Dose and Risk Evaluation to the Thyroid Gland in Intra-oral Dental Radiology

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Abstract: Intra-oral technique is one of the most frequently used procedures of dental radiology, allowing the detection of a variety of dental anomalies such as caries, dental trauma and periodontal lesions, while exposing patients to relatively low doses of radiation. However, although the adverse effects of doses generated by dental radiology are essentially stochastic, a number of epidemiological studies have provided evidence of an increased risk of thyroid tumors for dental radiography. Many studies have measured doses of radiation for dental radiography, but only a few have estimated thyroid dose. Furthermore, most of the studies on dose evaluation in dental radiology are based on standardized calculation phantoms, which neglect the variance of the patient size or even sex. The purpose of this study is to use the Monte Carlo code MCNPX and the FAX (Female Adult voXel) and MAX (Male Adult voXel) phantoms to investigate how absorbed doses to the thyroid gland in intra-oral dental examinations vary in female and male patients. The lifetime cancer incidence attributable to dental examinations were estimated using the Biological Effects of Ionizing Radiations (BEIR) VII Committee Report. The phantoms study proved a useful trial for detecting the radiation dose to the thyroid gland and conclusively supported that the anatomy may be regarded as an influencing factor in radiation dose received during dental examination. Finally, the results have also confirmed that the association of the MCNPX code and the MAX and FAX phantoms is very useful in dosimetric studies on radiographic examinations of female and male patients.

KEYWORDS: Dental radiology, voxel phantom, MCNPX, thyroid gland, radiation risk, bisecting angle.

1. Introduction

In dental radiology, intra-oral technique is one of the most frequently used procedures of dental radiology, allowing the detection of a variety of dental anomalies such as caries, dental trauma and periodontal lesions, while exposing patients to relatively low doses of radiation [1,2,3].

The thyroid gland, one of the most radiosensitive organs, is frequently exposed to scattered radiation and occasionally to the primary X-ray beam during dental radiography. Although many authors support the theory that the risk of radiation carcinogenesis to the thyroid gland during dental radiology is minimal when compared with other diagnostic imaging examinations and other global factors, a number of epidemiological studies have provided evidence of an increased risk of thyroid tumors from dental radiography [3-8].

Most of the studies on dose evaluation in dental radiology is based on standardized calculation phantoms, which are physical or mathematical (virtual) representations of the human body, and neglect the variance of the patient size or even sex. In physical phantom, organ and tissue-equivalent doses can be determined by averaging over many TLD measurements, inserted in a certain phantom volume. However, the definition of organ volume is often difficult because of the irregular shape of organs. In addition the energy dependence of the TLD response can also complicate the interpretation of measured data because the energy distribution of the radiation field inside the phantom is usually unknown [9]. On the other hand, although in mathematical human phantoms size and form of the body and its organs are described by mathematical expressions, these are still rather stylized models of the human body and of its organs [9,10].
Voxel phantoms are based on digital images recorded from scanning of real persons by computed tomography (CT) or magnetic resonance imaging (MRI). Compared to the physical and mathematical phantoms, voxel phantoms are true natural representations of a human body. Connected to a radiation transport code, voxel phantoms serve as virtual humans for which organ and tissue dose can be calculated [10,11].

Considering the information above exposed, the purpose of this study is to use the Monte Carlo code MCNPX and the voxel phantoms FAX (Female Adult voXel) and MAX (Male Adult voXel) to assess the radiation dose and risk of cancer in thyroid gland, during intra-oral radiography examinations.

2. Materials and methods

2.1 Voxel phantom

The FAX and MAX phantom are based on CT images of patients, and are the first female and male voxel phantoms whose organs and tissue masses are the same as those of the reference adult woman and man defined in ICRP 89 [12], which specifies human characteristics that have a bearing on prospective calculations of doses originated in internal or external radioactive sources. Figure 1 shows the FAX and MAX voxel phantoms. The FAX’s height is 1.65 m and her weight is 63.4 kg, while the MAX’s height is 1.75 m and his weight is 74.65 kg. Besides the different heights and weights, the masses of the thyroid gland are also different: 19.86g to the MAX and 17g to the FAX, presenting a percentage difference of 14.3%.

