

EXPERIMENTAL DETERMINATION OF THE DOSE COMPONENT PRODUCED BY THE SCATTERED X-RAYS IN EXTERNAL NASAL PYRAMID RADIOTHERAPY

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The goal of this work is to estimate and measure doses produced by scattering the X-rays used in the treatment of the nasal pyramid, on the protected eyeballs. Measurements were performed for a radiation field generated with different applicators and for various incident X-ray energies. For the eyeball protection lead shields of various thicknesses have been employed.

Keywords: X-rays, out-of-field dose, lead shields.

1. Introduction

Carcinomas represent most malignant tumors of the skin. According to their main histological forms, spino and baso-cellular are the most common ones. Moderate skin carcinomas are curable by radiological methods using the X-rays beams. From medical and aesthetic reasons, radiotherapy is the first choice in the treatment of epithelialomas located in the face and hands. In radiotherapy, the precise determination of the dose in the target volumes and in the risk organs represents important aspects for ensuring an optimal treatment plan [1]. Doses in the organs at risk are evaluated according to the international regulations QUANTEC [2]. Compliance with dose constraints reduces the early and late effects of radiation.

In particular, for the present work, precise determination of the skin dose is very important to reduce side effects [2]. The main concern with off-field radiation is that even relatively small off-target doses have the potential to induce secondary cancer (stochastic effects) and can also cause other problems such as eye cataracts [3]. Radiation protection must ensure an appropriate standard of protection without over-limiting the medical benefits. Many clinical cases use high atomic number materials as shielding to reduce the photon dose to the underlying healthy tissues. In this work, we investigate the effect of

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this shielding on both the surface dose and the scattered doses for the particular case of a tumor located in the nasal pyramid and eye as organ at risk [4,6].

Our work used photon beams with energy in the X-ray region produced by a generator. This equipment is generating radiation only during irradiation of the patients with the radiation field being dominantly restricted to the applicator. In this way is respected the ALARA (as low as reasonably achievable) principle, recommended by national and international regulatory bodies in the field, in order to minimize the damage caused by additional radiation exposures [5]. Also it is worth mentioning that in radiotherapy, medical exposure is not primarily about the ALARA principle, but about treating the patient.

The X-ray beam can be collimated, by using so called "applicator" [7] having the shape of a pyramid or a cone with the tip in the focus of the X-ray tube and the base in the irradiation plane [8]. For X-rays with energies up to 400 keV the reference point is located on the base of the applicator placed on the skin surface [9].

In the so called "kilovoltage therapy" the skin is receiving 100% of the maximum dose [10,11] prescribed by medical treatment.

In the present study our objective was to estimate an eyeball dose under certain conditions determined by the treatment parameters, including the size of the X-ray field, the presence of a lead sheet and the obliquity of the treatment area. Dose measurements were performed using an ionization chamber placed on the surface of a phantom, as presented in section II.

High-density, high Z materials such as lead are used to shield healthy tissues during kilovoltage X-ray beam treatments. It is important to note that lead will also reduce backscatter leading to a reduction in the surface dose. The dose received by the eye is a function of field size, lead shield thickness, beam energy, and source-skin distance [12].

The energy of radiation is an important parameter specially for the bone irradiation. Due to the bone's high absorption coefficient for low radiation energies, when a bone organ is penetrated by an X-ray beam, either its over-irradiation can occur, or the shielding phenomenon leading to a considerable decrease of the dose in the regions of interest [13].

In interaction with a material environment, such as skin, bone, etc. part of the incident X-ray beam is absorbed in the target region, by photoelectric effect, multiple Compton and Thomson effects, depositing an energy dose in the tumoral region. Some of the radiation will pass through the tumoral region and/or scatter at a certain angle relative to the incident direction and irradiate healthy organs around [14].

Our present work approaches the case of irradiated nasal pyramid as a target organ and the eye as the organ at risk irradiated by the scattered radiation. Different shields, applicators and X-ray generator settings (voltage, current intensity) have been considered. For the target organ we employed a water phantom and for the eye air phantom. Both are described in the following section.

It was not the goal of the present work to study the systematic variations of the irradiation parameter for large ranges, but rather to test the realistic values of these parameters used in the common medical practice.

