COMPARISON BETWEEN THE CALCULATED AND MEASURED DOSE DISTRIBUTIONS FOR FOUR BEAMS OF 6 MeV LINAC IN A HUMAN-EQUIVALENT PHANTOM

by

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Radiation dose distributions in various parts of the body are of importance in radiotherapy. Also, the percent depth dose at different body depths is an important parameter in radiation therapy applications. Monte Carlo simulation techniques are the most accurate methods for such purposes. Monte Carlo computer calculations of photon spectra and the dose ratios at surfaces and in some internal organs of a human equivalent phantom were performed. In the present paper, dose distributions in different organs during bladder radiotherapy by 6 MeV X-rays were measured using thermoluminescence dosimetry placed at different points in the human-phantom. The phantom was irradiated in exactly the same manner as in actual bladder radiotherapy. Four treatment fields were considered to maximize the dose at the center of the target and minimize it at non-target healthy organs. All experimental setup information was fed to the MCNP-4b code to calculate dose distributions at selected points inside the proposed phantom. Percent depth dose distribution was performed. Also, the absorbed dose as ratios relative to the original beam in the surrounding organs was calculated by MCNP-4b and measured by thermoluminescence dosimetry. Both measured and calculated data were compared. Results indicate good agreement between calculated and measured data inside the phantom. Comparison between MCNP-4b calculations and measurements of depth dose distribution indicated good agreement between both.

Key words: dose distribution, human phantom, urinary bladder radiotherapy, MCNP in radiotherapy

INTRODUCTION

Radiotherapy is the use of ionizing radiation to kill cancer cells and decrease tumor size. Radiation therapy aims to destroy cells in the tumor target volume being treated. Most cancer patients receive some type of radiation therapy [1]. Normal cells are also affected by radiation and radiotherapy techniques are modulated to spare these cells from radiation injury. In some cases, the aim of radiation treatment is the complete destruction of an entire tumor. In other cases, the aim is to reduce tumor size to relieve symptoms. Radiotherapy treatment planning always aims to spare as much healthy tissue as possible.

During radiotherapy, it is necessary to calculate dose distributions in both target and non-target organs in the body. Monte Carlo simulation techniques are the most accurate methods for this purpose [2-4]. The MCNP-4b is a general-purpose Monte Carlo N-particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport [5]. The principle of a Monte Carlo simulation is to simulate radiation transport, knowing the distribution probability governing each interaction of particles in materials [6]. In this work, the dose distribution from 6 MeV X-rays in four fields in a human equivalent phantom was calculated using Monte Carlo N-particle code and also measured by the thermoluminescence dosimetry technique (TLD). Results of both calculated and measured data were compared.

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MATERIALS AND METHODS

The urinary bladder was selected for this study because bladder cancer is one of the most common cancers in Egypt. The bladder is tetrahedral in shape, with a volume of about 248.7 cm^3. It lies entirely in the pelvis but, as it distends, it expands anterosuperiorly into the abdominal cavity. In the male, it is posteriorly related to the rectum and sacral vertebrae, while in the female, it is related to the anterior vaginal wall. CT scans for bladder were performed to identify the target size. The field size was marked on the phantom (13.5 cm width and 11 cm length) and the slices included in the field were determined.

The Elekta SL75-5 Linac, which is a compact isocentric megavoltage X-ray therapy machine producing X-rays of a maximum energy of 6 MeV was used. The FOCUS Treatment Planning System, which is a two-dimensional radiation Treatment Planning System (TPS), was used to develop treatment planning for cancer patients. It is developed by Computerized Medical Systems Inc. (CMS).

The Alderson Rando Phantom (ARP) was used to simulate human tissue-equivalent material composition. The irradiation was carried out at the Radiotherapy unit, Mansoura University. The ARP was simulated by the Ximatron CX radiology simulator, Varian – TEM. A computer program for the simulation automatically positions the phantom couch and the laser cross to define the scans and treatment fields. Varian – TEM Ximatron C series Version Cx:3.64.4. software was used.

Most of the commonly used computational models of the human body are the so-called mathematical models. Mathematical expressions representing planes, cylindrical, conical, elliptical or spherical surfaces are used to describe idealized arrangements of body organs. In this work, a mathematical model for the human body was used to calculate photon spectra, as well as the dose ratios at the surfaces and in some of the internal organs of this model. This type of a model was introduced by Fisher and Snyder [7] of the Oak Ridge National Laboratory for the adult human and was further refined by Snyder *et al* [8]. Distinct male and female adult mathematical models, called Adam and Eve, have been developed. For all of these models, the organ volumes are in accordance with the ICRP data on Reference Man [9].

