EFFECTIVE DOSE OF RADIATION ON THE EYE, THYROID AND PELVIC REGION RESULTING FROM EXPOSURES TO THE GALILEOS COMFORT CONE BEAM COMPUTERIZED TOMOGRAPHIC SCANNER

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DECLARATION

I, Bwanga Phanzu declare that this research report is my own work. It is being submitted for the degree of Master of Science in Dentistry.

Signature

……………………………day of……………………………………………2014

Dedication

To Chrystelle, Kevin and Roger Phanzu,

Mommy loves you

Abstract

Introduction: Dental Cone beam CT has encountered great success in diagnostics and treatment planning in dentistry. However, it makes use of ionizing radiation. Lots of concern on the effects of x-rays on vital organs of the head and neck region has been raised. Clarity on the amount of radiation received on these specific organs will be a contribution to a better use of the emergent technology.

Aim: The aim of this study is to determine the potential dose of radiation received on the eye and thyroid and to quantify the amount of potential scatter on the gonads during CBCT examinations.

Material and Methods: Calibrated Lithium- Fluoride thermoluminescent dosimeters were inserted inside an anthropomorphic phantom, on sites of the eye, thyroid and the gonads. After its submission to a CBCT examination, using the high and standard resolution for a similar scanning protocol, the dose of radiation received on each organ was calculated according to the ICRP guidelines.

Results: An equivalent dose of 0.059 mGy was calculated for the eye. Compared to the threshold dose of 0.5 Gy fixed by the ICRP 2007, this can be considered as relatively low. The thyroid with an effective dose of 23.5 µSv represented 20% of the full body effective dose existing in literature. The gonads absorbed an effective dose of 0.05 µSv, which was considered as negligible.

Conclusion: The doses calculated were considered as relatively low. However, dentists must be aware of risks of cumulative exposure. Therefore adherence to the ALARA principle and consideration of clinical indication for CBCT remain a priority.

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LiF: Lithium fluoride

RANDO®: Radiation Analogue Dosimeter

WITS: University of the Witwatersrand

FOV: Field OF View

ALARA: As Low As Reasonably Achievable

CHAPTER I: INTRODUCTION

I.1 Introduction

Technology has undergone profound changes during the past century. New equipment is available in all sectors of life, from communications to dentistry.
In the dental field, Cone Beam Computed Tomography (CBCT) is one of the most important technical innovations to this day[1]. This contemporary radiological imaging modality is specifically designed for use on the maxillo-facial skeleton. [2, 3, 4]

Prior to this new apparatus, oral and maxillofacial radiology mainly utilized two types of imaging modalities in order to visualize hard tissue lesions. On one hand, there were intra- oral surveys, panoramic radiographs and several extra oral views. Whether digital or analogue, they were considered as Conventional Radiography (CR)

On the other hand, there was Computed Tomography (CT), which provided a multiplanar accurate image of the exposed area. However, due to economic reasons, lack of expertise and great amount of exposure to ionizing radiations, CT was reserved for specialized imaging, depending on specific patient indications. This latter modality was able to produce three-dimensional projections which in certain cases proved useful in some aspects of dentistry.

These two technologies were considered as the standards of care in Oral and Maxillo - facial imaging.[5]

1.1.1 Definition

When evaluating an emerging technology, the ideal approach is to compare it with the existing gold standard, and make sure that its diagnostic accuracy is better, or at least, as good as the one it can be expected to replace. [1, 5]

Dental CBCT, can therefore be defined as an imaging modality that provides high resolution cross-sectional images of an exposed area limited to the maxillo-facial complex, analogous to CT, and which offers the capacity of a 3D reconstruction of that same area. [5]

1.1.2 Advantages and limitations

The first advantage of dental CBCT is that it overcomes the limitations of CR and produces an image that is accurate, undistorted and reproducible.[4] Indeed, the amount of information gained from conventional or digitally captured plain radiographs was limited by the fact that the three-dimensional anatomy of the area being exposed is compressed into a two-dimensional image.

As a result of superimposition, two-dimensional radiographs reveal limited aspects of three-dimensional anatomy, requiring, in most cases, a combination of different conventional films taken in various planes.[6]Another benefit of CBCT is the production of a multi planar image similar to CT for a less amount of radiation. Studies comparing these two imaging techniques have shown that in terms of image quality, reproducibility and validity CBCT produced superior images to the helical CT, with less radiation exposure.[5,7,8] It has been reported that the average effective radiation dose from CBCT varies from 36, 9 to 50, 3 µSv. This is considered a 98% reduction, when compared to established CT systems.[5, 9] For this reason, CBCT has been recommended as a dose-sparing technique for oral and maxillo-facial imaging. [5, 10] Relative affordability, x-ray beam limitation with the possibility of different scan protocols and rapid scan time are other reasons to make use of this impressive invention.[11] The superiority of dental CBCT compared to CT and CR is therefore well illustrated.

Unfortunately, like all excellent technologies, this machine has its limitations. One must bear in mind that the effective dose from CBCT is still considerably higher than that from CR.[10, 13, 14]Although better than CT from a radiation point of view, CBCT is just as much affected by radiographic artifacts related to the x-ray beam. This reflects as a distortion of images of metallic structures and the appearance of streaks and dark bands between two dense structures. Furthermore, patient movement during the scan can affect the sharpness of the final image.[4, 11]

A third disadvantage is that it can only demonstrate limited contrast resolution, mainly due to relatively high scatter radiation during image acquisition. CBCT would not pose a problem were the objective of the inquiry to visualize hard tissue only. However, it is insufficient for soft tissue imaging.[5]

Difficulty of interpretation may be considered a limitation.[10] Yet, the major inconvenience of this emerging technology remains the use of ionizing radiation. Risks related to the radiation doses generated by CBCT have been noted.[1] According to the 2009 ICRP reports, the risk of adult patient fatal malignancy related to CBCT is estimated to be between 1/100000 and 1/350000 individuals. For children, it can be twice as much.[5]

1.1.3 Effects of ionizing radiation

Ionizing radiations, such as X rays, cause ionization of atoms, molecules, cells, tissues, organs and eventually the whole body. This depends on the amount of radiation received.

The response of organs to ionizing radiations depends on the sensitivity of each tissue.

It has been reported that reproductive cells as well as the intestinal mucosa have a high sensitivity to ionizing radiation.

