Original article

CLINICAL APPLICATION OF IN VIVO DOSMETRY FOR EVALEUATION BREAST IRRADIATION USING TELECOBALT MACHINE

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Abstract

The delivery of a treatment in radiotherapy requires many sequential, complex steps of prescription, imaging, calculation and patient positioning. Every step can contribute to the total uncertainty of delivered dose. So it is necessary to check each step, in-vivo dosimetry (IVD) is the only check that performed during the patient treatment, and it is independent of the calculation method, it is the only method that can trace a number of errors. The aim of this study is to verify response of the thermo luminescence detectors (TDLs) type (LiF:Mg;Cu;P) used in radiotherapy, this type of the (TLDs) is preferable for diagnostic radiology and radiotherapy. To establish calibration procedure of (TLDs) (LiF:Mg;Cu;P) for therapy application at Radiation and isotope center Khartoum (RICK) and to calculate entrance dose obtained by the treatment planning system with measured dose using (TLDs) . In this study the (TLDs) calibrated against farmer type chamber (FC 65-G) with Cobalt-60 photon beam. The Rando phantom with 6 (TLDs) in place were irradiated with time obtained from treatment planning system (TPS) for tow tangential beams used for breast irradiation, and measured by the (TLDs) reader, then compared with calculated dose. For Breast entrance doe (TLDs) were placed on the patient surface and irradiated with time obtained by TPS for tow tangential beams used for breast irradiation, then (TLDs) were measured by (TLDs) reader, and compared with calculated dose, the comparison of the measured and calculated doses are expressed in terms of percentage difference. Comparison of the calculated dose by TPS (pinnacle) with the measured dose by (TLDs) for Rando phantom for Breast irradiation, each calculated dose was close to measured one and it's within the tolerance level.

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Introduction

The ultimate overall goal of radiotherapy is to deliver specified radiation dose to the prescribed target volume with the least dose to healthy tissues. This means a sophisticated balance between the cure of the illness and the possibility of radiation induced complications, therefore the demands of precision and accuracy in radiotherapy are high, because often small increase in radiation dose will have crucial influence on the probability of a cure but simultaneously the probability of induction of irreversible damage to the patient will increase the full benefit of radiotherapy treatment of cancer can only be achieved if the radiation doses to patients are accurate and reproducible. There are two fundamentally different but equally vital requirements for achieving this:

Firstly, accuracy and precision can be achieved by high quality measurements of treatment beams and careful calculation of

doses to target volumes, supported by a good preventive maintenance programme for the equipment, i.e. well implemented quality assurance programme.

Secondly, it is necessary to prevent a wide range of simple errors, which compromise safety. This second requirement has not always been acknowledged but its importance may be demonstrated by accidents at busy radiotherapy centres. Even all recommendations for quality assurance, local rules and practical guidelines are followed the occurrence of misadministration and accidents in radiotherapy departments are still very common. IAEA, International Atomic Energy Agency (1997).

1.1 The Role of *in vivo* dosimetry in radiotherapy

Although the technical and physical aspects of quality assurance are well documented, no guidelines exist for the verification of the whole radiotherapy process at the individual patient level (Fontenla *et al.,* 1996). Each step involved in the planning or accomplishing of a treatment is subject to a certain degree of uncertainty leading to cumulative discrepancy between prescribed and delivered dose, because it is not possible to eliminate all possible errors with conventional quality assurance programs, it increasingly recommended to perform verifications on individual patients to check the whole chain of radiotherapy (Howlett *et al.,* 1999).

The breakthrough of in (IVD) occurred at the end of the sixtieth last century, when (TLDs) became available and more recently when semiconductor detectors were introduced as radiation dosimeters. For most (IVD) measurements diodes proved to be the dosimeters of choice due to their advantages (real time read-out, high sensitivity, good spatial resolution, simple instrumentation, robustness and air pressure independence). (IVD) is the most direct method for monitoring the dose delivered to the patient receiving radiation therapy, it allows comparison between prescribed and delivered doses and thus provides a level of radiotherapy quality assurance that supplements port films and computational double check. When performed early in treatment as a supplement to the clinical quality assurance (QA) program, simple in-vivo measurements are an additional safeguard against major setup errors and calculation or transcription errors that were missed during pre-treatment chart check (AAPM Report NO. 87, 2005). In ICRU report 24 it is also specified what (IVD) might include (ICRU report 24, 2003).