2. Experimental setup

In this work we used a T300 equipment provided by WOLF-Medizin•technik GmbH (Womed) [15], in operation at Ploiesti Municipal Hospital (<https://spitalulmunicipalploiesti.ro>). For the test experiments done in this work the unit operates with voltages between 50 - 300 kilovolts that offers high doses for deep and semi-deep tumors. This instrument differs from other systems, due to its design of interchangeable filters on a carousel. The geometry of its applicators and the integrated software is for machine control and clinical use. Its software incorporates also information on patient demographics, enables treatment time calculations and manage dose delivery. The values of applied voltage (kV) and current intensity (mA) are being continuously monitored during irradiation and radiation is interrupted if any of this deviate more than +/- 3% from the nominal setup. According to the manufacturer specification, the alignment of the focal spot with the applicator axis is within +/- 5 mm [15].

The equipment allowed for the sets of high voltage and current tube parameters to be combined with a range of seven filters for a total of twenty different beam qualities. For radiation protection reasons, the applicators top plane is manufactured from stainless steel, shielded additionally by lead. The applicator faces are made from acrylic Pb glass, which has an inherent shielding of 0.5 mm Pb, and is optical transparent along its full length. The basis of the pyramidal applicators is closed by a slice of 1 mm PMMA (Poly methyl methacrylate), marked with a centering cross. For the present work the available applicators have FSD (focal-skin distance) of 30, 40 and 50 cm and base of rectangular shapes [16].

Irradiation doses have been measured by a cylindrical ionization chamber PTW 30013 [17,19] connected to a PTW electrometer UNIDOS E 10008 [18], commonly used in clinical dosimetry [20].

The central axis of the ionization chamber is parallel with the phantom's central axis and their surfaces are tangent. To ensure maximum accuracy, each PTW reference chamber is supplied calibrated with traceability to a primary standard. The reference point for the cylindrical ionization chambers is on the chamber axis, in the center of the cavity volume. For the present study the ionization chamber is used also as a "phantom" for the eyeball. Aside the geometry (eyeball has rather a spherical shape) the main drawback of this approach is the air content of the phantom. The eyeball is rather liquid medium. This drawback will be considered in future studies.

Specifications of the ionization chamber used in our work are: nominal sensitive volume 0.6 cm^3 , nominal response 20 nC/Gy , long-term stability $\leq 0.5 \%$ per year, chamber voltage 400 V nominal, $\pm 500 \text{ V}$ maximal, reference point on chamber axis, stability of the photon energy response $\leq \pm 2 \%$ ($70 \text{ kV} \dots 280 \text{ kV}$), total wall area density 56.5 mg/cm^2 , dimensions of the sensitive volume- radius 3.05 mm , length 23.0 mm , central electrode made from $\text{Al } 99.98 \%$ and diameter of 1.15 mm . The central axis of the ionization chamber is parallel with central axis of the phantom.

We employed a PTW electrometer UNIDOS E 10008 [17], mainly used for daily routine dosimetry in radiation therapy. Air density corrections are done by keying in air pressure and temperature specific to the measurement.