The salivary glands, the lens of the eye and the thyroid gland, on the other hand are slightly less sensitive. Muscle and nerve tissues have been classified as relatively insensitive.[9] With regard to tissue responses to radiation exposure; two types of effects have been described. Effects that depend on a certain threshold dose of exposure are called non stochastic or deterministic effects, whereas the effects that are independent of a minimal dose of exposure are known as stochastic effects.[15]

For the purpose of this study, our focus will be on the effects of ionizing radiations on specific organs in the maxillo-facial region, as well as on the gonads situated in the pelvic region. Indeed, although situated in the lower abdomen, the gonads may be involuntary victims of scatter radiation during patient exposure to CBCT.

The lens of the eye contains a single layer of highly active dividing epithelial cells which are sensitive to ionizing radiation. Some of these cells differentiate into mature lens fibre cells. Lens transparency depends on the good condition of this layer. Ionizing radiation may lead to mutation or death of these sensitive cells and cause disruption of this layer. This may cause clouding of the lens and therefore cause the impairment of vision known as cataract.[16] The ICRP considers cataract as a non-stochastic effect of ionizing radiation. They recommend an equivalent dose limit of 20mSv in a year, averaged over a period of 5 years, with no single year exceeding 50mSv. The threshold lens dose for radiation induced cataract is now at 0.5 Gy.[16,17]

The thyroid has been classified as an organ with a relatively low sensitivity to ionizing radiation. This means that cell damage that may lead to cancer may occur at a minimal dose, particularly before the age of 12.[15] Thyroid cancer is classified as a stochastic effect of radiation by the ICRP. [18]

Generative cells are highly sensitive to ionizing radiation and there is no threshold dose for cell injury. Exposure of the gonads may lead to damage of reproductive cells and induce cell death or mutation. While cell death can lead to a reduction in the number of gonads, mutation can lead to affected kindred cells that may harbor cancer or malformations.[19]

In dental and maxillo-facial diagnostic imaging, the amount of exposure seldom reaches the threshold doses for the eye. The chances of attainment of doses able to induce a chain of cellular reactions that may lead to cancer in organs such as thyroid or gonads are very low. However these doses are cumulative within a certain period of time. Therefore, there is a risk of cell damage if the patient is submitted to repeated exposures within a limited period. CBCT examinations are on the increase due to its popularity. As a consequence thereof, patients face a greater risk of cumulative doses of radiation. Dentists must therefore be aware of these consequences and take necessary precautions in order to prevent future mutagenesis, carcinogenesis or teratogenesis.

1.1.4 Method of calculation of effective dose of radiation

Determination of the dose or quantity of the radiation exposure is regulated by a part of physics sciences called dosimetry. This science provides estimates of the biologic effects of radiation and therefore permits its proper therapeutic and diagnostic usage.[22]

Dosimetry utilizes several concepts, but the most relevant to our study are absorbed dose, equivalent dose, effective dose, and the personal dose equivalent.

Absorbed dose is expressed in Grays (Gy). It describes the energy absorbed from any type of ionizing radiation per unit mass of any type of matter.[22]

Equivalent dose is more specific to the type of radiation concerned because it takes into consideration the Radiation Weighting Factor (W_R)

Equivalent dose (H_T) = Absorbed dose X Radiation weighting Factor (1)

Sieverts (Sv) = Gy X W_R

H_T may be expressed in Sv.

For the X-rays, the radiation weighting factor is 1. W_R is provided by the ICRP.

Effective dose takes into consideration the biologic risks in humans exposed to radiation. In other words it considers the absorbed dose of radiation, the type of radiation, sensitivity and carcinogenic potential of the irradiated tissue, even without a threshold dose. It therefore takes into consideration the possibilities of stochastic effects of radiation which are expressed by the Tissue Weighting Factor (W_T). (Table 1)

W_T is provided and updated by the ICRP. The fraction of organ exposed (f) is as well taken into consideration. It is expressed in percentage.[18, 21, 22]

$$E = H_T \times f \times W_T \qquad (2)$$

Personal dose equivalent $H_p(d)$ is an operational quantity defined by the International Commission on Radiation Units and measurements (ICRU) and the ICRP. It is recommended for monitoring low penetrating particles, such as β-particles as well as for assessment of doses of radiation on external surfaces. The personal dose equivalent utilized for the calculation of effective doses is $H_p(10)$.The skin and the lens of the eye are considered as external surfaces. The ICRP 2007 recommends a personal equivalent dose of H_p (0.07) for the determination of an equivalent dose for these two organs.[26]The previous ICRP recommendation of H_p (3) for the lens of the eye was discontinued in 2007.[26] The determination of H_p (0.07) requires a particular method of calibration of dosimeters using specific phantoms according to the selected external surface.[8,10,27] In the equation of calculation of equivalent dose, the factor absorbed dose is not a reading anymore, but a calculation using a specific conversion coefficient relative to the method of calibration.[16,18,23,24]

Table 1: Tissue weighting factors (ICRP 2007) [18, 22]

Organ	**Tissue Weighting Factor(WT)**
Gonads	0.08
Red Bone Marrow, Colon, Lungs, Stomach, Breast, Remainder tissues*	0.12
Bladder, Oesophagus, Liver, Thyroid	0.04
Bone surface, Brain, Salivary glands, Skin	0.01
*Remainder tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate, Small intestine, Spleen, Thymus, Uterus/cervix	0.12

1.2 Literature review

Several dosimetry studies on CBCT exist in literature and most of these studies rely on the use of TLDs. In this regard, the reliability of LiF (Lithium-Fluoride) chips has been proven. In 1987, Buch and Keddy conducted a study which demonstrated the reliability of LiF chips. These TLDs have the characteristic of exhibiting relatively null mechanically induced luminescence as well as the ability to store the information about the irradiation received. As a result, these TLDs are indicated for experiments which require displacements to sites remote from the measuring laboratory for purpose of exposure.[25]

Unfortunately, LiF dosimeters have two disadvantages. They present non-linear responses at high doses and are subject to background radiation at low doses.