The LiF TLD (Harshaw TLD-100 LiF:Mg Ti, Harshaw Chemical, Solon, USA) were used to perform measurements. LiF chips (3.2 3.2 0.9 mm) were annealed under the standard conditions: 400 C for 1 h, followed by 100 C for 20 h and then used in measurements during the irradiation process.

The total dose to the bladder was 5000 cGy over a 25-treatment session, the daily dose fraction was 200 cGy per treatment session. The weight fraction was 50 cGy for each of the four fields, with gantry angles of 0 , 180 , 270°, and 90° (anterior, posterior, right and left fields, respectively). The four treatment fields aimed to focus the maximum dose at the bladder center and to minimize the dose to the surrounding normal organs. The source to surface skin distance (SSD) was 100 cm. During the experiment, TLD detectors were placed at selected sites inside the phantom, as shown in fig. 1:

between the two nipples on the surface of the skin,
2 at the vault of the head,
3 one cm below skin surface, in the central beam axis,
4 three cm left from the central beam, at 4 cm below skin surface,
5 three cm right from the central beam, at 4 cm below skin surface,
6 at the target center (bladder), 7 cm below skin surface,
7 along the central beam, 1.5 cm from the target center (bladder),
8 three cm left from the central beam, 1.5 cm from the target center,
9 three cm right from the central beam, 1.5 cm from the target center (bladder), and
10 at the sacral region of the spine, 11.5 cm away from the bladder center.

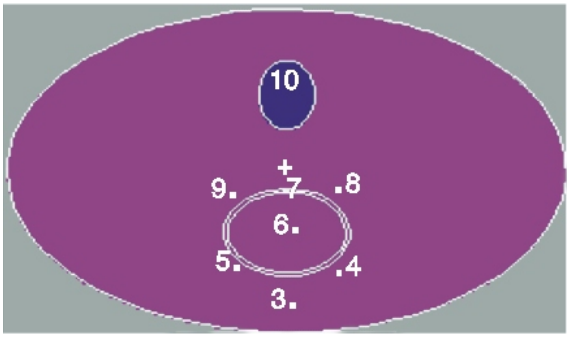

Figure 1. Horizontal section of the phantom, showing the position of the TLDs, numbers 3 to 10

After the irradiation process, the TLDs were removed and readout by the TLD reader (Harshaw 4000, USA) at the Radiation Protection Department, Nuclear Research Center, Atomic Energy Authority, Cairo.

Figures 2A, 2B, 2C, and 2D, show the horizontal cut of the computerized model at the center of the target (bladder) and the shape of the field size for the four treatment fields.

