

APPLICATION OF MONTE CARLO CALCULATIONS TO THE DOSE MEASUREMENTS

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ABSTRACT

Balloon dacryocystoplasty (fluoroscopically guided transluminal balloon dilatation of the lacrimal drainage system), a minimally invasive interventional radiological procedure, is a significant alternative to the surgical treatment of obstructive epiphora. The procedure, however, has a risk of radiation exposure, since radiosensitive organs such as the eyes remain in the field of the primary X-ray beam and thyroid remain in the field of secondary X-ray beam.[1-3] To properly evaluate the risk/benefit ratio of this interventional radiological treatment, accurate knowledge of the ionizing radiation dose to these organs is necessary. However, assessing the dose from fluoroscopy is difficult, primarily due to the range of many parameters (kilovoltage, milliamperage, field size and site, number of exposures, and fluoroscopy time). Since the Monte Carlo Technique eliminates these instrumental parameters, it can be used for dose calculation.

In this work, the radiation dose received by the thyroid at the patient suffering “obstructive epiphora” disease during diagnosis and treatment has been measured experimentally on a physical phantom and calculated theoretically by the Monte Carlo Method using a mathematical phantom. Then Tissue Skin Ratio being the ratio of the thyroid-to-entrance skin dose has been determined experimentally and theoretically and related table has been obtained. The methods used are found to be consistent with each other.

Key Words: Monte Carlo, tissue -skin ratios, dose measurements, dose, thyroid

1. MATERIALS AND METHODS

Experimental study

Phantom irradiation:

An adult male Rando® phantom (Alderson Research Laboratories, Stanford, CA, USA) was used for simulation. The procedures were performed by using an Advantx AFM C-arm unit coupled with a DX Hiline digital image acquisition and processing system (GE Medical Systems, Milwaukee, WI, USA). The 6-inch (15.2 cm) mode of a triple-filed (6, 9, and 15-inch) image intensifier was used with a circular collimation of the same or slightly smaller size. Digital subtraction dacryocystography (DS-DCG) in PA and/or LAT projections were performed at a rate of 1 to 2 frames per second by using the 1024x1024 acquisition matrix; fluoroscopy was limited to positioning the phantom for each projection. The distance between the under-couch X-ray tube and the image intensifier was 65 cm for PA and 76 cm for LAT projections. The image intensifier was placed as close as possible to the phantom head. The fluoroscopy was performed in the pulse progressive mode. The system was operated at 80 kVp during fluoroscopy and at 85 kVp for digital image acquisition. Total X-ray beam filtrations were measured as 2.77 and 2.83 mm aluminium, respectively. Mean values for fluoroscopic milliamperage and milliamperage x second settings per frame for digital image acquisition were 2 and 20, respectively. The total number of frames and fluoroscopy time were determined by the system's timer.

Thermoluminescent dosimeters

Two different lithium fluoride (LiF) TLD chips (Harshaw Chemical Company, Solon, OH, USA) were used for absorbed dose measurements: TLD700, approximately 4.5 mm in diameter and 0.9 mm in thickness; TLD100, 3.7 x 3.7 x 0.9 mm. TLDs were irradiated with X-rays and those with responses that deviated from the mean response by 5% or more were eliminated. Between examinations, the TLDs were annealed at 400°C for one hour. After heating, the TLDs were placed on a marble surface for cooling. TLDs were read using a Model 3500 Reader (Harshaw Chemical, Solon, OH, USA). Each chip was calibrated individually in the same radiation beam in an ionisation chamber (Rad Check Plus, Victoreen, Cleveland, OH, USA). The calibration process involved exposing the TLDs to known radiation doses and then measuring the μC output of these TLDs. These values were graphed, and the graphs were used to interpret the exposed TLDs. Background noise was systematically evaluated and subtracted from measurements before each reading. TLDs were then placed in small plastic packets and they were attached to the phantom. At least two TLDs per packet were used, providing the possibility to verify and compare measured values and as a contingency

for the possibility that some of the TLDs were damaged. Whenever possible, the mean value of the radiation doses measured by each set of dosimeters was calculated. As shown in Figure, to determine thyroid surface exposure dose, TLDs are placed on the skin, external to the thyroid gland (3). TLDs were also placed at some given points on the occipital bone (1) and on the lateral margins of the orbita (2), for the measurements of entrance skin doses for PA and LAT projections, respectively.

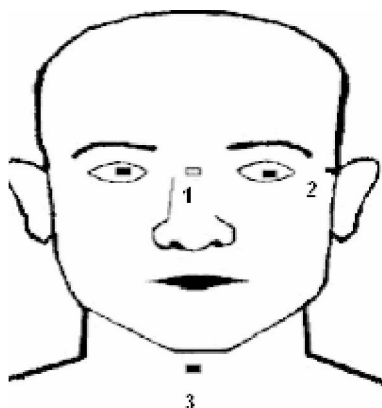


Figure. Location of TLDs. 1. Occipital bone. 2. lateral margins of the orbita. 3. Thyroid.