Although relevant, these disadvantages have been cited in studies carried out on LiF in the form of loose powder.[25]
LiF dosimeters historically existed in the form of rods and discs, but their major shortcoming was that of orientation dependence. There was a significant difference in readings in small surfaces compared to larger surfaces, with identical exposures.[25] The limitations of LiF in the form of loose powder were overcome by the use of LiF discs, that were submitted to a calibration of 1Gy of ionizing radiation from a standard source and submitted to the specific selection criteria of 5% below the mean dose calculated.[25]

In 2006, Ludlow *et al.* published a dosimetry study on three different oral and maxillo-facial CBCT devices. For this purpose, they utilized LiF TLD chips that were selected as advised in previous literature.[25]The exposures were effectuated on a Radiation Analogue Dosimeter (RANDO®) phantom in which the TLDs were inserted. This study determined the anatomical landmarks for insertion of TLDs and emphasized the use of effective dose as well as the influence of, kV, mA settings different FOVS in dosimetry studies. Although it did not make use of the Galileos Comfort ® CBCT, and calculated average body effective doses, this study is often used as a reference for dosimetry, with organ dose measurement as a research methodology.[26]

In 2008, Ludlow and Ivanovic compared the doses on CT with several CBCT devices, including the Galileos® Sirona with the scan protocol of 85kV, 42 mA on full FOV. This article focused on the doses in the maxillo-facial area and introduced the, ICRP tissue weighting factors (2007) as well as different CBCT scan protocols. They calculated equivalent doses of radiation for specific organs in the maxillo-facial region. The thyroid absorbed an equivalent dose of 450µSv with the Galileos at maximum exposure. The equivalent dose for the eye was not mentioned. The effective doses calculated were average full body doses.[10]

In a 2012 publication*,* Pauwels *et al.* elaborated on the effective dose for dental CBCT scanners. They calculated the doses on several machines, including the Galileos Comfort® CBCT. Unfortunately, they used a CBCT scan protocol of full FOV, 85kV and 28mA. They calculated equivalent organ doses and recorded a dose of 380µSv for the thyroid. The eye was not mentioned and the effective doses calculated were average full body doses. [27]

During the same year, Thorsten et *al.* compared the dosimetry of the CBCT with a digital X-ray machine in orthodontic imaging. For this purpose, he used organ dose measurement methodology, based on Ludlow's approach. The machines used for performing the exposures were i-CAT next generation® CBCT and an orthopantomograph OP100/OC 100®. The existing scan protocols for i-CAT next generation® and the Galileos Comfort® are different. They calculated equivalent doses for the organs in the maxillo-facial area. The thyroid's dose was of 167, 267, 150 and 350µSv according to the different scan protocols. The eye was excluded. The effective doses calculated for the different machines were average full body doses. They proved that the dose from CBCT was higher than the one from digital panoramic radiographs. Their conclusion was that, while information gained from a CBCT examination was benefic, it was the practitioner's discretion to weigh between the risks encountered by the patient and the benefit from the examination. [20]

In 2013, surface skin doses were measured after exposure with four dental x-ray imaging systems. For this purpose, three CBCT units and one combined conventional panoramic-cephalometric unit were utilized. The latter unit was ProMax® pan/ceph x-ray machine, while the CBCTs were Kodak 950® (Kodak Dental Systems, Care stream Health, Rochester, NY, USA), i-CAT next generation® and Galileos Comfort®. The selected FOVs were the large and medium ones only. This selection was justified by the popularity of these FOVs in orthodontics for diagnostic and treatment planning. Several scan protocols were included in the study. Amongst others, the full FOV, 85 kV. 42mA. The dosimeters utilized for this purpose were optically stimulated luminescence (OSL) dot dosimeters (nanoDOTS® dosimeters, Landauer Corp. Glenwood IL) and the phantom was a head anthropomorphic phantom RS110® (Radiology Supported Devices-RSD- Inc., Long beach, CA). The selected skin points for placement of the dosimeters were on the lens of the eyes, the parotid glands, the submandibular gland and the thyroid. After exposure of the phantom, according to the usual patient positioning protocol in a CBCT machine, the TLDs were read and the figures reported were converted into absorbed dose in mGys, using unit and scan specific calibration factors. With the protocol scan of 85kV, 42mA and full FOV, for the Galileos Comfort® CBCT the lens of the eye's calculated absorbed dose was 0.94mGy.The highest dose observed for the lens of the eye was of almost 4mGy with a scanning protocol of 120kV, 108mA and 20x18 FOV. The absorbed dose calculated at the skin surface on the thyroid was of 0.46mGy, for the full FOV scan protocol 85kV, 42 mA. They justified this negligible dose by considering the skin covering the anterior part of the thyroid gland as out of the primary x-ray beam.[28]

In 2014, a study in Ontario calculated effective doses of different protocols using the Sirona Galileos Comfort CBCT®. They used the organ dose approach in their methodology, but the thermoluminescent chips were InLight® nanoDot ™ OSL dosimeters (Landauer, Glenwood, Ill) placed on Polymethyl methylacrylate (PMMA) templates. These dosimeters were positioned on a RANDO phantom with referral to Ludlow's anatomic landmarks. Twelve scan protocols were used, including the Full FOV HR (VO1) and the Full FOV standard (VO2) at 85kV, 42mA. The calculated effective doses were maxillo-facial average dose. The scatter was considered negligible. Our focus in this publication was on the calculated effective doses of protocol Full FOV HR

85kV, 42mA resulting in 142µSv compared to Protocol full FOV standard resolution 85kV, 42mA resulting in 140µSv.

This suggested that the changes in resolution settings had little or any impact on effective dose.[22]

Finally, the manufacturer provided average full body effective doses on the different settings, referred from a study by Ludlow JB on the dosimetry of the Galileos Dental® CBCT provided settings. (Table 2) It was reported that in smaller FOVs (maxillary or mandibular collimation) dose values could be reduced by approximately 15%.[29]

Various reports on doses from CBCT have been published in the literature yet many of them refer to average full body doses or facial doses rather than to specific vital organs. Studies are still needed in order to determine radiation safety for specific organs in the maxillofacial region, as well as the effects of scatter radiation during CBCT examinations. The question still remains, however, whether or not the use of CBCT as a routine imaging modality for dental diagnosis induces overexposure to the patients.

1.3 Aim of the study

WITS Dental School has recently acquired the Galileos Comfort CBCT scanner. The manufacturers refer to average full body doses rather than to specific vital organs.[29] Most of the studies refer to average effective doses. It would appear that effective doses to specific regions of the face have been ignored.

It is established that exposed dose is influenced by the parameters FOV, kVs and mAs settings.[26, 28, 30] Yet, comparisons of amount of exposure at the different resolution settings, as well as the amount of scatter, particularly at the pelvic region, remain to be investigated.

The specific aim of the current study is therefore to calculate the potential effective doses of radiation to specific vital organs in the head and neck region emanating from the CBCT scanner housed in the WITS Dental School at different resolution settings (VO1 and VO2). It also aims to investigate the amount of scatter radiation to the pelvic region for both scan protocols. The results of these observations are to be compared with the average effective doses described in the literature as well as background radiation.

