e+00	18	1.722e+06	8.923e-01
8	1.449e+06	1.060e+00	19	1.597e+06	9.622e-01
9	1.226e+06	1.253e+00	20	1.755e+06	8.756e-01
10	1.619e+06	9.491e-01	21	1.630e+06	9.427e-01
11	1.698e+06	9.950e-01			
AVE	1.537e+06		SD	1.860e+05	

Table 2. ECC of each irradiated TLD by Gamma Knife 4C.

TLD number	TLD reading (nC)	ECC	TLD number	TLD reading (nC)	ECC
1	1.316e+06	1.147e+00	12	7.952e+05	1.452e+00
2	1.129e+06	1.254e+00	13	1.425e+06	9.179e-01
3	1.329e+06	9.978e-01	14	1.506e+06	8.898e-01
4	1.350e+06	1.015e+00	15	1.370e+06	9.719e-01
5	1.437e+06	9.882e-01	16	1.352e+06	9.750e-01
6	1.466e+06	8.991e-01	17	1.379e+06	8.898e-01
7	1.324e+06	1.038e+00	18	1.624e+06	8.923e-01
8	1.269e+06	1.060e+00	19	1.376e+06	8.622e-01
9	1.106e+06	1.253e+00	20	1.606e+06	8.756e-01
10	1.401e+06	9.491e-01	21	1.429e+06	8.427e-01
11	1.453e+06	9.050e-01			
AVE	1.354e+06		SD	1.785e+05	

3.1. Calibration curves

According to formula (2), two calibration curves for Theratron 780-C machine and Gamma Knife 4C unit were obtained by the most appropriate fitted equation with Matlab and SPSS software in which X and Y axes are determined the absorbed dose and TLDs response, respectively.

According to Figure 3 and Figure 4, regression coefficients of both curves are more than 0.99. Both curves' equation are linear. The linear equations are Y=14073X-9356.5 and Y=12438X+2162 for Theratron 780-C machine and Gamma Knife 4C unit, respectively which are indicated in curves.

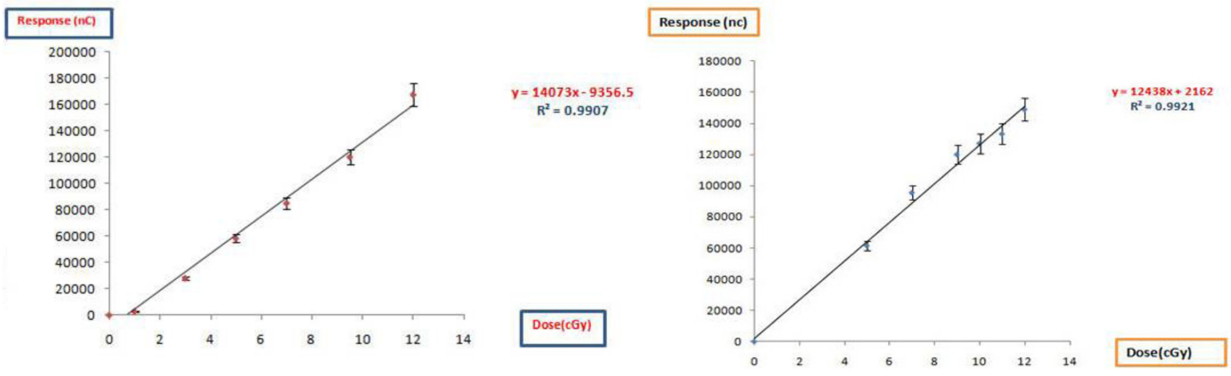

Figure 3. a) Calibration curve with line equation for Theratron 780-c machine, b) Calibration curve with line equation for Gamma Knife 4C.