Entrance dose measurements, exit dose measurements, transmission measurements and intracavitary absorbed dose measurements serve to check the output and performance of the treatment apparatus as well as the accuracy of the patient set-up. Exit dose measurements serve in addition, to check the dose calculation algorithm and to determine the influence of shape, size and density variations of the patient body on the dose calculation procedure.

1.2 Radiothermoluminescent dosimeters

(TLDs) has been developed considerably over the past ten years, the commercial availability of reliable detector materials and the commercialization of automatic readout systems being a decisive factor. For in vivo measurements, (TLDs) have the advantage of being highly sensitive under a very small volume and not to be connected to an electrometer with an unwieldy cable, their major disadvantage which is the time required for readout can be considerably decreased by a good choice of the equipment and a good methodology (Van Dan Jan and Marinello, 2006). (TLDs) is based upon the ability of imperfect crystals to absorb and store the energy of ionizing radiation, which upon heating is re-emitted in the form of electromagnetic radiation, mainly in the visible wavelength the light emitted is then detected by a photomultiplier tube (PM) and correlated to the absorbed dose received by the thermo luminescence (TL) material.

One of the possible mechanisms is presented in Fig. 1.0 Energy states in a crystal being represented with energy increasing upwards along the ordinate, free electrons and holes are produced under the irradiation effect both of them are free to travel throughout the Solid state in the conduction band for a short time, they may be ultimately either trapped at defects or fall back into the valence band and recombine either radiatively (fluorescence) or none radiatively with holes, or be captured at luminescent centres with the emission of light, the electrons may stay in the traps for prolonged periods (up to months), which confers to the (TL) method, the store information can then be collected by heating the crystal to a temperature depending upon its nature, the calorific energy is used by the electrons to escape from the trap again into the conduction band, where they are free

to travel and have three possible fates as before: either be retrapped at defects or fall into the valence band and recombine radiatively, or recombine radiatively at a hole-activated luminescence centre the light emitted by this last process is called (TL), heating and light collection are performed in a readout system called the (TLDs) reader the (TLDs) signal as a function of temperature (or of time if this parameter is correlated with temperature) is a complex nature and is called a glow curve, it consists of different (TLDs) peaks, each peak corresponding to a different energy state in the crystal they are either unstable, decaying more or less quickly with time according to the (TL) material, or stable, (TLDs) always contain both unstable and stable peaks, the later being the one(s) used in dosimetry, they are called dosimetric peaks, after readout the (TL) material is either entirely in its original state, in this case it is just ready for re-use, or it is requires a special heating treatment called annealing in order to restore it to its original state (Van Dan Jan and Marinello, 2006).