It is hoped by means of this study to contribute to the elaboration of conclusions relevant to the situation in South Africa.

1.4 Objectives

Primary objectives

The primary objectives of this study are:

-To calculate the potential effective dose of radiation to the lens of the Right eye after exposure to the Galileos Comfort CBCT scanner on the setting VO1, 85kV, 42mA --

-To calculate the potential effective dose of radiation to the lens of the Left eye after exposure to the Galileos Comfort CBCT scanner on the setting VO1, 85kV, 42 mA

-To calculate the potential effective dose of radiation to the lens of the Right eye after exposure to the Galileos Comfort CBCT scanner on the setting VO2, 85kV, 42mA

-To calculate the potential effective dose of radiation to the lens of the Left eye after exposure to the Galileos Comfort CBCT scanner on the setting VO2, 85kV, 42 mA

-To calculate the potential effective dose of radiation to the thyroid gland after exposure to the Galileos Comfort CBCT scanner on the setting VO1, 85kV, 42mA

-To calculate the potential effective dose of radiation to the thyroid after exposure to the Galileos Comfort CBCT scanner on the setting VO2, 85kV, 42mA

-To calculate the extent of scatter radiation to the gonads during maxillofacial examinations using the Galileos Comfort CBCT scanner on the setting VO1, 85kV, 42mA

- To calculate the potential extent of scatter radiation to gonads during maxillofacial examinations using the Galileos Comfort CBCT scanner on the setting VO2, 85kV, 42mA

Secondary objectives

The secondary objectives of this study are:

-To compare the calculated effective doses with the average effective doses as stated in the literature

-To compare the calculated effective doses on the two different scan protocols

-To determine whether or not there is a need for additional protection of the patient during such examinations

-To compare the equivalent absorbed dose on the eye with the threshold dose at the eye fixed by the ICRP 2007.

-To compare the calculated effective doses with the background radiation.

CHAPTER II: MATERIALS, METHODS AND RESULTS

2.1 Introduction

A systematic review of the different methodologies employed in dosimetry studies for CR, CT and CBCT has revealed that most of the studies encountered in literature have utilized the method of organ dose measurement.[21]

This method relies on phantoms, implanted with dosimeters. [10, 14, 20, 21,26, 31, 32]

Other methods such as computer tomography dose index by volume ($CTDI_{vol}$), Monte Carlo dose simulation programs, CT air-kerma length product ($P_{KL, CT}$), Air kerma area product (P_{KA}), entrance skin surface dose and energy imparted have as well been described.[22]

However, our study will rely on the organ dose measurement method. The calculations of effective doses will be based on the absorbed dose measurements on the dosimeters inserted inside a phantom, the radiation weighting factors, the tissue weighting factors and the fraction of irradiated organ.

The phantom simulates human tissues with regard to tissue layers and radiation absorption factors. It is therefore called an anthropomorphic phantom. Such phantoms are fabricated with a natural human skeleton cast inside a material that has a radiologic density equivalent to that of soft tissue. It is virtually indestructible, capable of withstanding substantial impact and continuous handling without damage. These phantoms are constructed in the form of detachable cross-sections with apertures created for placement of dosimeters in the region of interest. [33]

The specific phantom to be used is the RANDO® (Radiation Analogue Dosimeter, The Phantom laboratory, Salem, NY)

The selected organs were the lens of the L eye, the lens of the R eye, the thyroid gland and the gonads in the pelvic region. The first two organs were retained because of their anatomical position in the head and neck region and their relatively high sensitivity to ionizing radiation. Although they are not the primary indication for a CBCT examination, these regions are most likely irradiated during CBCT exposures as they are situated very close to the primary X-ray beam. As a result, they may receive inadvertent exposure, because of their position. The gonads area may be affected by scatter radiations. This region is very radiosensitive, as it harbors the reproductive cells.

The Sirona Galileos Comfort® CBCT scanner is housed in the Wits dental hospital. The software installed in it is a GALAXIS, RECO® software which extends SIDEXIS to include the processing of 3D data. Its functions are 3D reconstructions, storage, recall, display and processing of 3D data.

The tube voltage is fixed at 85kV, with a current varying between 5-7mA.There are six exposure settings where the tube voltage remains constant at 85kv, while the current may vary between 10-42mA according to the size of the patient. The different exposure settings available include 10, 14, 21, 28, 35 and 42mAs.

The Galileos Comfort® has two FOVs. The full FOV measures 15x15x15 spherically, and the medium FOV (upper or lower jaw only) is 8.5 x15 x 15.

It is equipped with four viewing settings: VO1, VO1HC, VO2 and VO2HC. The difference between these settings is simply the resolution and the contrast. In other words, it is a question of image quality.

In this study two different protocols will be used. One using the VO1 setting and the other using the VO2 setting. VO1 displays a high resolution and therefore has a smaller pixel size. As a consequence, it occupies more space in the memory and requires a bigger data volume (740MB).

VO2 displays a standard resolution and therefore has a bigger pixel size. As a result, the data volume is smaller (approximately 390 MB).[29]

These viewing settings do not influence the amount of exposure received by the patient. Yet, our study will compare the different amount of exposure received in the two different scan protocols.

The dosimeters exist in several types. Newly optically stimulated luminescent dosimeters (OSL) are the latest model in the market, but this study will make use of thermoluminescent dosimeters (TLDs), which are the most popular. (Fig. 2) TLDs rely on the principle of thermoluminescence. Their role is to measure the absorbed dose of radiation in the specific area, where they are placed.

Previous studies have elaborated on the reliability of lithium- fluoride TLDs. The superiority of lithium fluoride (LiF) over other thermoluminescent materials has been established. These discs when subjected to a standardized method of annealing and selection may be relied upon to an accuracy of 90%. [25]

However, with the introduction of personal dose equivalent H_p (0.07) by the ICRP in 1991, TLDs for external surfaces such as the skin and the lens of the eye require a specific calibration.[16, 24]The dosimeters utilized, for the purpose of this research are thermoluminescent TLDs (TLD100) discs.

The Medical-physics laboratory supplied the author with the facilities for annealing, handling and reading of the dosimeters**.** The venue was equipped with a PTW-Frieburg 1321® oven. The reader was a Harshaw 825®, model 3500. Both equipments were operated from a computer installed with the application softwares WINREMS for the reader, and THELDO for the oven. (Fig. 3, 4, 5)

The dosimeters were handled with a Dymax 30 Charles Austen vacuum pump, in order to prevent their contamination. (Fig. 6)

2.2 Materials and methods

The experiment took place in two different venues. The calibration and manipulation of the dosimeters were performed in the laboratory whilst the RANDO® phantom, although mounted and dismantled in the laboratory, was submitted to the exposures in the hospital.

