ORİJİNAL MAKALE/ORIGINAL ARTICLE
J Turgut Ozal Med Cent 2015:22(1):22-8

Journal Of Turgut Ozal Medical Center
www.jtomc.org

A Comparative Study of Radiation Doses and Treatment Area Dependence in Thermoluminescence Dosimetry Systems and Metal Oxide Semiconductor Field Effect Transistors

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Abstract
Aim: This study aims at examining the differences between thermoluminescense dosimeters and metal oxide semiconductor field effect transistors in terms of radiation doses at different photon energies treatment area dependence in patients who recieved radiotherapy at the Department of Radiation Oncology, İnönü University.
Material and Methods: Thermoluminescense dosimeter systems and metal oxide semiconductor field effect transistors were used at 6MV and 25MV in the range of 25-1000 cGy radiation doses to examine radiation dose dependence. Results were evaluated by taking measurements of treatment areas 5x5, 10x10, 15x15, 20x20, 25x25, 30x30, and 40x40 cm², respectively, to specify treatment area dependence of these systems.
Results: In both thermoluminescense dosimeters (TLD) and metal oxide semiconductor field effect transistors (MOSFET), reading values at 6 MV and 25 MV photon energies remained up to 800 cGy. We observed that both systems deviate from linearity at doses above 800 cGy. In TLDs, we recorded a %±1 (6 MV photon energy) and %+4 (25 MV photon energy) change in reading values. This change was %±1 (6 MV photon energy) and %+4 (25 MV photon energy) in MOSFETs.
Conclusion: Both dosimeter systems have advantages and disadvantages in terms of accuracy and applicability. Being familiar with dosimeter systems is very important in identifying the accuracy of dose to be admisnistered.
Key Words: Radiotherapy; Invivo dosimeter; Thermoluminescense Dosimeter; Metal oxide semiconductor field effect transistor; Linear accelerator.

Radyasyon Dozu ve Tedavi Alanı Bağımlılıklarının Termolüminesans Dozimetre Sistemleri ve Metal Oksit Yarıiletken Alan Etkili Transistörlerine Etkisi Üzerine Karşılaştırmalı Bir Çalışma

Özet
Amaç: Bu çalışmada, radyoterapi alan hastaların giriş dozunun belirlenmesi için İnönü Üniversitesi Tıp Fakültesi Radyasyon Onkolojisi Anabilim Dalı'nda kullanılan in vivo dozimetre sistemlerinin farklı foton enerjilerinde radyasyon dozu ve tedavi alanına bağımlılıklarının incelenmesi amaçlanmıştır.
Gereç ve Yöntemler: Çalışmada termolüminesans dozimetre ve metal oksit yarıiletken alan etkili transistör invivo dozimetre sistemleri ile lineer hızlandırıcı cihazının 6 MV ve 25 MV foton enerjileri kullanılmıştır. Dozimetre sistemlerinin radyasyon dozu bağımlılığının incelenmesi için 25-1000 cGy radyasyon dozu aralığında ışınlamalar yapılmıştır. Sistemlerin tedavi alanına bağımlılığının belirlenmesi için ise sırasıyla 5x5, 10x10, 15x15, 20x20, 25x25, 30x30, 40x40 cm²'lik tedavi alanlarında ölçümler alınarak sonuçlar değerlendirilmiştir.
Bulgular: 6 MV ve 25 MV foton enerjilerinde artan radyasyon doz değerlerine bağlı okuma değerleri değişimi metal oksit yarıiletken alan etkili transistör dozimetre sisteminde lineer iken, temolüminesans dozimetrede 800 cGy'e kadar lineer, 800 cGy'den sonra ise lineerlikten saptığı gözlenmiştir. Artan tedavi alanı boyutuna bağlı okuma değerleri değişimi ise temolüminesans dozimetrelerde 6 MV foton enerjisi için %±1, 25 MV foton enerjisi için %+4 değerindedir. Metal oksit yarıiletken alan etkili transistör dozimetre sisteminde 6 MV foton enerjisinde değişim %± 1 iken 25 MV foton enerjisinde % ± 4 değerinde olduğu görülmüştür.
Sonuç: İnvivo dozimetrelerin birbirlerine göre bazı üstünlükleri vardır. Günlük kullanımda kullanıcıların dozimetre sistemlerini tanımaları ve ölçüm sonuçlarını etkileyecek özelliklerini bilmeleri, radyoterapi uygulanan hastaya verilen dozların doğruluğunun tespit edilmesi açısından oldukça önemlidir.
Anahtar Kelimeler: Radyoterapi; İn vivo Dozimetre; Termolüminesans Dozimetre; Metal Oksit Yarıiletken Alan Etkili Transistör; Lineer Hızlandırıcı.