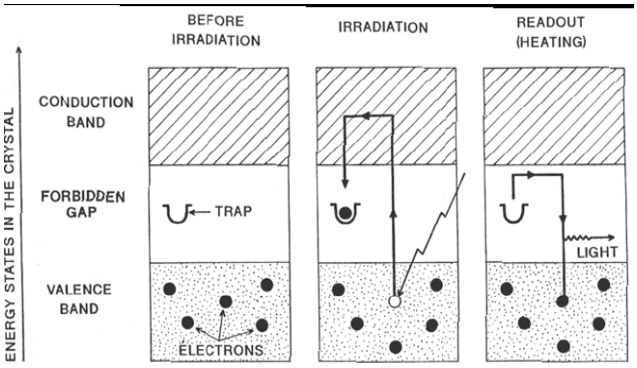

Fig. (1.0) One of the possible mechanisms of thermoluminecence

1.3 Clinical application of in-vivo dosimetry (IVD)

First possible aim of (IVD) is to compare the doses derived from the signal of the detectors placed on the skin with the theoretical values, as calculated by the Treatment Planning System TPS, however the accuracy of the calculation of the dose to the skin is questionable, and in many cases irrelevant, the signal of the detector is converted to the dose, at a point which is still close to the skin, but at a certain depth where the accuracy of the TPS is much more satisfactory. One point is close to the entrance, while the other is close to the exit surface of the beam. The corresponding doses are called entrance and exit doses, respectively, with regard to the exit dose, there is a considerable loss of backscatter, and while the TPS calculations are valid for semi-infinite patients implying complete backscatter at the exit surface a correction is then necessary. A more ambitious aim of (IVD) is to check the target dose, in order to verify the correct delivery of irradiation except when detectors can be introduced in natural body cavities such as oesophageal tube, rectum, vagina, etc, this is impossible. As a matter of fact, a check of the entrance and exit dose is also an indirect check of the target dose. However, if a deviation is observed between the computed and measured entrance or exit dose (under the assumption that the experimental value is correct) it may be because the target dose is wrong (due to a wrong in time, an error in the irradiation parameters, an incorrect patient set-up or an unexpected variation of the machine output), or because the calculation of the entrance or exit doses, or even from a correct target dose is wrong, or because of a combination of both types of error. A more selective check of the target dose is then of the high interest. A third possible aim of (IVD) can be the determination of the skin dose itself, this measurement is critical and requires a special methodology (Van Dan Jan and Marinello, 2006).

1.4 Use of TLDs in the *in vivo* dosimetry

Theoretically, for (IVD) with (TLDs), the same approach as for diodes could be used. Indeed, a calibration factor should be prescribed to each (TLDs) as it is done to a diode, it would then of course be necessary to monitor these factors over time, at each readout session patient detectors are just analyzed together with some calibration detectors, these methods applied in (TLDs), are presently well documented and, thanks to the availability of modern automated readers, the large scale applicability of this dosimetry method, especially for invivo measurements, has increased considerably. (Van Dan Jan and Marinello, 2006).

2.1 The Importance of the Study

Worldwide, cobalt unit have been replaced to a large extent by linear accelerator (linacs), especially in developed countries, but is still, widely used in developing countries. Usually the telecobalt units are available with symmetric collimator and individualized wedges (universal wedges). Until now, the concept of advanced technology with motorized wedges and asymmetric jaws was used in linacs only. Installation of a modern telecobalt unit at our centre provided opportunity to investigate the optimal clinical implementation of asymmetry

jaws and motorized wedges. Moreover the breast cancer is first common disease in the female patient in Sudan.

2.2 **The Aim of the Study**

Knowledge of the dose distribution and the absolute dose for two tangential beams for breast irradiation is necessary for their use in clinical practice. The objective of this study is to evaluate the difference between measured and calculated dose and to determine the accuracy to which the TPS calculates the absorbed and relative doses for open and wedges fields.

2.3 The specific objectives of this study

To perform TLDs calibration against farmer chamber (FC 65-G). With Cobalt-60 photon beam.

To perform relative and absolute dose measurements in Rando phantom.

To perform entrance dose measurements for two tangential beams for breast irradiation.

To compare measured and calculated doses for two tangential beams for breast irradiation and Rando phantom.

3. Materials and Methods

3.1 RANDO Phantom

The RANDO Phantoms provide the detailed mapping of dose distribution that is essential for evaluating radiotherapy treatment plans (WWW.phantomlab.com.html, RANDO Phantom 2018). The phantom utilized in this study is the Female RANDO Phantom, which does not have arms or legs and have been mastectomy. Fig: 2.0 shows Rando phantom.

3.2 Thermoluminescence dosimeter (TLDs) (LiF:Mg;Cu;P(GR-200A)

Measurements were made using (TLDs) Chips type LiF:Mg;Cu;P(GR-200A), (TLDs) detectors are gaining popularity as dosimeters in radiation therapy.These types of (TLDs) have unique features such as small size, inexpensive, rugged, and reusable because the sensitivity of the (TLDs) usually remains consistent for many cycles of measurement (Dogan, 2002).

The automatic (TLDs) reader type PCL3 was used in this experiment, it is designed for the evaluation of different (TLDs) material in the form of rods, chips or powder in one loading, it can read 80 dosimeter with varies type of TLDs depending on the type of material used, the system can be applied for dose levels ranging from environmental monitoring to radiation therapy and beyond. (TL Detectors, 2003).