Inclusion and exclusion criteria

These criteria are based on the methods of selection of TLDs as discussed by Buch and Keddy, 1987.[25] The calibration of the 67 TLDs was performed using a photon energy of 6 MV on a Siemens linear accelerator. 1Gy of radiation was given to the batch of TLDs for a field size of 14cm x14cm at the depth of 4.4cm in Perspex, which is equivalent to 5cm in water and the procedure was carried out in a black plastic container. The 49 TLDs that did not vary more than 5% from the mean value were considered in the inclusion criteria. All the others were excluded. The gender of the phantom was of no consequence as male and female gonads are situated in the pelvic region.

All of the 67 dosimeters responded positively to the selection criteria, in other words they were all below 5% of the mean absorbed dose. According to the medical physicist who performed the calibration, this could be justified by the fact that these dosimeters were still relatively new and had not been submitted to a great number of exposures.

The forty-nine TLDs that had the readings nearest to the mean value were therefore selected.

The first reading of the forty-nine dosimeters was done in order to measure the background radiation. Afterwards, the TLDs were submitted to a second annealing in order to exclude background radiation, prior to their insertion in the RANDO® phantom. For this process the chips were placed inside a square annealing copper plate provided with apertures to contain each dosimeter. The placement of the TLDs in the phantom was realized according to anatomical positions used in literature with three in each of the selected organs[31, 32]

For the thyroid, the TLDs were placed in position 9 of RANDO® phantom.

For the lens of the left and the right eye, they were placed in specific pouches, held in place with tape on the anterior surface of the eye. As for the lower abdomen, the TLDs were placed on position 33 of the RANDO® phantom.
In the three organs, considering the phantom in an anatomic position, the TLDs were placed according to a linear pattern with one anterior, one medial and one posterior.

All the manipulations of the dosimeters were done in the medical physics laboratory, where all the conditions for handling and reading of TLDs were met.

Once the TLDs in place, the phantom was conveyed from the medical-physics laboratory to the dental hospital, where the Galileos Comfort® CBCT is housed.

In the hospital, the phantom was positioned in the machine with the midsagittal plane centered in the image field and the occlusal plane parallel to the scan rotation plane.[10,14, 20, 26]It was then subjected to the same type of x-ray examinations as those that are usually conducted on patients. (Fig.7)

Two different CBCT scan protocols were used for this exposure. The first one was at 85kV, 42 mA on setting high resolution setting, and the second one at 85 kV, 42 mA on standard setting.

After exposure, the phantom was returned to the medical physics laboratory, for reasons of appropriate manipulation and reading of TLDs.

This procedure was repeated five times, three for the first protocol, and twice for the second protocol.

Once the readings were processed, the background radiation was subtracted from the radiation absorbed dose for each TLD. The mean absorbed dose per organ was then calculated for both protocols and this led to the calculations of the different effective doses per organ, for both protocols, according to the ICRP specifications.

2.3 Results

The data was collected in the form of tables where each selected TLD was attributed a specific name symbolized from 1A1 to 9G9.These calibrated TLDs kept the same position in the annealing copper plate during the entire experiment. The first table symbolizes the readings of the background radiation on each TLD. (Table 7)

The absorbed dose of each TLD was recorded for both protocols. These doses are presented in tables 8, 9, 10, 11 and 12.

The shortcomings were encountered with the calculation of the effective dose on the implementation of the equation: $E= W_T \times H_T \times f$ (2)

The equivalent dose (H_T) could easily be calculated as the product of the absorbed dose and the radiation weighting factor, based on the collected data. Limitations, however, were encountered with the identification of the two other parameters in the equation. Each organ had its own specifications for the tissue weighting factor and the fraction of irradiated tissue.

The tissue weighting factor (W_T) for the selected organs was obtained from the literature. However, according the ICRP 2007 publication, the eye was not viewed as an organ that would develop stochastic effects of ionizing radiation. It was therefore not listed in the ICRP 2007 guidelines, among the organs that were attributed a tissue weighting factor. (Table 1) However the threshold dose for cataract, considered a deterministic effect of ionizing radiation on the lens of the eye was clearly stipulated. A minimum exposure of 0.5 Sv, could induce radiation cataract. As a result, the calculated dose of radiation for the lens of the eye was reduced to an equivalent dose with no carcinogenic potential. The equivalent dose is always expressed in Sieverts.

The gonads and the thyroid are attributed tissue weighting factors by the ICRP. These two organs are therefore considered by the ICRP, as having a carcinogenic potential when exposed to a minimum dose of ionizing radiation. The dose of radiation to be calculated for these two organs was therefore to remain an effective dose.

The determination of their respective fractions of irradiated tissues (*ƒ*) was a challenge. There are estimations for this parameter in the literature for the thyroid gland and other organs in the maxillo-facial region. Most of the dosimetry studies on dental CBCT focus on the head and neck region. As a result, this study referred to Ludlow and Ivanovic 2008 estimations of fraction of irradiated tissue values for the thyroid gland. (Table 2) The gonads were given an estimated value of 1%. This was based on the anatomical situation of the gonads, which are very far from the primary x-ray beam. An estimation of 0% would have brought our results to null. This would have been contrary to the observations on the data collection which recorded an absorbed dose on the TLDs placed in this organ.

Table 2: Extract of values of fraction of irradiated organs from Ludlow and Ivanovic

Organ	**Fraction irradiated**
Thyroid	100%
Eyes	100%
Salivary glands	100%
Skin	5%
Mandible	1.3%

The values of the equivalent and effective doses calculated for each organ are presented in tables 3, 4and 5. The first two tables refer to the two different scan protocols. (Table 3-4)

The third table summarizes the average dose values after the five exposures. (Table 5)

The average dose of exposure received on both eyes L and R is therefore: 58.995 µSv.

The comparison of the values of the effective doses on the two resolution settings is illustrated on fig.1.

