Comparison of dosimeter response: ionization chamber, TLD, and Gafchromic EBT2 film in 3D-CRT, IMRT, and SBRT techniques for lung cancer

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Abstract. This research was conducted by measuring point dose in the target area (lungs), heart, and spine using four dosimeters (PTW N30013, Exradin A16, TLD, and the Gafchromic EBT2 film). The measurement was performed in CIRS 002LFC thorax phantom. The main objective of this study was to compare the dosimetry of those different systems. Dose measurements performed only in a single fraction of irradiation. The measurements result shown that TLD has the least accuracy and precision. As the effect of volume averaging, ionization chamber reaches the discrepancy value up to -13.30% in the target area. EBT2 film has discrepancy value of <1% in the 3D-CRT and IMRT techniques. This dosimeter is proposed to be an appropriate alternative dosimeter to be used at point dose verification.

1. Introduction

The role of radiotherapy in the treatment of lung cancer consists of several different techniques, which have been developed to achieve conformal dose distribution in the target volume while minimizing dose to the surrounding normal tissue. Treatment of lung cancer using irradiation needs a high accuracy and precision due to the presence of OARs around the target volume. Research conducted by Brahme in 1984 showed that the dose difference by 5% of target volume resulted in changes in the probability of tumor control by 10-20%; and increase the probability of healthy tissue complication by 20-30% [1]. Therefore, the dose verification is needed -especially in small field-, such as IMRT and SBRT- and it can be performed by measuring point dose in several investigated points. Dose verification can be done by measuring the point dose using ionization chamber or in vivo by thermoluminescence dosimeter (TLD) and film [2].

The ionization chamber is a benchmark of dosimeter, and had been known to provides the most accurate and reliable results. One difficulty with ionization chamber is that the measured dose can be perturbed by volume averaging over their relatively large active volume [3]. Practically, there are several things to consider, such as the large volume of active and effective point of measurements (EPOM) [4]. When ionization chamber measurements are impractical, it can be replaced by TLD. The small size of TLD allows it to be inserted in an anthropomorphic phantom. For fractional dose (± 200 cGy) measurement, the corrections for energy and dose response are taking into account [5]. To achieve dose measurement precision on the order of 2-3%, a TLD implementation program requires a rigorous annealing and response measurements protocol, and routine QA of the TLD reader and...
annealing oven temperature control [6]. Another in vivo dosimeter is radiochromic film, which has high spatial resolution and specifically designed for use in the dose range 0.1-106 Gy. These properties allow the radiochromic film to be used in small field measurements, that difficult to measure by the ionization chamber. In addition, weak energy dependence in a wide range of beam qualities for radiotherapy and near tissue equivalence makes them suitable for dose measurement in radiation fields with high dose gradients [4]. Because this system is not influenced by the effects of volume averaging owned by ionization chamber, the radiochromic film potentially becomes an effective option in point dose measurement. Due to the several types of the dosimeter, it is better to know and understand the characteristic of each dosimeter before deciding which the appropriate one to yield the optimum results.

2. Methodology

2.1. Contouring target and OARs

This research was performed using CIRS thorax phantom 002LFC (CIRS Inc., Norfolk, Virginia). This anthropomorphic phantom consists of four different materials, representing tissues/organs inside the thorax: lungs, spinal cord, and soft tissue (later used for represents heart). All of those different materials became investigated points of target and OARs that will be evaluated.

The target was simulated inside the right lung by a cylindrical form, using an imaginary boundary; which means that there was no real mass, the target was formed only by contouring. In other words, the target has the same density with lungs. The dimensions and volumes of the target were adjusted depend on related techniques. Contouring results are shown in figure 1, where region A is the volume of interest (VOI) for 3D-CRT and IMRT techniques; and the smaller one, region B, is the VOI for SBRT technique.

![Figure 1. Contouring result: regions A and B are volume of interests (VOIs) for 3D-CRT/IMRT and SBRT techniques, respectively.](image)

2.2. Treatment planning and delivery

Treatment plans were generated in Pinnacle® (Philips Radiation Oncology Systems, Fitchburg, WI) TPS, by using superposition-convolution algorithm. A 6 MV photon beam produced by Synergy-S (Elekta AB, Stockholm, Sweden) accelerator has been employed in this study. Treatment plans were generated in three irradiation techniques: 3D-CRT, IMRT, and SBRT. Each technique was planned using two CT-density curves from different phantom (CIRS 062M and CIRS 002LFC). Prescribed dose and number of fields delivered were different for each technique; it was set based on the clinical
data. Seven irradiation fields were applied to 3D-CRT and IMRT; and fifteen fields for SBRT. In addition, there were three segments for each field in IMRT plan.

2.3. Dosimeter preparations
The TL dosimetry system consists of LiF TLD cylinders (TLD-100, Harshaw) of $3 \times 1$ mm diameter and a Harshaw 3500 read-out system. Whereas EBT2 films were cut into small square with a size of $2 \times 2$ cm$^2$. Because TLD has a relatively high standard deviation, it is prior to grouping the TLD before being calibrated. TLD and EBT2 film were calibrated in twenty seven-steps dose (50 to 1800 cGy), applied with field sizes of $10 \times 10$ cm$^2$ in 5 cm depth.