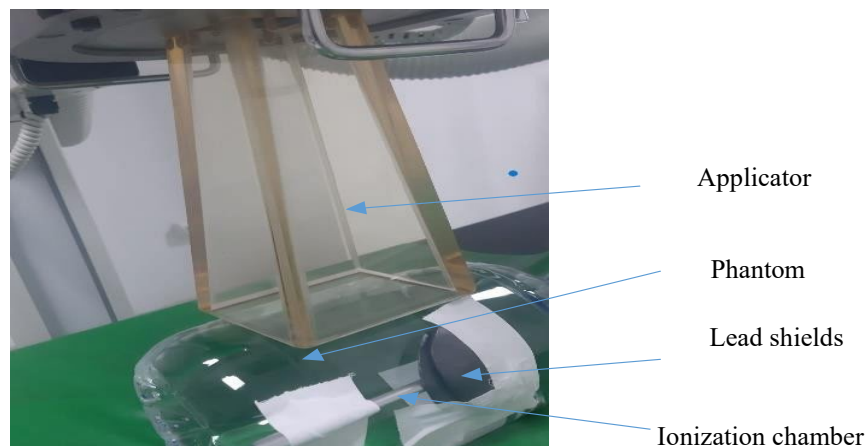


Figure 1a

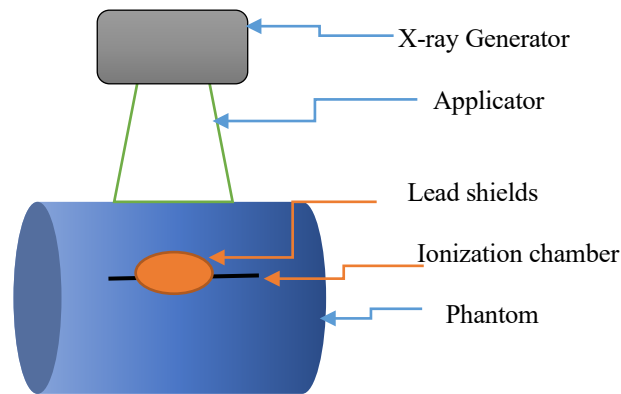


Figure 1b

Fig. 1. Experimental set-up employed in the present work. See text for details.

In Figure 1a is given an image of the experimental setup and in Figure 1b a schematic representation of our experiment.

The base of the applicator was placed tangent to the phantom surface, and its longer edge was placed parallel with the phantom cylinder. The phantom was made from a cylindrical container with thin plastic walls, filled with water. The water phantom cylinder is 33 cm long and 14 cm in diameter with a wall thickness of 0.16 mm and contains 5 liters of water. Water closely resembles soft tissue in terms of density and composition - especially since the human body is made up of about 60 - 70% water - it is the reference material for most dose measurements. The central point of the applicator base is placed on the surface of the phantom.

For all measurements the reference value for the dose in the center of the applicator base was 2 Gy, a usual one used in radiotherapy treatment. This value is insured by the instrument calibration prior to our measurements. The ionization chamber was mounted tangent to the phantom cylinder and its central axis was placed at 3 cm distance from the longest edge of the applicator base.

Two sheets of Pb each of 2 mm thick were placed on the ionization chamber surface simulating the shielding of the eyeball.

3. Working procedure and results

The experiment reported in the present paper follow the sequence :

- i) setting of the irradiation parameters (voltage, intensity, applicators, etc.);

- ii) measurement of dose flow with the ionization chamber calibrated under air kerma conditions;
- iii) evaluation of the attenuation produced by the lead shields.

This steps have been followed for each new irradiation configuration. A change even in a single parameter can strongly affect the deposition of the actual dose on the skin.

Applicators with different *Source to Skin Distance (SSD)* and sizes of the rectangular base have been employed. The dose at the entrance surface (on the central axis of the open treatment fields) with the normal incidence of the beam was measurement at distances SSD of 30, 40 and 50 cm.

Measurements were performed on several energy - current combinations and Cu filters on the X-ray generator. Several applicators sizes as shown in column 2 of Table 1 where employed. The study was performed for the prescribed dose of 2 Gy on the center of the applicator base, the usual one used in radiotherapy.

As mentioned in the introduction no systematic variation in the parameters have been followed. Rather we selected values used in the current medical practice. The experimental parameters and the obtained results are shown in Table 1. This dose can be distributed in depth differently by several parameters adjustments.

In our case the selected parameters of the experiment are the voltage on the X-ray tube (kV), electron current (mA), and the carousel Cu filters. The most used combination are given in the columns 3, 4 and 5 of the table, allowing the combination of the 2 Gy dose usually prescribed, according to the T300 control software system.

Used Pb sheet of various thicknesses, placed over the ionization chamber the eye phantom, given in column 6 of the table, and the measured doses reported in columns 7 and 8.

Table 1

Numerical values obtained from the experiment

| No · Crt · | Applicator surface cm X cm (SSD) | X-ray tube generator voltage (kV) | Current Intensity (mA) | Cu Filter thickn ess (mm) | Pb Sheet thickness (mm) | Incident Dose (Gy) | Trans mitted Dose (%) |
|---------------------|---|---|------------------------------|---------------------------------------|-------------------------------|-----------------------|--------------------------------|
| 1 | 4x6 (30) | 100 | 20 | 0.2 | 6 | 0.050 | 2.50 |
| 2 | 4x6 (30) | 120 | 20 | 0.2 | 6 | 0.100 | 5.00 |
| 3 | 4x6 (30) | 150 | 20 | 0.5 | 6 | 0.050 | 2.50 |
| 4 | 4x6 (30) | 150 | 20 | 0.5 | 4 | 0.075 | 3.75 |
| 5 | 8x10 (40) | 200 | 15 | 1.0 | 4 | 0.080 | 4.00 |
| 6 | 10x15 (40) | 200 | 15 | 1.0 | 4 | 0.075 | 3.75 |
| 7 | 10x15 (50) | 300 | 10 | 1.0 | 4 | 0.090 | 4.50 |