Table 3: Effective dose of radiation per selected organ in CBCT setting VO1, 85kV, 42mA

Selected Organ	**Mean Absorbed Dose of Radiation (µGy(**	**Tissue Weighting Factor (ICRP 2007)/ Radiation weighting factor**	**Estimated Fraction of irradiated tissue in %**	**Dose of Radiation (ICRP 2007) µSv**
L eye	35.717	1	100	35.717 H_T
R eye	68.569	1	100	68.569 H_T
Thyroid	1001.755	0.04	100	40.072 E
Gonads	89.310	0.08	1	0.071 E

Table 4: Effective dose of radiation per selected organ in CBCT setting VO2, 85kV, 42m

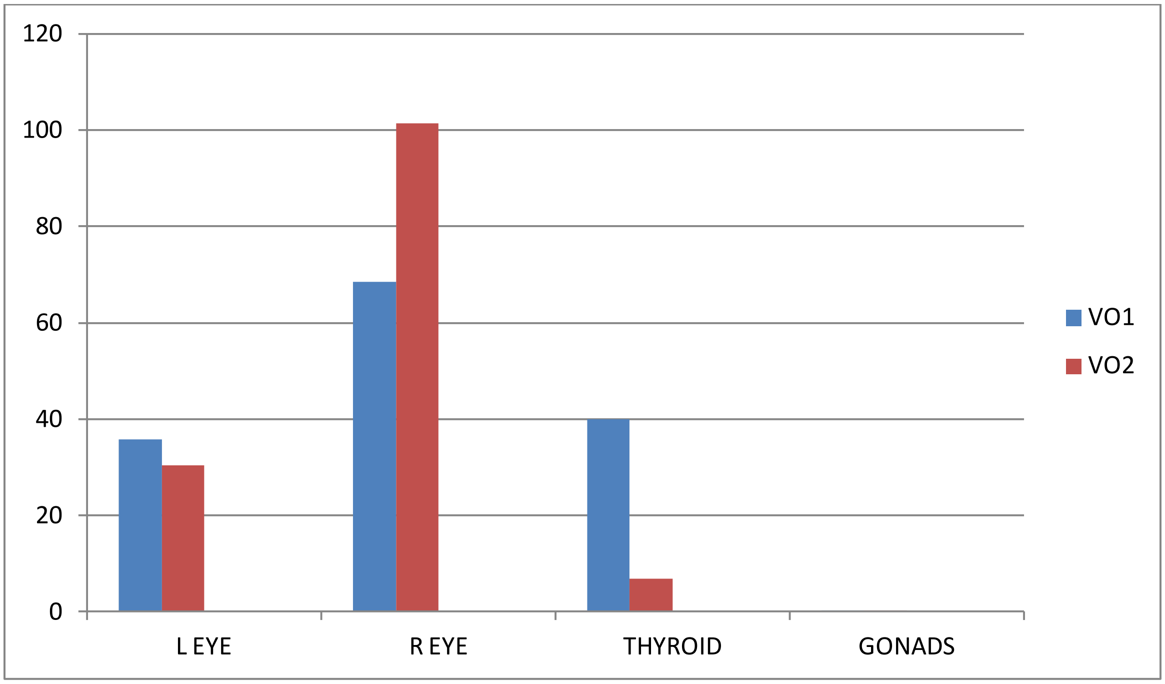
Selected Organ	**Mean Absorbed Dose of Radiation µGy**	**Tissue Weighting Factor (ICRP 2007)/ Radiation weighting factor**	**Estimated Fraction of irradiated tissue in %**	**Dose of Radiation(ICRP 2007) µSv**
L eye	30.378	1	100	30.378 H_T
R eye	101.335	1	100	101.335 H_T
Thyroid	173.46	0.04	100	6.938 E
Gonads	28.310	0.08	1	0.003 E

.

Table 5 : effective dose of radiation after the five exposures

Selected organ	**Mean absorbed dose of Radiation µGy**	**Tissue Weighting Factor (ICRP 2007)/Radiation weighting Factor**	**Fraction of irradiated tissue in %**	**Dose of Radiation (ICRP 2007) µSv**
L eye	33.04		100	33.04 H_T
R eye	84.95		100	84.95 H_T
Thyroid	587.60	0.04	100	23.500 E
Gonads	58,81	0.08	1	0.047 E

Fig1: Column chart comparing values of doses of radiation on VO1 and VO2



CHAPTER III: CONCLUSION

3.1 Discussion

This study examined doses of ionizing radiation emitted during a CBCT examination to the eye, the thyroid and the gonads. Of all the organs exposed, the eye was the one which seemed to show the highest dose of radiation. This could easily be explained by the fact that the dose of exposure to the eye is an equivalent dose that is not influenced by tissue weighting factors. One must therefore not compare the doses calculated for the eye with those for the two other organs which may develop stochastic effects, according to the ICRP 2007. The average equivalent dose for the lens of the eye was 59µSv. A dose of this nature, being almost 10 000 times less than the threshold, may be considered negligible for producing a cataract. Literature has reported an estimated dose of background radiation per annum received by every individual in normal circumstances of approximately of 3mSv. However, there is a great discrepancy between the equivalent dose of 0.059mSv to the eye as calculated in this study and the absorbed dose of 0.94mGy calculated by Akyalcin *et al.* in 2013. Such a comparison seems possible because the radiation weighting factor in the equation for calculating the equivalent dose, based on absorbed dose, is 1. As a result, the dose calculated by Akyalcin *et al.* seems to be 20 times greater. One must bear in mind that although both these studies used the Sirona Galileos Comfort® CBCT scanner with similar scan protocols and FOVs, as well as the organ dose measurement methodology, the equipments used and the methods of calibration of dosimeters were totally different. One study used the standard method of calibration used for deep tissues, while the other used specific calibration of dosimeters and coefficients relative to external surfaces. Another factor that could explain the discrepancy is the different types of dosimeters used in both studies i.e. LiF versus OSL dosimeters. Nevertheless, both results were relatively low.

The gonads showed results approximating the null figure attributed to the study effected by Chambers D, 2014. The effective dose of 0.05µSv could be considered negligible. This is consistent with Alkyacin *et al.*'s theory that justified the low dosage obtained at the skin surface of the thyroid by considering it as being situated in the scatter region.

The thyroid was the organ where calculation of effective dose was the least challenging as all the parameters to determine the effective dose were present. The specific calibration of the dosimeters was that indicated for deep tissues. The organ is anatomically situated in the proximity of the primary beam. However, Ludwig and Ivanovic do not consider it as part of the scatter as they attributed it a fraction of irradiated tissue similar to that of the salivary glands, which, anatomically are definitely situated inside the primary beam. The figure of 23.5 µSv recorded in this study as an effective dose for the thyroid is difficult to compare with doses in the literature because most of the doses for this specific organ found in the literature are equivalent or absorbed doses, the radiation weighting factor for X-rays being 1. However, the ICRP classifies the thyroid as an organ that could develop cancer or mutation related to ionizing radiation. As a result, the calculation of radiation exposure on this organ must take into consideration the tissue weighting factor and the fraction of irradiated tissue. This justifies the use of effective dose for the thyroid gland in this study.