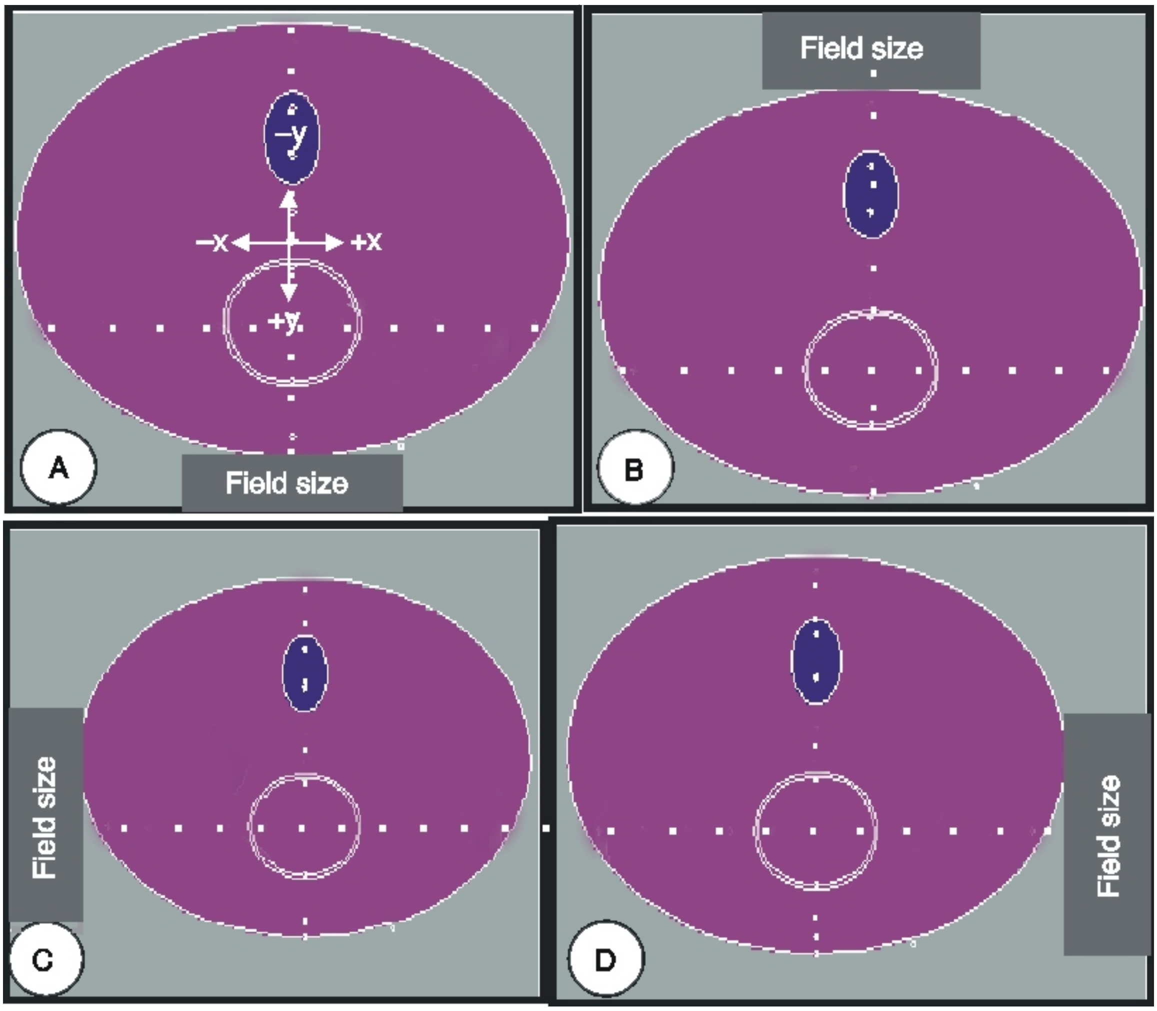

Figure 2. Horizontal cut at the center of the bladder: (A) Anterior field, (B) Posterior field, (C) Right field, and (D) Left field

RESULTS

Calculated and measured dose distribution at selected points

The sites of the selected points (1 10) are specified in the methodology. The total dose measured during the irradiation process, compared with that obtained from the calculation, is presented as a dose ratio relative to the given dose (200 cGy). The number of TLDs on the x-axis (from 3 up to 10) is illustrated in fig 1. Figures 3 and 4 illustrate that the maximum dose was at the center of the bladder, with the dose decreasing with the distance from the center of the target. The calculated and measured doses were very small for positions 1 and 2, because the radiations that reached these sites were mainly scattered photons. The comparison of calculated and measured dose ratios for all points indicated good agreement between code calculated and measured TLD data.

Depth dose distribution

An essential step in the system of dose calculation in radiotherapy is to establish the depth dose variation along the central axis of the beam. One way of characterizing the central axis dose distribution is to normalize depth doses with respect to doses at a reference depth along the central axis. The quantity percentage depth dose may be defined as the quotient expressed as a percentage of the absorbed dose at any depth "d", to the absorbed dose at a fixed reference depth "d_0", along the central axis. A number of parameters affect the central axis depth dose distribution. These include beam quality (energy), depth from skin surface, field size and shape, source to surface distance and beam collimation [10]. Measurements of depth dose distribution were performed using a water phantom of a capacity of 80 cm^3 by ion chamber 0.125 cm^3.