Fig: (2.0) Rando phantoms

3.3 TLD preparation

3.3.1 Annealing procedure

The thermal treatment is essential procedure for re-usability of (TLDs), and the ideal annealing parameter can depend on the actual material and instrument annealing procedures consisted of two steps high temperature, and flowed by fast cooling, as describe the procedure in the user manual (Instruction manual, 2003). The (TLDs) were first placed in the annealing tray, the tray used for annealing was made of steal and the (TLDs) were put in the (TLDs) containers (cupels) and then in the tray, in each cupel holds one (TLD). The steal tray was heated to 240 C in the ovens for 10 min; then flowed by 10 min cooling; this procedure should be done before and after each measurement.

3.3.2 The Linearity response of TLDs

It is important in any (TLDs) application to have, if it is

possible, a linear relationship between the (TLDs) emission and the absorbed dose, the linearity zone, if exists, is more or less depending on the material, as well as on the reader, a typical first order relationship can be written as shown in equation [3.1].

$$Y = ax + b \quad \text{…….. [3.1]}$$

The linearity range, as already mentioned, depends on the particular thermo luminescent material. The plot of Eq. [3-1] is a straight line with slop,, a,, and intercept ,,b,, on the Y-axis the physical meaning of the x and y variables, when use the Eq.[3-1] to describe the (TLDs) yield as a function of the dose are: the independent variable x represents the absorbed dose D received by the (TLDs), and the depending variable y is the TL light emitted by the dosimeters irradiated at the dose D.A subset of chips from LiF:Mg;Cu;P (RG-200A) were selected to be used for linearity investigation by exposing with the known dose of Co60 γ-ray 0.6, 1, 1.5, and 2Gy, three (TLDs) in each group and the average were calculated, the irradiation were performed by placing the (TLDs) at 10.0 cm depth in water phantom, with 90.0 cm SSD, in a 10.0 x 10.0 cm^2 radiation field size for photon beam the average doses measured by the (TLDs) were plotted as function of the irradiation value. Signals were recorded and listed in Table (3.1). And the responses are shown in Fig (3.1).

Table (3.1) (TLDs) linearity

	Signal(nC)	Average	Dose (Gy)
1	377349		
	483256		
	686290	515631.7	0.6
2	1788161		
	1717194		
	1694169	1733174.7	1
3	2026673		
	2740253		
	2027115	2264680.3	1.5
4	3586520		
	3444359		
	3380681	3470430	2

3.3.3 Fading effect

Usually, when the (LiF:Mg;Cu;P (RG-200A) is stored at room temperature after irradiation and before measurement, there is no fading in two months period of time, even in the high humidity of 95% at room temperature there is no fading. At the temperature of 50° C, after 1 month storage, the fading is less than 3%., in this study the fading factor was consider one, because the chips were reading immediately after irradiation.

3.3.4 Calibration of (TLDs)

TLDs as detector they need to be calibrated against accurate dosimetry references, such as an ionization chamber traceable to an accredited dosimetry calibration laboratory and determined the calibration factor use for in vivo dosimetry. In this study the TLDs calibrated against farmer chamber (FC 65-G) with Cobalt-60 photon beam the ionization chamber was inserted into waterproof sleeve and placed into water phantom, the user chamber was aligned with field center and placed at reference depth of 10.0 cm ,SSD equal 90.0 cm , field size 10.0x10.0 and horizontal beam is used and irradiated with 2.0Gy, the chamber was connected to DOSE-1 electrometer; reading was corrected for influence quantities, following the IAEA TRS-398 code of practice, then the ionization chamber was removed and a set of sixty (TLDs) type (LiF:Mg;Cu;P (RG-200A) were used, the set was grouped to twelve patches; each patch consisted of five (TLDs), the patching was done to allow accurate position and to avoid the field edge each patch was inserted in a (TLDs) holder, which can be fitted into a calibration water phantom, the (TLDs) holder was centred along the central axis of Cobalt-60 beam each time using ceiling and wall mounted lasers, the (TLDs) in each patch were exposed uniformly to 2.0 Gy, the beam was horizontally incident on the water phantom, the irradiation setting was 10.0 x 10.0 cm^2 Field size, 90.0 cm SSD and 10.0 cm depth on an Equnix-100 Cobalt-60 machine, during the setup for irradiation, the phantom with (TLDs) were carefully placed such that no (TLDs) would lie in the shadow of the metal cross-hair of Cobalt-60 head to avoid small dose variation caused by the wire. Vacuum tweezers was used to handle the (TLDs), this careful handling is very important to protect the (TLDs) from contamination the (TLDs) were read out using (TLDs) reader system (type fimele PCL3). All (TLDs) were read out at the Radiation and Isotope Centre Khartoum. After being read out the calibration factors (F) of each (TLDs) groups were determined by the following equation.