These different types of dosages of the amount of radiation for one specific organ set a limitation to our comparison between the doses in the study and the ones in literature. Yet, the average full body doses recorded in literature are effective doses. They are therefore comparable to the doses in the current study. Ludlow and Ivanovic calculated 128µSv for full FOV and maximum exposure, whereas Chambers recorded an exposure of 140µSv for similar conditions. The manufacturer's effective dose for a similar protocol was shown to be the same as that of Ludlow and Ivanovic i.e. 128µSv.

Considering the author's recording of 24µSv for the thyroid, one could estimate it as approximately 19% of the full body average effective dose as compared to Ludlow and 17% compared to Chambers. In other words, the thyroid, according to the study under consideration, would be absorbing approximately 20% of the full body irradiation emanating from a CBCT scan.

It has been established that the amount of radiation to which a patient is exposed during a CBCT examination is a function of the FOV, the kV of the machine and the amperage setting. One of the objectives of this study was to compare the readings on the high resolution and standard settings of the Galileos Comfort® CBCT without changing the FOV, the kV or the mA. Chambers compared the two settings on the same machine with a similar scan protocol and concluded that the there was no significant difference in the effective doses. The study under consideration compared the two resolution settings at an organ level. There was found to be a discrepancy between the two scan protocols in general, although the greatest discrepancies were found for the right eye and the thyroid. LiF dosimeters have been used in several organ dose measurement studies, and their reliability has been shown in previous studies. Also the phantom used is appropriate for the type of dosimeters used. It has, in fact, been established that the majority of cases recorded in the literature were done on an anthropomorphic phantom and LiF TLDs.[21]

According to literature studies, discrepancies have been explained by the position of dosimeters in the apertures of the phantom.[26]Indeed, in the three organs studied, the dosimeters were placed in sets of three, in a linear pattern: one anterior, one medial and one posterior. This means that one dosimeter was always cranial to the field of radiation while another was always caudal to the field. This fact might explain the discrepancies on all three organs.

Another observation is that the method of calibration of dosimeters used in this study for both the eyes and the other organs was similar. Literature studies consider the eye to be a superficial structure and therefore require the calculation of a personal dose equivalent for this organ.

Finally, the discrepancy might be the result of the number of exposures for each setting. Indeed, three exposures were carried out for the high resolution, while the standard resolution was only submitted to two exposures. The different population samples considered in the calculation of the means for both scan protocols could have influenced the results.

3.2 Conclusion

CBCT is a very useful tool in dentistry. However our study has demonstrated low doses of radiation to the eye, a fairly insignificant amount of scatter to the gonads and a contribution of approximately 20% of the full body dose to the thyroid. For a child of about 12 years undergoing orthodontic treatment this could be considered a fairly substantial dose. However, compared to our measurement of background radiation these doses are still relatively low. As for the different resolution settings, further studies at an organ level are still needed in order to justify these values. Meanwhile application of the ALARA (As Low As Reasonably Achievable) principle by reduction of the FOV and mA settings where applicable as well as a specific indication for a CBCT examination is essential.

Appendices

Appendix 1:

Table 6: Dose values for different exposure settings in full FOV[29] D_{eff}: effective dose value -

Programs	1	2	3	4	5	6
Values	10 mAs	14mAs	21 mAs	28mAs	35mAs	42mAs
D_{eff} ICRP 1991	14µSv	19 µSv	28 µSv	39 µSv	48 µSv	52 µSv
D_{eff} ICRP 2007	30µSv	41 µSv	70 µSv	83 µSv	103 µSv	128µSv

Appendix 2 :Table 7: name of dosimeter and value of background radiation associated

1A1 **72.9**	1B1 **10.92**	1C1 **6.139**	1D1 **7.332**	1E1 **11.24**	1F1 **3.865**	1G1 **Skipped**
2A2 **30.53**	2B2 **7.378**	2C2 **4.415**	2D2 **3.765**	2E2 **3.229**	2F2 **Skipped**	2G2 **3.271**
3A3 **21.16**	3B3 **11.59**	3C3 **8.167**	3D3 **4.034**	3E3 **2.698**	3F3 **6.036**	3G3 **4.222**
4A4 **5.846**	4B4 **5.128**	4C4 **3.840**	4D4 **3.929**	4E4 **2.281**	4F4 **2.562**	4G4
5A5 **48.77**	5B5 **2.75**	5C5 **6.001**	5D5 **7.345**	5E5 **2.412**	5F5 **2.706**	5G5
6A6 **Rejected**	6B6 **Rejected**	6C6 **Flagged as bad**	6D6 **Rejected**	6E6 **3.192**	6F6 **3.105**	6G6
7A7 **13.47**	7B7 **3.339**	7C7 **2.411**	7D7 **8.966**	7E7 **2.645**	7F7 **3.215**	7G7
8A8 **7.202**	8B8 **3.778**	8C8 **2.892**	8D8 **Skipped**	8E8 **8.404**	**8F8** **2.734**	8G8
9A9 **6.197**	9B9 **4.326**	9C9 **2.545**	9D9 **4.355**	9E9 **3.420**	9F9 **Skipped**	9G9

Appendix 3

Scan protocol 1

Table 8: First measurement of absorbed doses on the three selected organs after exposure with the Galileos Comfort CBCT on setting VO1, 85kV, 42mA

TLD name and selected organ p	**Absorbed dose of radiation Reading (µGy)**	**Background Radiation (µGy)**	**Absorbed dose of radiation on Organ (µGy)**
1A1 Gonads	114,4	72,9	41,5
2A2 Gonads	78,54	30,53	48,01
3A3 Gonads	48,57	21,16	27,41
4A4 R eye	31,01	5,84	25,17
5A5 R eye	50,34	48,77	1,57
6A6 Rejected	_	Rejected	_
7A7 R eye	36,63	13,47	23,16
8A8 L eye	35,52	7,202	28,318
9A9 L eye	38,55	6,197	32,353
1B1 L eye	38,79	10,92	27,87
2B2 Thyroid	796,1	7,378	788,722
3B3 Thyroid	962,9	11,59	951,31
4B4 Thyroid	2332	5,128	2326,872

Appendix 4

Table 9: Second measurement of the absorbed dose on the three selected organs, after exposure with Galileos Comfort CBCT on setting VO1, 85 kV and 42 mA