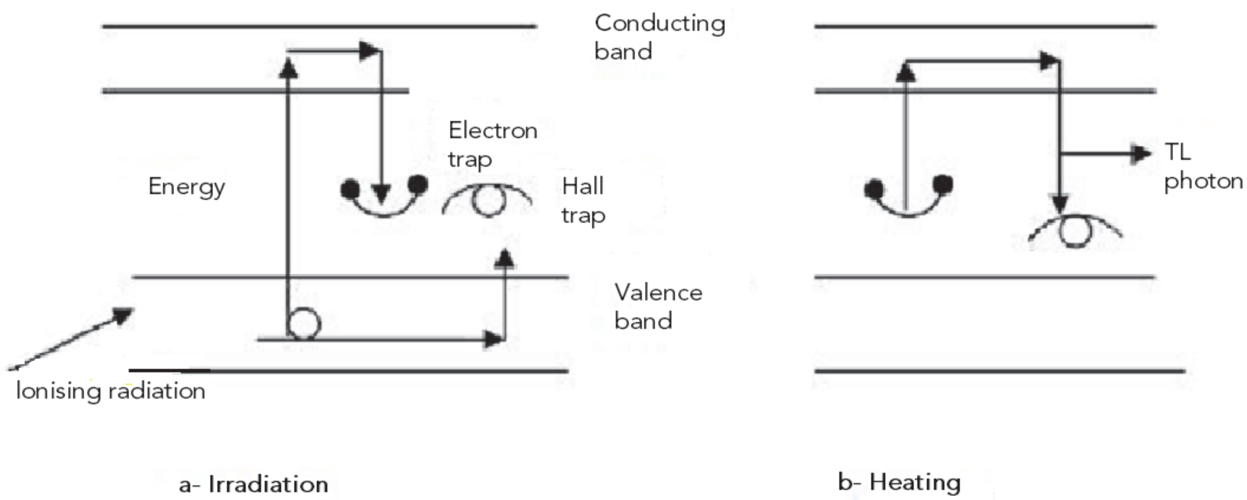
INTRODUCTION

To control the dose to be administered in radiotherapy, it is very important to know that the target volume receives the defined dose accurately (1-3). To ensure that patients undergo targeted doses accurately and reliably, practitioners make use of in vivo dosimetry systems. By providing accurate data about the volume of the radiation patients should receive during the treatment, and detecting possible dosimetric errors prior to the session, in vivo dosimeters prevent patients from taking less or more radiation than the planned doses (4).

For in vivo dosimetry measurements, practitioners use diodes and thermoluminescence dosimeters (TLD) (5). Metal oxide semiconductor field-effect transistors (MOSFET), radiochromic film dosimetry, conventional portal films, plastic scintillator dosimeters, electronic portal imaging, and gel dosimeters are among other dosimeters used in electronic radiation dosimetry measurements (6, 7).

Thermoluminescent dosimeters are based on the principle that a crystal with thermoluminescence properties becomes radiated through ionising and absorbs energy, which, in turn, is released in the form of thermoluminescence radiation as the crystal is exposed to temperature. Due to the defects in the structure of matter between conduction and valence bands or the presence of foreign atoms in itself, thermoluminescence crystal has quasi-steady energy levels. These energy levels create trap centres for the electrons and halls. When the matter is exposed to ionising radiation, some of the electrons in the valence band gain energy and move towards the conduction band or get caught in the electron traps in the forbidden energy gap (Figure 1a).

As a result of collisions, a portion of the electrons in the conduction band move to the valence band or get caught by the electron trap zone in the forbidden gap. When the crystal is heated, the electrons trying to avoid the traps and halls employ lower energy levels; whilst in lower energy levels, these electrons reflect their energy load in the form of thermoluminescent radiation (Figure 1b). The thermoluminescent radiation emitted from this phenomenon is proportional to the amount of radiation dose reflected on the crystal (8).