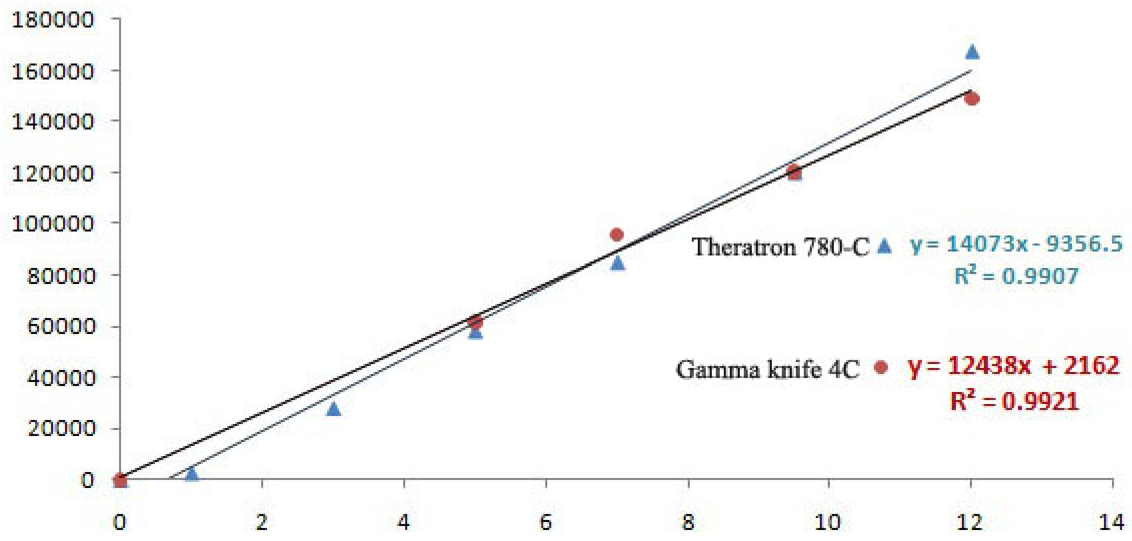

Figure 4. Calibration curves of devices in single plot.

3.2. TLD response under various field sizes

TLD response by changing the field size in Theratron 780-C machine is shown in Figure 5 in which the best fitted equation was obtained $C(L)=0.0052L^2-0.1673L+2.1493$. Measurements showed that TLD has a high response at 8×8 cm^2 field size and has a decreasing trend while the field size increases till 15×15 cm^2. TLD response of Gamma Knife 4C unit under changing field sizes is shown at Figure 6 whereby the best fitted equation was achieved $C(L)=0.0041L^2-0.1599L+2.5538$.

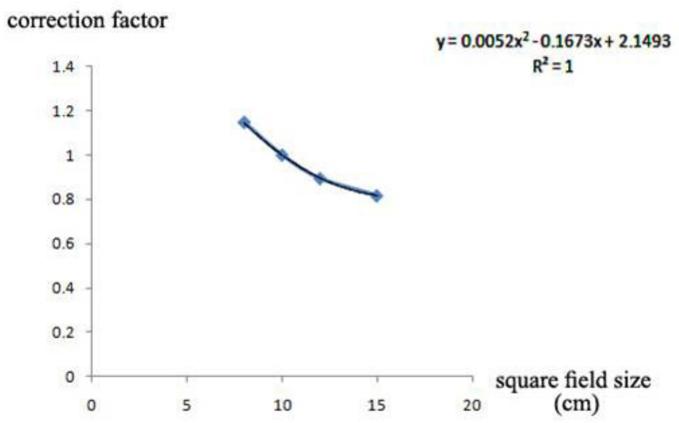

Figure 5. TLD correction factor curve for Theratron 780-c machine in different square field size.