$$F = D/M \quad \text{……..… [3.2]}$$

Where D is ionization chamber reading at reference depth and M

is (TLDs) signal.

3.4 External beam therapy equipment

Beam data were obtained from (Theratron Equinox 100 MDS Nordion, Canada) teletherapy Cobalt unit (Theratron Equinox - 100., 2003). Using the phantom that designed for absolute dose measurements in radiation beams with horizontal beam incidence, furthermore it is suitable for the calibration of ionization chambers used in radiation therapy the phantoms' design allows cross calibration of a field ionization chamber against a calibrated reference chamber at the user's facility. The Farmer type Chamber FC- 65 –G is a waterproof, vented chamber suitable for electron and photon beam dosimetry, it is used for dose measurements, depth dose measurements and field profile analysis in a water phantom or in free air (Scanditronix Wellhofer, 2003). It is connected to Therapy electrometer –Dose -1 which is a very sophisticated and accurate measuring device for the dose and dose rate in radiation therapy, it has ability to store all correction factors required in the measurements and then compensate the corrected reading (ScanditronixWellhoferDose-1, 2003).

3.5 C.T simulator

C.T-Scan data obtained from AcQSim C.T^{TM} scanner that designed specifically for oncology departments, the system features a unique 85.0 cm bore that facilitates positioning difficult to image exams such as breast, mantle, and large patients, and a set of laser with three positions one on the roof and two on the opposite walls for patient positioning (C.T, 2005). User manual, PhilipsAcQSim, (2016) was used as patient imaging device with corresponding to tissue density, the C.T scan image displays both high density tissue such as bone, and low density tissue such as lung and soft tissue, the image data can be transferred to the pinnacle TPS by DICOM.

An experiment was preformed to verify the Rando Phantom dose and entrance dose; it is divided into five parts:

- Dose calculation in TPS for Rando phantom.
- Rando Phantom dose measurement by TLD.
- Patient Set-Up in the C.T Simulator for breast irradiation.
- Dose calculation in TPS for breast irradiation.
- Patient dose measurement by TLD.

3.6.1 Dose calculation in TPS for RONDO phantom

The reference laser point was used to set the phantom and used the catheters to mark the phantom for simulation; the C.T image data for the Rando phantom were acquired and transferred to TPS. A daily 266.7cGy prescribed dose was calculated for two tangential beams for breast irradiation, the dose for five hold and entrance were calculated for all beams. The central slice isodose line is shown in Fig (3.1) and dose volume histogram to evaluate this plan is show in Fig (3.2).

3.6.2 The TLD measurement in the Rando phantom

The Rando phantom with 6 (TLDs) in place were irradiated with time obtained from TPS for tow tangential beams use for breast irradiation, then all 6 (TLDs) were taken out from Rando phantom and measured by (TLDs) reader, and compared with calculated dose, the comparison of the measured and calculated doses is expressed in terms of percentage difference.

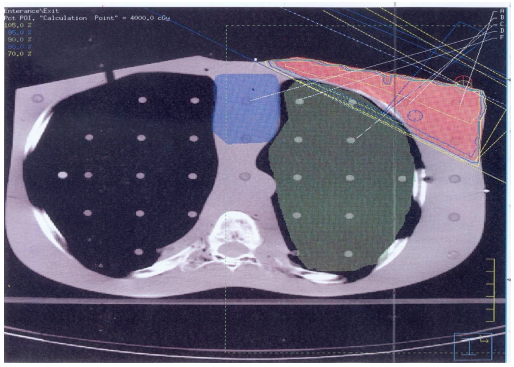

Fig. (3.1) Center slice isodose line for Rando phantom, Lt Breast irradiation.