Figure 5 shows the comparison between MCNP-4b code calculations and the measure-

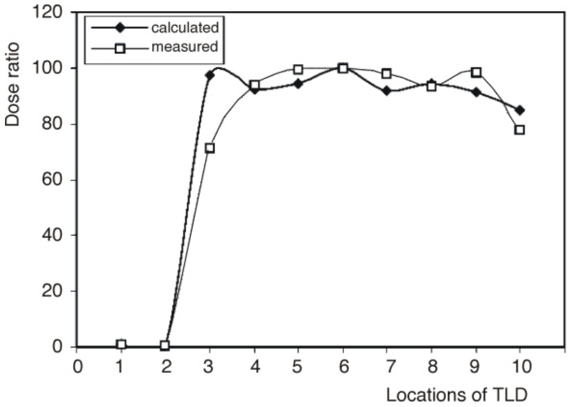

Figure 3. Calculated (solid line) and measured (dotted line) dose ratios for all ten points

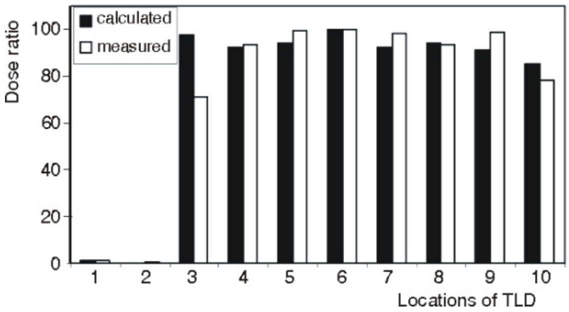

Figure 4. Calculated (solid column) and measured (white column) dose ratios for all ten points

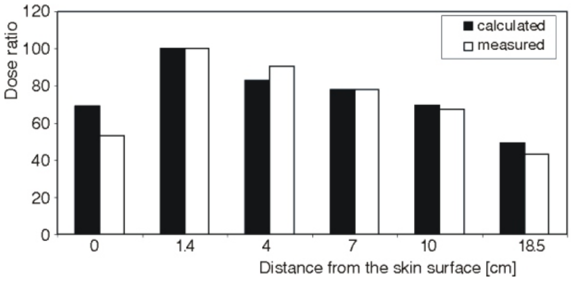

Figure 5. Comparison between MCNP-4b calculation and the measured depth dose distribution

ments of the percentage depth dose distributions for a 6 MeV X-ray. The variation in skin doses between calculated and measured data is due to the methodology (using the water phantom instead of the tissue equivalent phantom). These indicate good agreement between the compared data.

Depth dose distribution for the four treatment fields was determined theoretically by the MCNP-4B code. Figure 6 shows the depth dose distribution for the anterior field at an angle of 0°. The doses indicated are in reference to the dose at the building up point, at 1.5 cm under the skin surface.

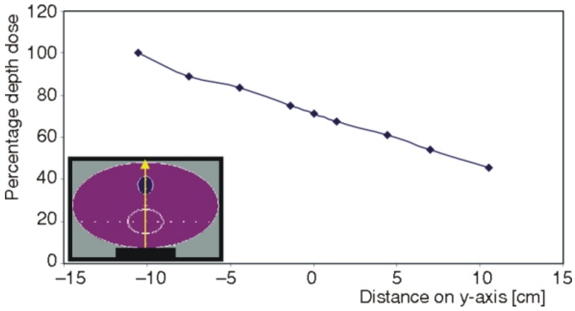

Figure 6. Percentage depth dose distribution in the anterior field

As shown in the figure, the dose decreases gradually from the reference point to the point at the spine (11.5 cm from the posterior bladder center).

The dose distribution for the posterior field is presented in fig. 7. The doses are in reference to the dose at 10 cm on the y-axis. As shown in the figure, the dose decreases gradually from the reference point to the opposite surface.

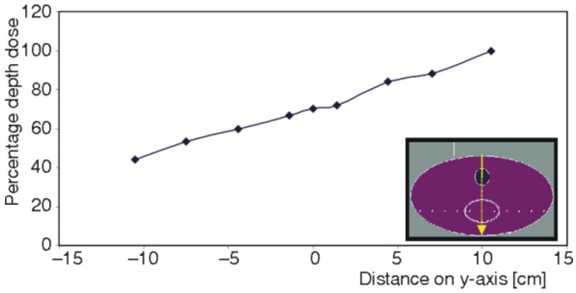

Figure 7. Percentage depth dose distribution in the posterior field

Figure 8 shows the depth dose distribution for the right field. The doses are in reference to the dose at –16 cm on the x-axis, under the skin surface by 1.25 cm. As shown in the figure, the doses decrease gradually from the reference point, to the corresponding point at the positive direction of the x-axis.