Figures 1a and 1b. Energy diagram of thermoluminescent crystal; **a)** irradiation **b)** heating.

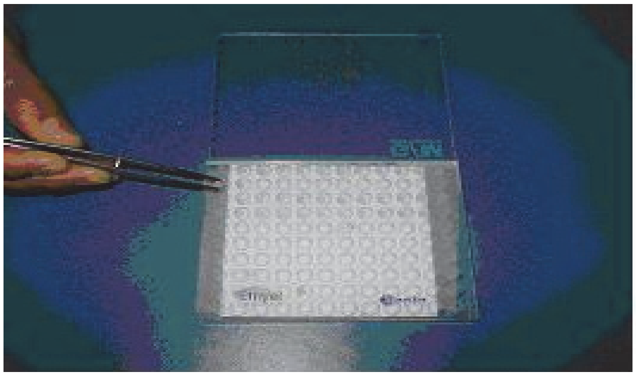
MOSFETs are either n-type or p-type semiconductors. N-type semiconductor is formed by the contribution of five-valence elements called donors. Each donor contributes to the free electrons of the semiconductor. In N-type semiconductors, majority carriers are the electrons while minority carriers are the holes. P-type semiconductor is formed by the contribution of the three-valence elements called the acceptors. Each acceptor is treated as an electron. In P-type semiconductors, the equivalent of the positive charge carriers are holes that move. Again, in P-type semiconductors, majority carriers are the holes while minority carriers are the electrons. As semiconductors are exposed to radiation, holes and electrons are formed; so the amount of the collected charge is proportional to the amount of radiation (9).

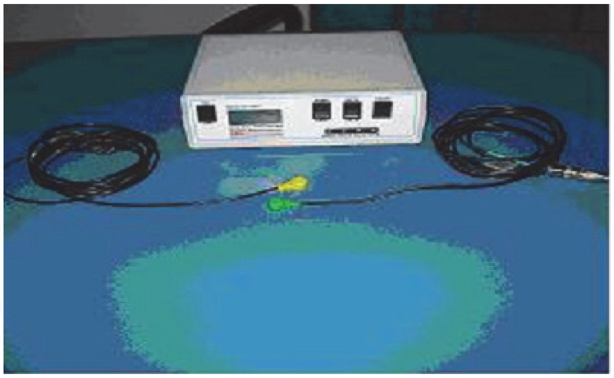
Although the physics underlying TLD and MOSFET detectors are different, both dosimeters are placed on the skin of patients during the irradiation. MOSFETs display the dose after irradiation directly, which allows a quick and easy way to identify the doses. While MOSFETs are dependent on energy and heat as they are also effected by radiation, they still have advantages like their high precision, repeatability, and stability (8, 10, 12-13). In TLDs, dose measurements are made after irradiation. So, there is need for a second reading system to obtain the post-dose irradiation. Although delays in reading is a disadvantage for TLDs as they cause low dose measurements, it is a low-cost system (8-11,14-16).

To determine the accuracy of the delivered dose and improve the quality of treatment, practitioners should be familiar with the dosimetry systems they are using and their features that may influence measurement results. This study aims to determine dose and treatment dependence of the patients. In this way, our study also aims at reducing errors in TLD and MOSFET applications, which are used to determine initial doses for radiation therapies.

MATERIAL AND METHODS

In this study, we have made use of TLD-100 chips, which are made up of LiF (lithium fluoride) crystals, and MOSFET dosimetry systems (Figure 2). Irradiation was carried out in a Linear Accelerator device (LINAC) (Electa-Precise) by using solid water phantom. First, we performed calibration on the dosimetry systems. In the second stage of our research, we examined the energy dependence of the systems, and in the third step, we performed measurements to investigate dependence on the therapy area.