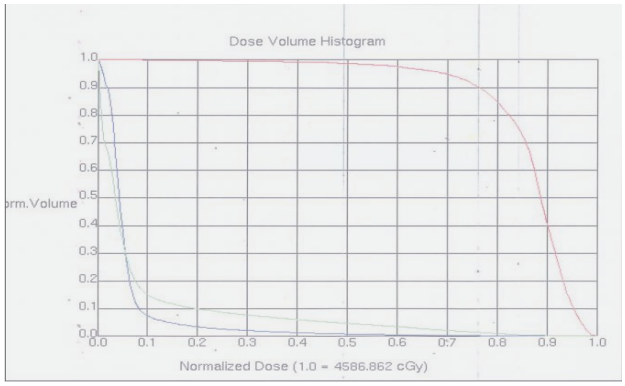

Fig (3.2) Dose volume histogram

3.7.1 Patient Set-Up in the C.T Simulator for breast irradiation

Patient position for Set-up in the C.T Simulator was as follow:

- Place board on the table with the pins for the arm and forearm supports snug against the table.
- Position the patient on the board with her arms by her sides and with her shoulder joint over the pivot of the arm support.
- Straighten the patient on the table.
- Raise the patient's arm and place it into the arm support and wrist support.
- Adjust the arm support and shoulder to find a position that is comfortable for the patient but places her arm out of the way of the tangential fields, make sure the upper arm is well cradled and not binding in the arm support.
- Raise the patient's head and slip the head platform and headrest into place; put the platform into the set of holes closest to the patient's head position.

3.7.2 Treatment planning and dose calculation for the lt. breast irradiation

Dose calculated for multiple slides C.T scan image, 5mm slice thickness and 3mm distance between adjacent slices in the TPS, a daily 266.7cGy prescribed dose was calculated for two tangential beams for breast irradiation and entrance dose were calculated for all beams, the center slice isodose line was shown in Fig (3.3) and dose volume histogram in Fig (3.4).

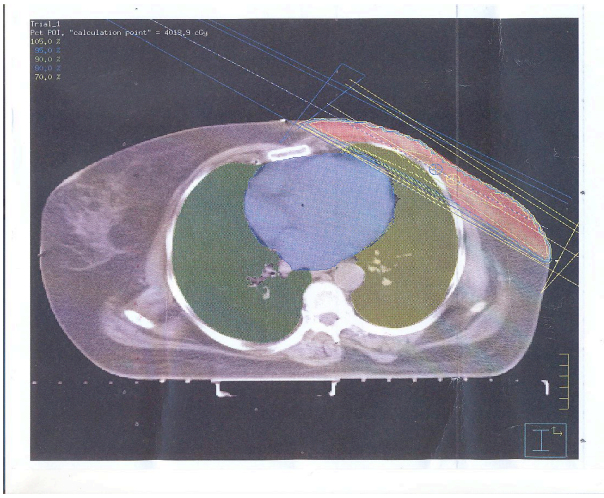

Fig (3.3) Center slice isodose line for Lt breast irradiation

3.7.3 The (TLDs) measurement in the breast irradiation.

The (TLDs) were placed on the patient surface irradiated with time obtained by TPS for tow tangential beams used for breast irradiation, then (TLDs) were measured by (TLDs) reader, and compared with calculated dose, the comparison of the measured and calculated doses is expressed in terms of percentage difference**.**

4. Results and Discussion

4.1 Linearity test of the TLDs

The plots of the average dose measured by the (TLDs) as a function of irradiated value were linear with R^2 equal 0.9999 as shown in Fig (3.1). (TLDs) showed excellent linearity, according to equation (3.1) "a" equal 296998 and represents the absolute sensitivity of the dosimeter, or with the inverse of calibration factor, and "b" equal 233214 and represents the (TLDs) reading due to intrinsic background for the same dosimeter just annealed and not irradiated.