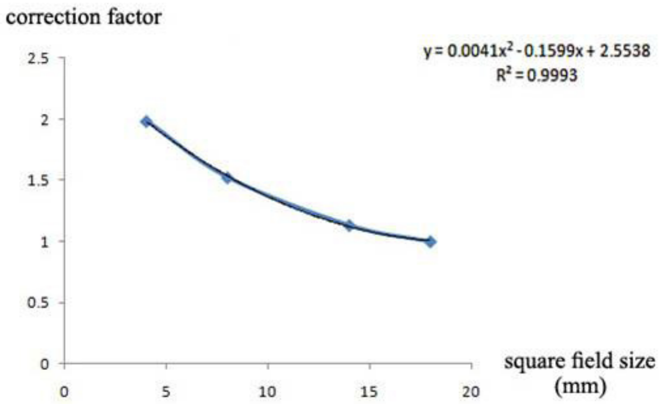

Figure 6. TLD correction factor curve for Gamma Knife 4C in different field size.

4. Discussion

Eventually, after analyzing the obtained data by Excel and Matlab software in both systems, fitted curves have been plotted. Line slope of the curves showed that both calculated equations are linear and the response of TLD dosimeters is growing with an increasing dose. According to the results in the fact of linearity, the line slope of each equation has become different from each other but serial numbers of TLDs were the same which have remained after an individual calibration. In reference to the Null hypothesis test, if the correlation between X and Y in one population is the same as the correlation between X and Y in another population, Fisher test can be used according to the procedure developed by R.A.Fisher in 1921 [24]. The calculated p-value was obtained 0.92 by Fisher test which was more than 0.05 and the difference is not significant and meaningful. Therefore, the results showed that two calibration curves do not have any considerable differences from Theratron 780-C as a conventional radiotherapy machine and Leksell Gamma Knife 4C as a stereotactic radiosurgery system.

Although several studies have been undertaken about the calibration of radiotherapy devices, nobody has compared the thermoluminescent dosimeters calibration of Theratron 780-C machine with that of the Gamma Knife 4C unit. In many studies, TLD dosimeters have been calibrated by other gamma ray producer systems instead of the machine which has been used for the treatment or research on dosimetry goals. Our main interest was to measure an unknown dose in stereotactic radiosurgery and conventional radiotherapy. Due to our performance which is related to an absolute dosimetry, we need an accurate and exact measurement of the dose. Therefore, in this type of research, the dosimetry could not be determined by estimations and possibilities. In addition, accurate measurements should be considered in each instrument. Hence, every system should be calibrated separately. Despite this fact and distinctions between the two machines and also their different calibration conditions, as already mentioned, the p-value showed no significant relationship or any differences between two calibration curves in both machines which has been discussed above. Furthermore, we can calibrate TLD-100 by the alternative machine instead of the other system which emits an identical radiation with the same source that produces gamma ray.

In a study by Banaee *et al*, the effect of energy on the calibration of thermoluminescent dosimeter has been evaluated with 120 kVp, 200 kVp, 6MV, 18 MV and ^{60}Co beams. Comparing our data with Banaee *et al* showed that both TLD calibration curves are linear for ^{60}Co beams. In our study, TLD-100 has been used and calibrated in the dose range of 0 to 12 cGy, but in their study, GR-207A detector has been used and calibrated in the dose range of 0 to 250 cGy [14].

According to Camargo da Costa *et al*, fetus absorbed dose has been evaluated for patients undergoing 6 MV linear accelerator by TLD-100 dosimeters that they have been calibrated by ^{137}Cs which is different from our radiation source for TLD calibration while the type of the dosimeter is the same as our research. Confirming to the results of both studies, the obtained TLD calibration curves are linear while the dose value range from 0 to 60 cGy and 0 to 12 cGy have been used in Camargo da Costa *et al* and the present study, respectively [25].

Comparing our data with Farid Ahmed *et al*, the TLD calibration curve is linear and the type of dosimeter which has been used is identical in both studies. In the study above, different teletherapy units (^{60}Co gamma ray, 120 kVp and 250 kVp x-ray) had been used for estimating the dose distribution in distances up to 40 cm from the field edge along the central axes of the field size, and TLDs have been exposed with the doses of 101.55 mGy, 152.25 mGy, 203.1mGy, 253.9 mGy and 304.65 mGy by ^{60}Co source which is the same as our study. Their given doses were lower than the range of doses in our research [26].