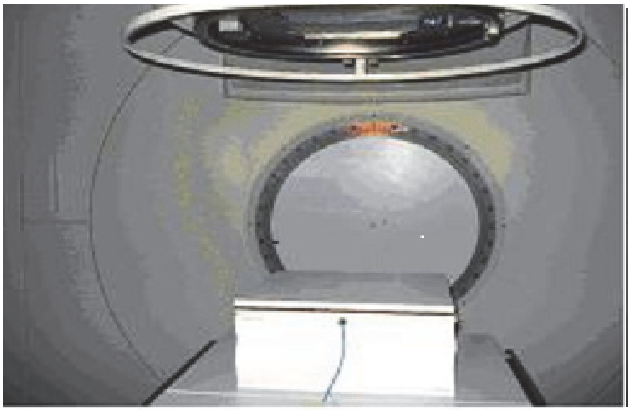


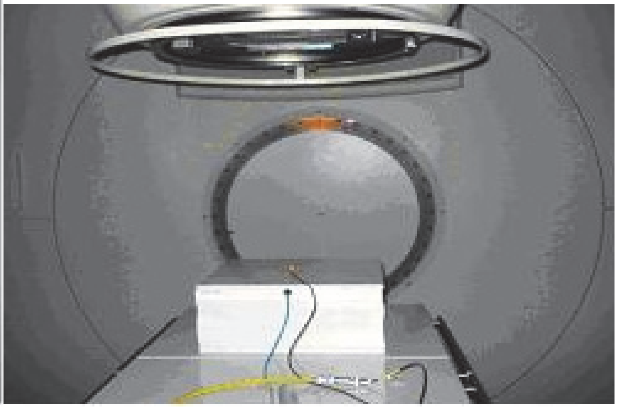
Figures 2a and 2b. a) TLDs b) MOSFETs

1) Calibration

Prior to the radiation measurement with TLD, we started the calibration and categorisation. We performed the following to stabilise 70 TLD crystals: to empty the traps in TLDs, we applied a annealing process by placing the crystals on metal trays. The annealing was performed in two stages: the long annealing process at 400 degrees C for 5 hours and the short annealing at 100 degree C for an hour. The annealed TLDs were then placed in a plexiglas tray in LINAC. The tray was 6 mm in diameter and 1mm in depth. Next, the crystals were irradiated at a radiation dose of 100cGy on a 5mm deep, 10x10cm2 treatment area, at a 100cm source skin distance (SSD). After the irradiation application and reading TLDs in the TLD reading system with the Winrems software, they were let loose in the traps. All these processes were repeated 10 times to increase the sensitivity of the dosimeters, to stabilize the dosimetry measurements, and to determine reproducibility. By using the Winrems software, we selected the best 15 TLD-100 chips (with a sensitivity rate of ±1%) from among seventy 1x3x3mm3 TLD-100 chips.

To let MOSFETs adapt to external factors such as temperature, pressure, and humidity, they were brought to the environment in which they would be used. In order to have a homogeneous dose, detectors were positioned to the isocenter as closely as possible. Since 100-200 cGy at a dose rate of 100 to 300 cGy/min is enough for calibration, we administered 100-200 cGy of radiation and recorded the values. After the calibration, we administered additional irradiation in the normal measurement mode of the dose monitor to confirm the calibration. The measurement sets used for irradiation in TLD and MOSFET are displayed in Figures 3a and 3b.





Figures 3a and 3b. a) Measurement set (TLD) b) Measurement set (MOSFET)

2) Determining Radiation Dose Dependence of the Dosimeters

We determined the irradiation dose dependence of the TLDs and MOSFETs, both of which are used in 6 MV and 25 MV photon energies in radiation therapy. The gantry (treatment head) and collimator on the LINAC were set to 0°. We placed ten PTW brand RW3 solid water phantoms (bulk density: 1,045g/cm^3; electron density: 3.43x1023e/cm^3; dimensions: of 40x40cm^2) on top of one another. The treatment area size was 10x10cm^2 and and the dosimeters were set in the centre 100 cm SSD from the treatment area; then, we performed radiation at 25, 50, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 cGy, respectively. Each irradiation session for each value was repeated 3 times and we took the average result of the three readings as the mean dependence rate.

3) Determining Treatment Area Size Dependence of the Dosimeters

Since photon input dose is dependent on collimator scatter factor (Sc) and phantom scatter factor (Sp), dosimeter readings may depend on the treatment area size (4, 9). Therefore, it is necessary to determine the treatment area dependence of the dosimetres.