From these values and the fixed prescribed dose of 2 Gy we obtained the doses transmitted values (in percent) given in the last column of the table. Measurement uncertainties were around 0.1%, as indicated by typical value obtained in the calibration procedure of T300 setups.

The results show sensitivity of the irradiation to the type of applicators, the X-ray spectrum controlled by voltage, current and Cu filter and to the thickness of the Pb sheets.

The first 4 measurements employed the same applicator. The use of a 6 mm attenuator compared to 4 mm (keeping all others experiment parameters unchanged) makes the radiation dose passing from the total dose lower (2.50 % compared to 3.75 %). For a given applicator (4x6(30)) and different energies (120, 100 kV) we observed a doubling variation of the transmission. By comparing measurements 1 and 3 we observe that to the voltage increased from 100 kV to 150 kV the thickness of Cu filter increases also to 0.2 mm to 0.5 mm, the dose transmitted remains constant. This could be very useful in same practical conditions implying certain configuration of the instrument and treatment geometry.

By changing only one parameters of the instrument at each step (voltage, current, Cu filter) and the thickness of the Pb sheet, dose transmission can be reduced by 50 % as shown by the measurements 1 and 2. The measurement 5 and 6 are done with identical parameters excepting the base of the applicator reflecting only the focusing of the X-ray beam. By changing the surface of the applicator base surface from (8x10(40)) to (10x15(40)), the dose transmission decreases from 4.00 to 3.75.

In the measurement 7 we used the highest voltage of the X-ray tube (300 kV) and the lower electron current (10 mA) to keep the 2 Gy, reference value. The other parameters are identical with measurements 5 and 6. Measurement 7 test the extreme value of voltage (300 kV) and current (10 mA). It shows that the highest dose transmission (4.50 %) is obtained with the largest SSD value applicator (50 cm).

4. Conclusions and perspectives

The experiments presented in this work are of interest for estimating the parasitic irradiations of nearby organs occurring in X-ray radiotherapy treatments. We considered the case of nasal pyramid treatment and the nearby eye as organ at risk. The sets of the irradiation parameters employed are the one from common medical practice. It was not our goal to performed a systematic variation in these parameters.

In medical practice is know that commercially available treatment planning systems do not calculate correct doses at more than a few

centimeters (3 to 5 cm) outside the treatment fields [21]. As a result, the extent of radiation doses outside the main field is not known with a high degree of precision, providing a strong motivation for the present work.

A schematically experimental setup was designed by using a medical X-ray irradiation equipment, a water phantom for simulating the nasal pyramid and lead shields in order to protect the eyeball. The ionization chamber was also the "eye-phantom" employed for the eye. Several standard applicators have been employed to focus the X-ray beams on the irradiated targets and commercial cylindrical ionization chambers to measure the doses behind the screening lead sheets. The results of our experiments are presented in Table 1 and consider the variations in the operational parameters of the X-ray generator, and the Pb shield thickness. The main impediment in measuring the scattered radiations is its inherent complexity both as angular and energetically distributions [22]. Further studies are envisaged to increase the precision in measuring the scattered radiations doses by spectrometric instruments and simulate the irradiations by employing for example the Monte Carlo techniques.

This experiment was carried out as a result of the treatment of skin carcinomas with radiotherapy carried out in the Ploiesti Municipal Hospital, Radiotherapy Laboratory. As it concerns lesions that affect superficial tissues, the technique is based on physical processes, so the absorption of radiation in the first layers they pass through, while avoiding the irradiation of tissues and organs in depth. In superficial therapy, low-penetrating, poorly filtered or unfiltered radiation is chosen. Protecting healthy tissues in the vicinity of the lesion is as important as protecting deep tissues. For this, lead shields are used for attenuation [23].

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