Figure 1 – The MAX and FAX voxel phantoms.

2.2 System Modeling

The computer code used in this study was MCNPX version 2.5, the newest version of Monte Carlo MCNP [13]. Although a number of Monte Carlo codes can be used for dosimetry in diagnostic radiology, MCNPX has been chosen because it is largely employed and has already been validated in studies on radiation transport involving neutrons, photons, electrons, and more recently protons, in medical physics and radiological protection. It is also a very versatile code, allowing users to specify
parameters such as source type and geometric configuration, to indicate general conditions of the system such as size, shape, energy distribution and composition of the medium where radiation interaction takes place, and also to configure the information recording commands (tally). The coupling between the FAX and MAX phantoms and MCNPX code was carried out through a software called SCMS [14], a computational tool for the construction of geometries and anatomic models of medical images such as computed tomography (CT) and other similar digital images. SCMS interprets images and save the interpretations in an input file used by Monte Carlo code MCNPX in the simulation of radiation transport [15].

The two different intra-oral techniques that can be used for teeth examination are the paralleling and bisecting angle techniques, and both have been widely studied by researchers to determine which is the most beneficial [16,17]. Although the studies show significant evidence of dose reduction in the thyroid gland, with the application of the paralleling technique and rectangular collimator, background research indicated that, despite evidential proof [16,17], the choice of the paralleling technique and rectangular collimator is not sufficiently integrated within dental practices. Considering this, the radiographic technique used in this work was the bisecting angle technique with circular collimator, once using this technique the thyroid dose and the cancer risk will be probably greater [3,8,16,17]. A standard collimator with 6.5 cm diameter and length of 30 cm was used.

The exposures were performed for examination of upper 1, 2 teeth (incisor). For this configuration, the thyroid gland is in line of the primary X-ray beam. Figure 2 illustrates the set-up modeled in this work. The collimator’s angulation is 45°.

![Figure 2](image)

**Figure 2** – Radiographic image simulated for confirmation of the collimator's positioning. The image is a lateral projection of MAX phantom. The image was obtained using the methodology developed by Souza et al [19].

The energy spectrum of X-rays used as input parameter in the simulation of the radiation beams was obtained with the software SRS 78 [19], using an aluminum typical total filtration of 1.5mm. The energy spectrum was distributed in energy intervals of 0.5 keV.

### 2.3 Dose calculation and cancer risk estimation

The radiation dose in the thyroid gland was assessed for dental radiology film types D and fast film E, with the tube voltage ranging from 50 to 80 kV. The absorbed dose was normalized by the delivered dose in skin entrance surface for each film type. The typical delivered dose in skin entrance for sensitivity class D film is about 0.5 mGy, while the typical delivered dose for sensitivity class E is about 0.25 mGy.