TLD name and selected organ	**Absorbed dose of radiation reading (µGy)**	**Background Radiation (µGy)**	**Absorbed dose of radiation on Organ (µGy)**
1A1 R eye	181.4	72.9	108.5
2A2 R eye	103.4	30.53	72.87
3A3 R eye	75.48	21.16	54.32
4A4 L eye	50.67	5.846	44.824
5A5 L eye	37.04	48.77	Incoherent
6A6 Rejected	_	_	_
7A7 L eye	35.77	13.47	22.3
8A8 Thyroid	276.4	7.202	269.198
9A9 Thyroid	208.3	6.197	202.103
1B1 Thyroid	264.7	10.92	253.78
2B2 Gonads	301.6	7.378	294.222
3B3 Gonads	44.7	11.59	33.11
4B4 Gonads	Rejected	5.128	_

Appendix 5

Table 10: Third measurement of absorbed dose on the three selected organs, after exposure with Galileos Comfort CBCT on setting VO1, 85 kV and 42 mA

TLD name and selected organ	**Absorbed dose of radiation reading (μGy)**	**Background Radiation (μGy)**	**Absorbed dose of radiation on Organ (μGy)**
5B5 Gonads	40.22	2.75	37.47
7B7 Gonads	100.6	3.339	97.261
8B8 Gonads	64.93	3.778	61.152
9B9 Thyroid	100.7	4.326	96.374
1C1 Thyroid	2667	6.139	2660.861
2C2 Thyroid	1471	4.415	1466.585
3C3 R eye	224.8	8.167	216.633
4C4 R eye	115.1	3.840	111.26
5C5 R eye	63.96	6.001	57.959
6C6 _	_	Flagged as bad	
7C7 L eye	47.58	2.411	45.169
8C8 L eye	46.73	2.892	43.838
9C9 L eye	45.77	2.545	43.225

Appendix 6

Scan protocol 2

Table 11: First measurement of absorbed dose of radiation per selected organs, after exposure with Galileos Comfort CBCT on setting VO2, 85 kV and 42 mA

TLD name and selected organ	**Absorbed dose of radiation reading (µGy**	**Background Radiation (µGy)**	**Absorbed dose of radiation on Organ (µGy)**
1D1 Gonads	31.58	7.332	24.248
2D2 Gonads	21.20	3.765	17.435
3D3 Gonads	21.36	4.034	17.02
4D4 Thyroid	37.95	3.929	34.021
5D5 Thyroid	273.5	7.345	266.155
6D6	_	Rejected	_
7D7 Thyroid	221.7	8.966	212.734
8D8	_	Skipped	_
9D9 R eye	46.75	4.355	42.395
1E1 R eye	61.56	11.24	50.32
2E2 R eye	29.53	3.229	26.301
3E3 L eye	35.64	2.698	32.942
4E4 L eye	29.90	2.281	27.619
5E5 L eye	30.27	2.412	27.858

Appendix 7

Table 12: Second measurement of absorbed dose of radiation per selected organ, after exposure with Galileos Comfort CBCT on setting VO2, 85 kV and 42 mA

TLD name and selected organ	**Absorbed dose of radiation reading (µGy**	**Background Radiation (µGy)**	**Absorbed dose of radiation per Organ (µGy)**
6E6 Gonads	40.89	3.192	37.698
7E7 Gonads	38.41	2.645	35.765
8E8 Gonads	29.53	8.404	21.126
9E9 Thyroid	300.9	3.420	297.48
1F1 Thyroid	123.4	3.865	119.535
2F2	_	Skipped	_
3F3 Thyroid	116.9	6.036	110.864
4F4 R eye	367.8	2.562	365.238
5F5 R eye	80.32	2.706	77.614
6F6 R eye	49.25	3.105	46.145
7F7 L eye	49.44	3.215	46.225
8F8 L eye	22.85	2.734	20.116
9F9	_	Skipped	_
1G1	_	Skipped	_
2G2 L eye	30.79	3.271	27.519

Appendix 8

Tables 13,14 and 15

Table 13: Mean absorbed dose of radiation per selected organ in CBCT setting VO1, 85 kV, 42mA

Selected Organ	**Average exposed dose on first exposure (µGy)**	**Average exposed dose on second exposure (µGy)**	**Average exposed dose on third exposure (µGy)**	**Mean dose of exposure (µGy)**
L eye	29.514	33.56	44.077	35.717
R eye	16.633	60.458	128.617	68.569
Thyroid	1355.634	241.693	1407.94	1001.755
Gonads	38.973	163.666	65.29	89.310

Table 14: Mean absorbed dose of radiation per selected organ in CBCT setting VO2, 85 kV, 42 mA

Selected Organ	**Average exposed dose on first exposure (µGy)**	**Average exposed dose on second exposure (µGy)**	**Mean dose of exposure (µGy)**
L eye	29.47	31.287	30.378
R eye	39.672	162.999	101.335
Thyroid	170.97	175.95	173.46
Gonads	19.567	37.054	28.310

Table 15: Comparison of effective doses of radiation on selected

Selected Organ	**Dose of radiation in setting VO1 (μSv)**	**Dose of radiation in setting VO2 (μSv)**
L eye	35.717 H_T	30.378 H_T
R eye	68.569 H_T	101.335 H_T
Thyroid	40.072 E	173.46 E
Gonads	0.071 E	28.310 E

Appendix 9

Figures 2, 3, 4, 5

Fig 2: Copper plate with LIF TLDs

Fig 3: Computer with softwares

Fig 4: Annealing oven: PTW Frieburg 1321®

Fig 5: Hasrhaw 3500 ®reader

Appendix 10

<u>Figures 6 and 7</u>

Fig 6: Vacuum pump

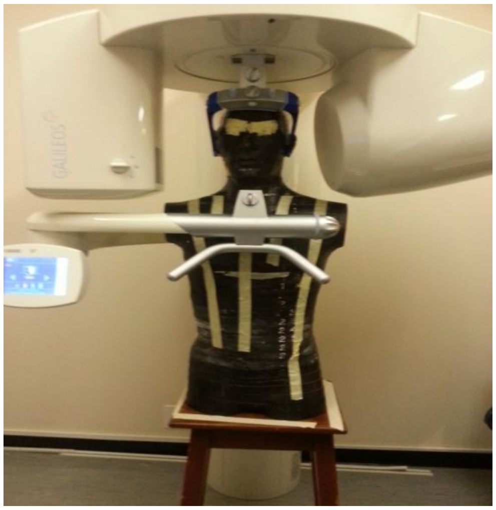


Fig 7: Rando® positioned inside the CBCT

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