In order to see the changes in the size of the treatment area and TLD readings, we placed the TLD 1cm below the center area of the solid water phantom and a cylindrical ion chamber 1,5 cm beneath the maximum dose depth. The SSD was 100cm and the treatment area size was adjusted to 5x5, 10x10, 15x15, 20x20, 25x25, 30x30, 35x35, and 40x40 cm^2, respectively. To minimise the effects of parameters on irradiation time, we performed irradiation at a constant irradiation volume of 100 MU. To increase the stability of the application, we repeated each process three times and averaged the results. All measurements were repeated for 6 MV and 25 MV.

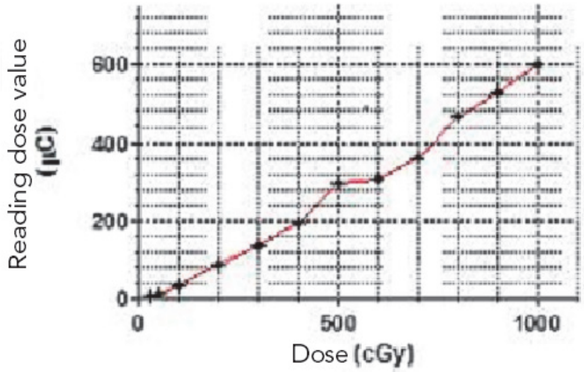
In order to see the changes in the size of the treatment area and diode readings, we repeated the measurements by placing a diode on the surface and in the centre of the solid water phantom and a cylindrical ion chamber 1,5 cm beneath the maximum dose depth. The readings for different therapeutic areas were normalised to the reading values of the treatment area of 10x10cm^2.

RESULTS

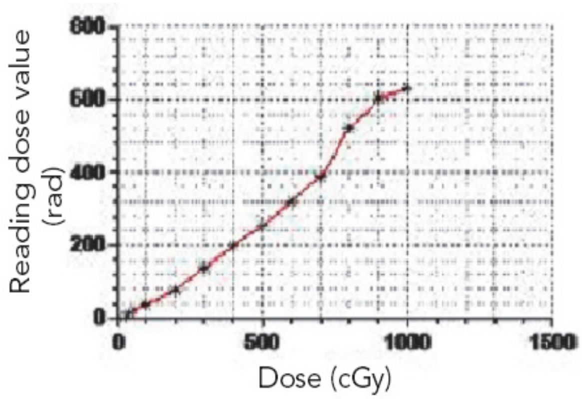
1) Radiation Dose Dependence:

TLD

Graphs 1 and 2, respectively, shows the radiation dose related changes of the readings at 6 MV and 25 MV photon energies in the range of 25-1000cGy.



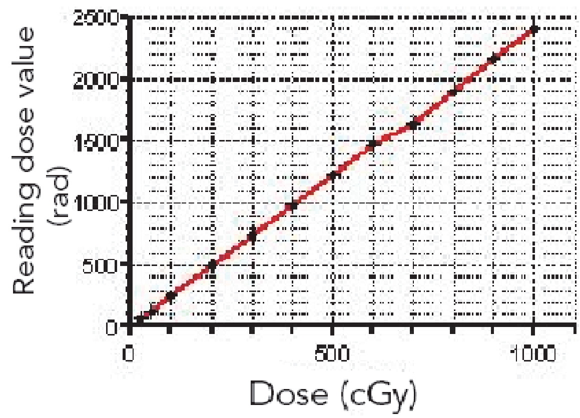
Graph 1. Radiation Dose Dependence of TLDs at 6 MV photon energy



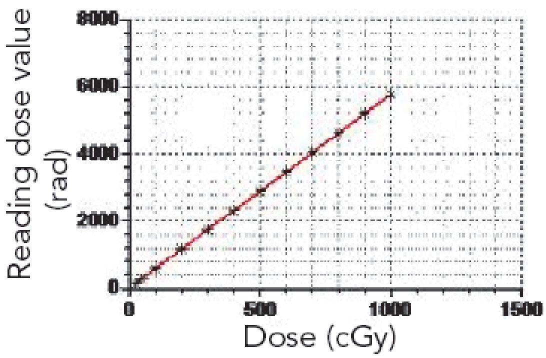
Graph 2. Radiation Dose Dependence of TLDs at 25MV photon energy

MOSFET

Graph 3 shows the radiation dose related changes of the MOSFETs at 6 MV photon energy in the range of 25-1000cGy while Graph 4 shows the radiation dose related changes at 25 MV photon energy.