2.4. Phantom measurements
Generally, the dose measurement was divided into 1) target; and 2) OARs. In target dose measurement, there were four dosimeters employed: PTW N30013, Exradin A16, TLD, and Gafchromic EBT2 film. OARs dose were measured by PTW N3013 and Exradin A16 only. Dose measurements using TLD and film were performed using holders which have made from cork. Holders were designed resembling the original interchangeable rod from the thorax phantom.

2.5. Analysis of results
For the evaluation of the TPS calculated dose ($D_{\text{calc}}$) and measured dose ($D_{\text{meas}}$) value, we follow the equation:

$$\delta(\%) = \left(\frac{D_{\text{max}} - D_{\text{calc}}}{D_{\text{calc}}}\right) \times 100$$

The agreement criterion was determined according to ICRU recommendation, which suggest the accuracy of $\pm5\%$ in the delivery of an absorbed dose to a target volume [7].

3. Results and discussion

3.1. Target dose measurements
The results of target dose measurements in 3D-CRT, IMRT, and SBRT technique are shown in Figure 2. Generally, the measurement results confirmed that every dosimeter has its own characteristic. The use of different CT-density curves did not provide any significant change in discrepancies; because actually there was no significant difference between the two curves.

In 3D-CRT, EBT2 film provides the smallest discrepancies, -0.71% and -0.18% for CIRS 062M and 002LFC respectively. Other dosimeters gained the similar results, about 6%. This value is similar to results obtained by Watts [8] and Wibowo [9] that perform measurements on the same phantom using 0.6 cm$^3$ ionization chamber and TLD. It can be inferred that the pattern of results obtained in this study is regarding the medium inhomogeneity contained in the phantom. Watts suggests that irradiation in central axis beam which passes through the lung materials become the largest source of error in the measurement; whereas Wibowo found the irradiation ML/LM (media-lateral/lateral-medial) is the largest contributor of error in the measurement of point dose in lungs.

In IMRT, the measurement results showed that the ionization chamber with smaller active volume yields more accurate results. The dose values obtained by PTW N30013 and Exradin A16 were different enough; the difference was reached 9 cGy for both CT-density conditions. This difference can be caused by several things: 1) the effects of intra-leaf MLC leakage; and 2) the influence of beam intensity modulation. Beam intensity modulation is done by providing multiple segments on the radiation field. There was a possibility that segment variations led to the formation of high dose gradient region, right on the measurement area.

Similar to the results of 3D-CRT, all measurement results in SBRT were lower than planned dose (underestimate). This is caused by lateral electron disequilibrium (LED) [10]. In depths beyond the maximum longitudinal electron range, LED occurs when the lateral range of electrons become equal.
or greater than the radius of the field. Under this condition, electrons liberated from the beam’s central axis will scatter beyond the field edge. They are not replaced and lead to dose reduction along the beam’s central axis.

3.2. OARs measurements

The OAR dose measurement results gave the same pattern as the results obtained in the target. Generally, it was found that PTW N30013 yields the lower dose value than Exradin A16 on all variations of irradiations; it indicates volume averaging effect occurred in PTW N30013.

3.3 Dosimetric comparison

PTW N30013 is good to be used in 3D-CRT and IMRT technique; by the condition that the uniform dose area in the target must have a much larger size, incomparable to the ionization chamber cavity dimension. It is important to ensure that the radiation fluence entering the cavity is homogeneous, to obtain the accurate results. The ionization chamber with volume of 0.6 cm³, the commonly used dosimeter, apparently was not suitable for use in the small size and non-standard measurement field due to a lack of accuracy and spatial resolution.

![Figure 2](image)

**Figure 2.** Measurements results for: (a) 3D-CRT; (b) IMRT; (c) SBRT. The horizontal axis represents dosimeter employed: A) PTW N30013; B) Exradin A16; C) TLD-100; D) EBT2 film.

Basically, Exradin A16 with an active volume of 0.007 cm³ is suitable for use in high-dose measurement in a small field. At low-dose measurement, the signals obtained from the electrometer
are probably not much different from the existing noise. As occurred in dose measurement of the spine, the value of SNR (signal-to-noise ratio) is not big enough, so that the results obtained are underestimate (smaller than expected). In SBRT, although it indicates the volume averaging effect, Exradin A16 being the best dosimeter to use in small field dosimetry in this study.

Whereas TLD, showed the lowest accuracy and precision in all measurement result in this study. Although in IMRT the discrepancy of TLD was about 1%, but in the other techniques, TLD did not represents the results well. It proved that the dosimeter with smallest dimension may not necessarily be the best dosimeter to be used in small field measurement. The fluctuation of measurement results makes TLD was considered to being replaced by another dosimeter which more practical in use and have better accuracy and precision.

The EBT2 film gained an average uncertainty value of 1.41%; it confirmed research conducted by Devic et al. which declared that EBT2 film has uncertainty value not more than 2% [11]. High accuracy results obtained in 3D-CRT and IMRT, with average discrepancy value of -0.45% and 0.69%, respectively. The results obtained in this study general support the hypothesis: because of its tissue equivalent and high spatial resolution, EBT2 film can be used as an appropriate dosimeter for point dose verification.

4. Conclusion
The selection of dosimeters in dose point verification requires some consideration, such as radiation technique and field size of the investigated case. Generally, Gafchromic EBT2 film yields the better results in all variations, and it is proposed to be an appropriate alternative dosimeter to be used at point dose verification.

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