Depth dose distribution for the left field is shown in fig. 9. The doses are in reference to the

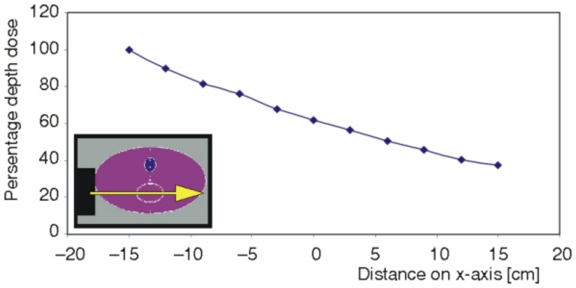

Figure 8. Percentage depth dose distribution in the right field

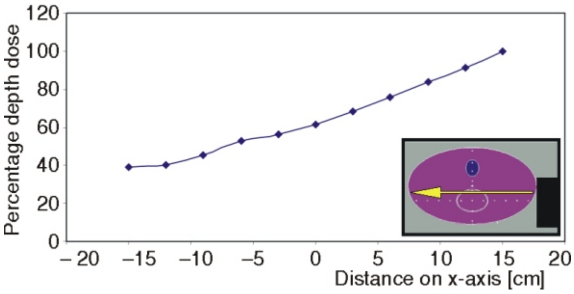

Figure 9. Percentage depth dose distribution in the left field

dose at 16 cm on the x-axis. It is obvious that the doses decrease gradually, from the reference point to the opposite surface.

Figures 6 to 9 indicate that the dose reaching the center of the target from the anterior and posterior fields amounts to 71% of the reference dose at 1.5 cm below skin surface. The doses that reach the center of the target from right and left fields amount to 62% of the reference dose. The total dose from the summation of the four fields amounts to 100% of the given dose at the center of the target.

DISCUSSION

It is important to point out the observed, slight differences in the results obtained from code calculations and TLD measurements. These differences are most noticeable in dose measurements for the ten selected points, especially points 3 and 10 (most anterior and most posterior points, respectively), showing a higher reading for the calculated than the measured data. However, for points 4 to 9, the measured data appear to be approximately equal or slightly higher than that of the calculated data. The most plausible explanation for this lies in the variations of distances of the fields from the central point (point No. 6), which is the center of the target organ (bladder). It is also possible that undulations in beam energy, slightly more or slightly less than 6 MeV, are possible in X-ray equipment. However, the variations between the calculated and measured dose distribution are accepted to be, experimentally, in good agreement.

CONCLUSION

There was good agreement between calculated and measured doses for the bladder (target organ) and the surrounding healthy organs. Monte Carlo calculations are valuable for predicting dose distribution in the patient and also useful for predicting the radiation scattered by the patient. The MCNP-4b dose calculation system proved an important vehicle for demonstrating the promise of Monte Carlo modeling in radiation therapy.

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ПОРЕЂЕЊЕ РАЧУНАТИХ И МЕРЕНИХ РАСПОДЕЛА ДОЗА У ХУМАНОМ ФАНТОМУ ИЗЛОЖЕНОМ ДЕЈСТВУ ЧЕТИРИ СНОПА ЛИНЕАРНОГ АКЦЕЛЕРАТОРА ОД 6 MeV

У радиотерапији су од значаја не само расподела доза зрачења у различитим деловима тела, већ и релативне расподеле доза по дубини тела. За ове сврхе, технике Монте Карло симулације представљају најтачније методе прорачуна, те се обављају Монте Карло симулације фотонског спектра и односа доза на површинама и неким унутрашњим органима хуманог фантома. У овом раду приказане су расподеле доза у различитим органима током терапије бешике X-зрацима од 6 MeV добијене термолуминисцентним дозиметрима смештеним у различитим тачкама хуманог фантома. Фантом је био озрачен на потпуно исти начин као у правој радиотерапији бешике. Примењена су четири терапијска поља да се учини максималном доза у центру мете, а минималном у здравим органима ван мете. Сви подаци о експерименталној поставци унети су у MCNP-4б програм ради прорачуна расподела дозе у изабраним тачкама унутар претпостављеног фантома. Одређена је расподела релативне дозе по дубини. Шта више, програмом MCNP-4б рачуната је апсорбована доза у околним органима као релативни однос према оригиналном снопу, а мерена је и посредством термолуминисцентне дозиметрије. Упоређени резултати упућују на добро слагање мерених и рачунатих вредности унутар фантома. Такође, поређење MCNP-4б прорачуна и мерења расподеле дозе по дубини указује и на њихово добро слагање.

Кључне речи: расподела дозе, хумани фантом, радиотерапија мокраћне бешике, MCNP у радиотерапији