Graph 3. Radiation Dose Dependence of MOSFETs at 6 MV photon energy



Graph 4. Radiation Dose Dependence of MOSFETs at 25 MV photon energy

In TLDs, radiation dose related changes at 6 MV and 25 MV were linear up to 800 cGy; these changes showed deviation after 800 cGy. In MOSFETs, radiation dose dependent changes were linear throughout both 6 MV and 25 MV measurements. Both dosimetry systems had a rising tendency in the readings as the photon energy increased; this rising inclination, eventually, is reflected in the graphs

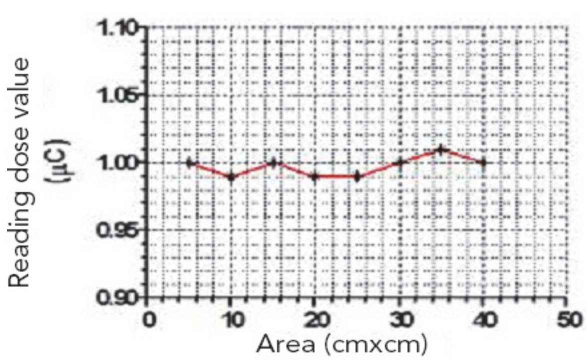
2) Treatment Area Size Dependence:

TLD

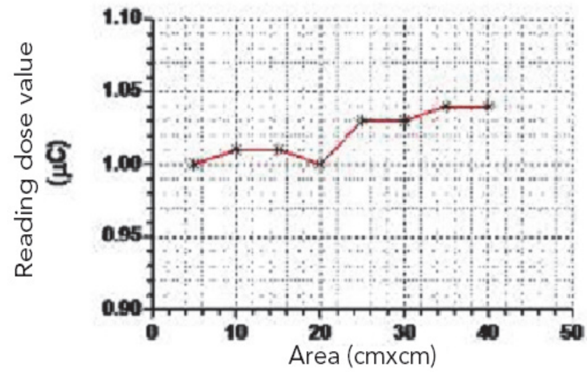
Graph 5 provides the changes observed in the area dependence of TLDs while SSD was 100 cm at 6 MV in 5x5, 10x10, 15x15, 20x20, 25x25, 30x30, and 40x40 cm^2 by using Elekta Precise LINAC device.Graph 6 presents the increase in the area dependence as the photon energy goes up to 25 MV; here, the maximum value for these changes was observed to be +4%.

MOSFET

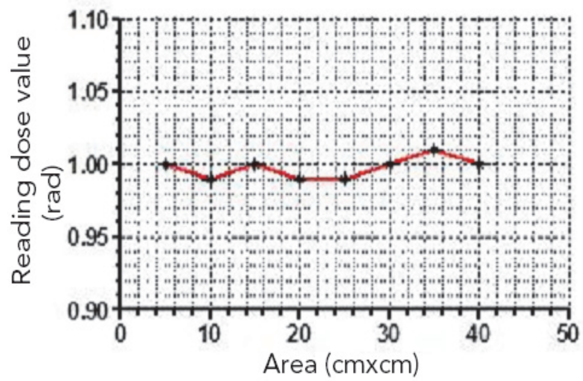
Graph 7 shows the changes observed in the area dependence of MOSFETs while SSD was 100cm at 6 MV in 5x5, 10x10, 15x15, 20x20, 25x25, 30x30, and 40x40 cm^2. At 6 MV and depending on the increase in the treatment area, the change in the reading value was +1%. Graph 8 presents the increase in the area dependence at 25 MV; here, the maximum value for these changes was observed to be +4%.



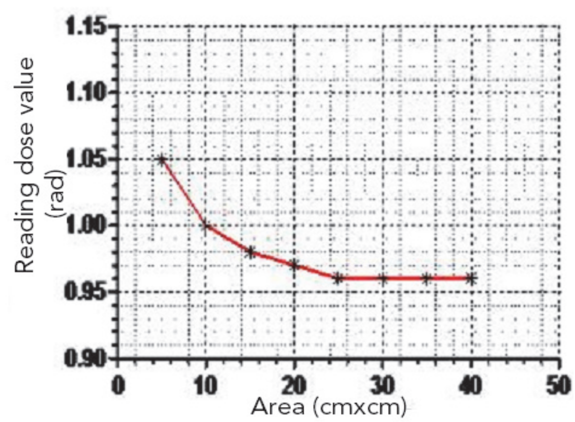
Graph 5. Treatment Area Dependence of TLDs at 6 MV photon energy