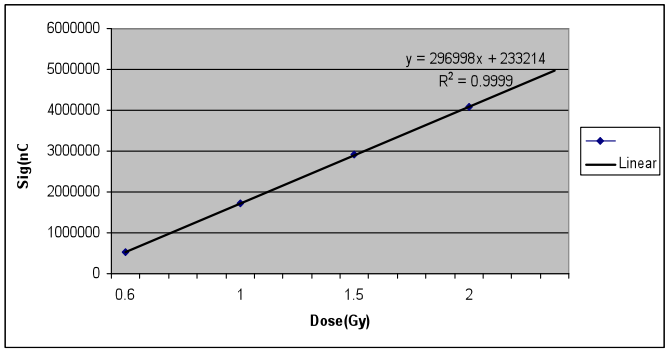

Fig (3.5) TLDs linearity

4.2 Fading effect

Fading factor was considering one because there is no fading; the signals were reading immediately after measurements.

4.3 Calibration factor calculation

The calibration factors were used to convert the reading in nC of each (TLDs) to absorbed dose the calibration factors calculated by using equation (3.2).

4.4The measurement of dose in Rando phantom

The comparison of the calculated dose by TPS (pinnacle) with the measured dose by (TLDs) was shown in Table (3.2) and Fig (3.6), each calculation dose was close to measured one and it's within the tolerance level.

Table (3.2) percentage difference of the calculated doses compared with measured doses for Rando phantom.

Point	Calculated Dose	Measured Dose	%Difference
Entrance dose (Med.T.F)	296.6	279	6
A (in PTV)	293	274.8	6.6
B (in PTV)	272.8	257.6	5.9
C (in lung)	21.2	19.5	8.7
D (in hurt)	17	15.7	8.3
F (in lung)	17.9	16.8	6.5

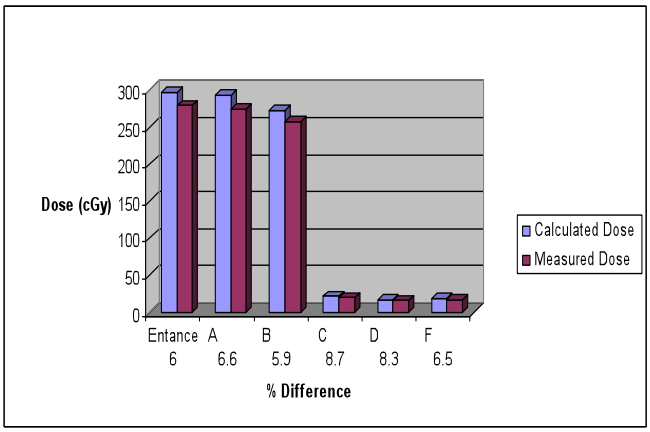

Fig (3.6) Calculated& Measured dose Vs % Difference

4.5 The measurement of dose in breast irradiation

The comparison of the calculated dose by TPS (pinnacle) with the measured dose by (TLDs) was shown in Table (3.3), the calculation dose was close to measured dose and it's within the tolerance level.

Table (3.3) percentage difference of the calculated dose compared with measured doses for breast irradiation.

Point	Calculated dose	Measured dose	%Difference
Entrance dose (Med.T.F)	186.3	170.3	9.3
Entrance dose (Lat.T.F)	178.9	164.2	8.9

Conclusion

(TLDs) (LiF:Mg;Cu;p) chips were annealed and calibrated by using farmer chamber (FC 65-G), with Cobalt-60 photon beam. The Rando phantom with 6 (TLDs) in place were irradiated with time obtained from TPS for tangential beam use for breast irradiation, and measured by (TLDs) reader, then the measured value was converted to absorbed dose by applying correction factors, such as energy correction, fading and non-linearity corrections the result was compared with calculated absorbed dose the comparison of the measured and calculated doses is expressed in terms of percentage difference**,** the percentage different for calculated and measured absorbed dose for Rando phantom was found to be between (5.9 - 8.7) % and for breast irradiation (8.9-9.3) %.

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