During the simulations, the absorbed dose to the thyroid gland (D_T) of the FAX and MAX phantoms was calculated through MCNPX’s *F8 command. The absorbed dose was calculated using the following equations [13]:

```plaintext
D_T = \sum_{i} D_i T_i
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where \( D_i \) is the absorbed dose due to each component of the radiation beam and \( T_i \) is the transmission factor for each component.
\[ D_T(rads) = \frac{F8(MeV)}{m} (1,602 \times 10^{-8} \text{ erg/MeV}) \left( \frac{1}{100 \text{ erg/g/rad}} \right) \]  

(1)

\[ D_T(rads) = \frac{F8}{m} 1,602 \times 10^{-8} \]  

(2)

\[ D_T(Gy) = \frac{F8}{m} 1,602 \times 10^{-10} \]  

(3)

where \( m \) is the thyroid mass.

In order to estimate the delivered dose at skin entrance surface, a point detectors (tally F5) was modeled in phantom skin surface, in nasal spine region (under the nose tip), and the fluence in this detector was registered.

The values of fluence registered by point detector were converted to the air kerma through the conversion factors provided by ICRP 51 [20]. The absorbed dose values (\( D_T \)) were normalized by the value of air kerma (\( k_{a,ext} \)) in skin entrance surface of the phantom using the equation below.

\[ D_n = \frac{D_T}{k_{a,ext}} \]  

(4)

where \( D_n \) is the absorbed dose normalized by the air kerma at the skin entrance.

The lifetime cancer incidence in thyroid gland and lifetime cancer mortality attributable to intra-oral examinations was estimated by multiplying the radiation dose in thyroid gland with a risk coefficient for females and males provided by the Biological Effects of Ionizing Radiations (BEIR) VII Committee Report [21]. The BEIR VII models are developed for estimating lifetime risks of cancer incidence and mortality and take account of sex, age at exposure, dose rate and other factors.

3. Results and discussion

The values of calculated absorbed dose in thyroid gland and the comparison with other author’s results are shown in Table 1.

**Table 1:** Results of thyroid doses and comparison with others authors.

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<td><strong>Thyroid</strong></td>
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<td>4.12 - 11.14 (FAX)</td>
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<td>Film D:</td>
<td>38.63 - 61.92 MAX)</td>
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<td>8.24 - 22.28 (FAX)</td>
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The values show that the absorbed dose results for male and female voxel phantoms are in agreement with those obtained by other authors. The average value of absorbed dose obtained with the MAX phantom is similar to the one published by other authors that have used anthropomorphic phantoms, that are based on masculine models, while the values calculated with the FAX phantom are near the absorbed dose obtained by Gibbs et al, that used a phantom based on CT scan of female cadaver [4].
These values evidence the importance of studies considering the patient's sex, once the absorbed dose distribution in organs depends on the anatomical characteristics of the patient, and consequently of the patient's sex.

**Figure 3** shows the absorbed dose to the FAX and MAX thyroid, using sensitivity class D film (a) and high sensitivity class E film, for several tube voltages.

![Figure 3](image)

**Figure 3** – Dose values in the thyroid gland for several tube voltages, using film types D and fast film E. In (a) Sensitivity class D and (b) Sensitivity class E.

In **Figure 3**, the absorbed doses to the MAX’s thyroid tend to be almost three times as high as those delivered to the FAX’s thyroid. This behavior is due to the anatomical differences between the phantoms and their thyroid masses. The absorbed doses increase when voltage is raised. This can be explained by the fact that the penetrating power of the beam increases with voltage. Higher voltages lead to higher “depth” dose and more scatter of X-rays.

**Figure 3** also shows that the most practical method to reduce patient exposure by approximately 50% is to use high sensitivity film class E instead of the popular sensitivity film class D. The impact of this dose reduction in risk of cancer incidence in thyroid gland can be observed in **Figure 4**, where is shown the risks of cancer incidence for patients of 15 and 20 years old. Individual risks in dental radiography are greater in the younger age groups (below 30 years) in which dental radiography is most frequently performed [3].
Figure 4 – The lifetime cancer incidence as a function of voltage for different film class. (a) Sensitivity class D and age at exposure: 15 years, (b) Sensitivity class E and age at exposure: 15 years, (c) Sensitivity class D and age at exposure: 20 years, (d) Sensitivity class E and age at exposure: 20 years
The results shown in Figure 4 confirm that the risk of cancer incidence to thyroid depends on the age and mainly of the exposed individual's sex. The estimated risks of cancer to thyroid in female patients are greater than estimates for male patients because the woman’s thyroid is more radiosensitive than man’s one [21]. It can be seen from Figure 4 that it is also possible to minimize the risk of thyroid cancer incidence by reducing the voltage applied to the X-ray tube and by using the lower dose sensitivity film class E.

4. Conclusion

The phantoms study proved a useful trial for detecting the radiation dose to the thyroid gland and conclusively supported that the anatomy and patient sex may be regarded as an influencing factor in radiation dose and risk of adverse effects from radiation exposure during dental examination. Finally, the results have also confirmed that the association of the MCNPX code and the MAX and FAX phantoms is very useful in dosimetric studies on radiographic examinations of female and male patients.

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