Graph 6. Treatment Area Dependence of TLDs at 25 MV photon energy



Graph 7. Treatment Area Dependence of MOSFETs at 6 MV photon energy



Graph 8. Treatment Area Dependence of MOSFETs at 25 MV photon energy

DISCUSSION

In radiation oncology, the accuracy of the radiation dose delivered to the patient is the most important part of the quality assurance programmes. In this study, we have compared the linearity of the dose-dependent change and dependence on the treatment area in TLD and MOSFETs, two devices used in radiotherapy, to find whether these dosimetry systems are at ideal levels in terms of dose and area dependence.

Ideally, a dosimeter must show a linear change as radiation dose increases (8). In our study, TLDs maintained a linear change at 6 MV and 25 MV up to 800 cGy. However, above 800cGy, there were deviations in its linearity. A.J. Troncall et al. has perviously shown that the standard deviation was around 3% range in all doses in TLDs up to 1000 cGy (17). As far as our study is concerned, we believe that this deviation in linearity in terms of dose response above 800 cGy can be explained by the incapability of TLDs to respond to this increase in dose due to overloaded traps.

In MOSFETs, we observed an increase in reading values resulting from the increase in radiation dose. This change remained linear in both photon power levels up to 1000 cGy radiation dose. However, as it has been pointed out in other studies (11), when the amount of irradiation increases, there may be decreases in the response sensitivity of the diodes. We have observed that the change at 6 MV was smaller than it was at 25 MV in both photon energy levels. As a result of this, a further observation was the increase in the dependence on radiation dose due to the increase in energy levels (9).

Dependence on treatment area arises from scattered electrons and photons. The collimator scatter is added to the primary beam as the area enlarges, and accordingly, scattered radiation increases the amount of the absorbed dose (6).

For larger areas (40x40 cm^2), dosimetry system's dependence on the treatment area size may increase up to 5% in ion chamber measurement. This is due to the effect of the Sc, Sp, and collimator phantom scatter (Scp) on the dose distribution (8). At 6MV, the dependence to treatment area size was +1% for MOSFETs while the same value was ±1% for TLDs. At 25 MV, as the treatment area enlarged, the treatment area size dependence reached up to %± 4 in MOSFETs. This was up to +4% in TLDs.

CONCLUSION

Comparing TLDs and MOSFETs, it can be concluded that MOSFETs are more linear in terms of dependence on radiation dose. Apart from the daily fractionated doses, practitioners should prefer MOSFET to TLD by taking this deviation from linearity into consideration in TLDs especially in special applications like total body irradiation (TBI) and total skin electron irradiation (TSEI) that require fractional treatment doses above 800cGy. However, it should also be kept in mind that even MOSFETs share deformation at high doses of radiation. In dosimetry systems used at 6 MV, the increase in the treatment area size does not have an effect on reading though dosimetry systems should be calibrated by using appropriate calibration factors in line with the treatment area size at 25 MV photon energy.

MOSFET system is advantageous because it provides dose display, does not require secondary reading, and allows immediate detection and correction of potential errors. TLDs, on the other hand, are easier to use. TLDs can be easily placed on the skin and body cavities while they can also be used with random phantoms. TLDs do not require any additional components such as cables and electrometers during irradiation. MOSFETs get easily affected by changes in temperature and humidity. TLDs, compared to the diodes, are less affected by these changes.

To sum up, users should be familiar with the features of the dosimetry systems they are using to determine the accuracy of the administered dose. Therefore, by controlling the accuracy therapeutic doses, treatment quality increases while possible errors are minimised.

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Received/Başvuru: 10.02.2014, Accepted/Kabul: 08.04.2014

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For citing/Atıf için

Kaya Pepele E, Barlaz Us S, Yaray K, Eroglu C, Dirican B, Soyuer S. A Comparative study of radiation doses and treatment area dependence in thermoluminescence dosimetry systems and metal oxide semiconductor field effect transistors. J Turgut Ozal Med Cent 2015;22:22-8
DOI: 10.7247/jtomc.2014.1764