In the PA projections, the primary beam was directed to the LDS under study, and for LAT projections, the investigated eye was on the image intensifier side, whereas the other eye was on the tube side. All dose values for one minute of fluoroscopic exposure and 10 frames of DS-DCG exposure were individually measured for PA and LAT projections. These values were determined based on the study by Ilgit et al. [5]. Experimental Tissue Skin Ratio being the ratio of the thyroid-to-entrance skin dose was determined. (see Table 1) Prediction of thyroid and entrance skin doses can be carried out using these values in the equation below (Equation 1)[1]; where D_F and D_D are the respective organ doses for one second of fluoroscopic exposure and one frame of DSDCG exposure [1]. T_F and T_D are the fluoroscopic on-times and the total number of DS-DCG frames recorded for each projection, respectively. LAT is the lateral view and PA is the posteroanterior view [4].

$$D = [D_F T_F + D_D T_D]_{LAT} + [D_F T_F + D_D T_D]_{PA} \quad (1)$$

Theoretically study:

The Monte Carlo technique and mathematically described adult head phantom were used for the theoretical estimation of Tissue-Skin Ratio value. The head is represented by an elliptical cylinder topped by a half ellipsoid and assumed to consist of skull (cranium and facial skeleton), brain and eye lenses. The cranium and facial skeleton are represented by the total and partial volumes between two concentric ellipsoids. The brain is represented by an ellipsoid and eye lenses are defined as portions of the volume between two concentric elliptical cylinders. The lobes of thyroid lie between two concentric cylinders and are formed by a cutting surface [6,7]. For the selection of the size of the long and short axes of ellipsoids the dimensions of the Rando Phantom was taken as reference. The densities and the elemental composition of the skin, soft tissue and bone were taken from the literature [8]. In the Monte Carlo calculations, photoelectric absorption, coherent and incoherent scattering of a polychromatic broad beam of X-rays in the simulated head were considered. In the case of photoelectric interaction, the photon was assumed to be totally absorbed at the interaction site terminating the history of the photon. In the cases of coherent and incoherent scattering, the deflection angles of the photons were calculated by sampling the Thomson differential cross - section corrected for the relativistic atomic form factor and Klein-Nishina differential cross section corrected for the electron binding energy, respectively. The history of the photon was terminated when it escaped out of the phantom or its energy had decreased to less than 5 keV [9,10,11,12]. Each single photon through the head was followed and only the energy deposition (E) of the photons absorbed by the thyroid was considered for the thyroid dose (D) calculation;

$$D = E / M \quad (2)$$

where M is the mass of the tissue. Suitable data were selected from the literature for the simulation of the spectral output of the X-ray tube used in patient studies (data were interpolated for intermediate values) and entrance skin doses at the phantom entrance was also determined for each spectrum [13]. The calculated

thyroid and entrance skin doses were then used for the assessment of the theoretical tissue skin ratio value. Theoretical Tissue Skin Ratio being the ratio of the thyroid-to-entrance skin dose has been determined and related table has been obtained. (see Table 1) Prediction of thyroid dose can be carried out using this factor in Equation (1).

2. RESULTS

In this work, the radiation dose received by the thyroid at the patient suffering “obstructive epiphora” disease during diagnosis and treatment has been measured experimentally on a physical phantom and calculated theoretically by the Monte Carlo Method using a mathematical phantom for one frame of digital subtraction dacryocystography and one second of fluoroscopy. The methods used are found to be consistent with each other. The results of experimental and theoretical tissue-skin ratios are given in Table 1.

Table 1. Experimental and theoretical tissue-skin ratios for one frame of digital subtraction dacryocystography and one second of fluoroscopy

		Experimental Tissue-Skin Ratio	Theoretical Tissue-Skin Ratio
kVp	Position	Thyroid	Thyroid
80	PA	0.006	0.002±0.006
85	PA	0.009	0.003±0.007
80	LAT	0.017	0.01±0.02
85	LAT	0.014	0.01±0.02

LAT : lateral view, PA : posteroanterior view.

This study suggests that useful information for dose determination can be obtained by measurement of the radiation dose to the thyroid, which is received during radiological procedures of the LDS, for one frame of DS-DCG and one second of fluoroscopy. Equation 1 and Table 1 can be used for this purpose and subsequent patient dose assessments can be attained using the data on fluoroscopy time and number of DS-DCG frames. Recording these patient data also allows for retrospective dose assessment.

3. REFERENCES

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