In a study by Hassanzadeh *et al*, the calibration of TLD dosimeters have been done by ^{60}Co with TLD-100 dosimeter and the assessment of absorbed dose to organs out of radiation field have been estimated by Gamma Knife C, but the evaluation delivered dose to every site has been analyzed by ^{60}Co machine calibration curve. In our study, we have calibrated dosimeters with both Theratron 780-C machine and Gamma Knife 4C unit even though the same source of ^{60}Co were used. In both studies, calibration curves have become linear while the dosimeters which have been used were the same and have been irradiated with different doses value ranging from 0 to 50 cGy and 0 to 12 cGy in their study and the present study, respectively [7].

According to Najafi *et al*, contrary to our study, the calibration curve of the two devices (Theratron 780-C and Gamma Knife 4C) was compared by using EBT3 film dosimeter while TLD-100 is the dosimeter which was used in our study. Their study showed that calibration curves of EBT3 film dosimeter have had the same response for ^{60}Co and Gamma Knife 4C machines and calibration curves did not have any meaningful difference which is the same as our result [27].

According to the analysis of TLD response under various field sizes which is presented in Figure 5 and 6, the measurements of the two machines showed that by increasing the collimator size, TLD response is decreasing. It seems when the field size is small, the scattered radiations is more than the bigger filed size_from both machines. It goes without saying that both measurement set-ups was quiet different but decreasing the trend of TLD response by increasing the field size is identical in both machines. This is mainly due to the growing number of scattered electrons by collimator in the air and collimators.

According to Prasetio *et al*, it is important to consider the field size correction factor to increase the accuracy of measurement by Thermoluminescent Dosimeter. Furthermore, when the field size is small, there are more scattered radiations from the head of radiotherapy units which have lower energy. Since the TLD is very sensitive to lower energy, TLD response will be higher in a small field size [28].

In a study, Apipunyasopon *et al*. showed that there are no distinguishing differences in several field sizes and measurements were performed on surface. Therefore TLD dosimeters are generally independent of the square field size for the surface dose, and the correction factor increases with the length of square field size. The differences between their study and our present data is that they found out that the correction factor is a function of the length of field size and it increases with the length of square field size while in the current study, the measurement was performed in a depth of 5 cm. Therefore, the correction factor is a function of the length of the field size which decreases with increasing field size. [28].

In agreement with studies by Prasetio *et al* and Apipunyasopon *et al*, our results showed that TLD has a high response in a small field size and has a decreasing trend while the field size is increasing [27, 28].

5. Conclusion

The results show that with the best considering fitting curve and with the same energy of both systems and calculated p-value, each machine can be used instead of each other to calibrate TLD-100 dosimeter for estimating the unknown delivered dose in stereotactic radiosurgery and conventional radiotherapy. The calibrati on curve response of both machines even with the differences among the TLD calibration conditions, such as SSD, source to axis distance, number of sources, calibration depth, size and shape of the radiation field and dose rate in every system individually is not different. As a consequence, we can use the TLD-100 for the purpose of radiation dosimetry under different calibration conditions. In addition, the calibration curves of these two systems (i.e. Gamma Knife 4C as a stereotactic radiosurgery and Theratron 780-C as a conventional radiotherapy machines) are appropriate to earn the absolute delivered dose in stereotactic radiosurgery and conventional radiotherapy.

Eventually, the conclusion of TLD correction factor measurements in several field sizes showed that the response of Thermoluminescence Detector is decreasing by increasing the small field size despite different field sizes and collimators with distinct set-ups in Theratron 780-C machine and Gamma Knife 4C unit. However, it is obvious that the TLD correction factor should be considered in both machines when the treatment condition is different from calibration conditions while the field size changes, especially in Gamma Knife 4C in which the TLD response variation is significant between the collimator 4 mm and 18 mm.

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