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ORIGINAL ARTICLE

# Evaluation of Effective Dose with Two-dimensional and Three-dimensional Dental Imaging Devices

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## ABSTRACT

**Objectives:** Different types of X-ray equipment are used in dental radiology. Purpose of this study was to measure the absorbed doses of some critical organs and tissues in head and neck which were exposed by dental imaging devices that are used routinely in dental radiology.

**Materials and methods:** Radiation exposures were performed by using a human equivalent head phantom and dose measurements were determined with thermoluminescent dosimeters (TLD). After exposure of the phantom with dental imaging devices, absorbed and effective doses of critical organs were determined.

**Results:** Digital imaging systems produced lower effective doses. Effective doses of cone beam computed tomography (CBCT) and multi-slice computed tomography (MSCT) devices were close to each other.

**Conclusion:** Effective doses of digital imaging devices were measured lower than conventional imaging devices. Effective doses of 3D imaging devices were measured higher than all the other imaging devices. However, effective doses of 3D imaging devices were considered in acceptable levels.

**Keywords:** Computed tomography, Cone beam computed tomography, Effective dose, Intraoral radiography, Panoramic radiography.

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## INTRODUCTION

Shortly after the use of X-rays for medical purposes the harmful effects of radiation were specified and the first X-ray related cancer case was reported in 1902.[1] It was also connoted that radiation revealed different effects on each tissue or organ, and the harmful effects varied according to irradiation of all or a portion of body.[2,3]

International commission on radiological protection (ICRP) expressed that radiation will not be harmful to people if the certain limits do not exceed. Depending on this, limits of safe radiation dose was determined (Table 1). International commission on radiological protection also adopts the concept of safely lifetime working on condition that staying below dose limits.

Sitocastic risks can be calculated if patient doses are known in diagnosis and treatment aimed use of radiation. For that purpose, ICRP defined the concept of effective dose.[4] According to the report, reorganized and published by ICRP in 2007, effective dose can be calculated by taking into account the weighting factors given for 14 radiosensitive organs within all organs (Table 2).

Absorbed radiation in human body is not felt by sense organs or evoked any sensation of pain. However, absorbed radiation can cause serious damages on living tissues. So, it is necessary to know and accurately calculate the radiation level exposed during examination.

**Table 1:** Annual dose limits for radiation staff and public determined by ICRP

| | *Radiation staff* | *Public* |
|---|---|---|
| Effective dose | Average of 5 years is 20 mSv (no more than 50 mSv for 1 year) | 1 mSv (As an exception a higher effective dose may be allowed if average of 5 years is not exceeded 1 mSv) |
| Equivalent dose for lens | 150 | 15 |
| Equivalent dose for skin | 500 | 50 |
| Equivalent dose for hands and feet | 500 | — |

**Table 2:** Tissue and organ weighting factors used in effective dose calculation*

| *Tissue/organ* | *Tissue weighting factors* | *Total values of tissue weighting factors* |
|---|---|---|
| Bone marrow, colon, lung, abdomen, chest, other organs | 0.12 | 0.72 |
| Gonads | 0.08 | 0.08 |
| Bladder, esophagus, liver, thyroid | 0.04 | 0.16 |
| Bone surface, brain, salivary glands, skin | 0.01 | 0.04 |
| Total | | 1.00 |

*The weighting factors given for 14 bitivermesinden organs within all organs were reorganised and published by ICRP in 2007[4]

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Thermoluminescent dosimeter (TLD) technique is the most frequently used radiation dose measurement method. Thermoluminescent dosimeters have been used quite a lot in dosimetry studies because they are easy to use, mechanically and chemically durable and partially not being dependent to energy, and these properties are not found in classical dosimetry systems. Furthermore, being smaller than the volume of 1 $mm^3$ makes spot dose measurement possible.[5]

In modern dentistry, radiological examination is a requirement of diagnosis and treatment planning, and digitally compatible 2D and 3D dental imaging devices are also produced according to development of digital technology in recent years. Additionally, as a result of technological advances in dental imaging field, digital imaging and 3D imaging techniques have become used routinely.

The purpose of our study is measurement and comparison of radiation doses absorbed by some critical organs and tissues in head and neck region with using TLD-100's on phantom head respectively exposed by intraoral radiography, panoramic radiography, cone beam computed tomography (CBCT) and computed tomography (CT) devices.

## MATERIALS AND METHODS

The exposures were performed on an anthropomorphic phantom head (model 76-606 DX Atom Max dental head phantom, Fluke Biomedical, Germany) which is manufactured with resin-based hard and soft tissue equivalent material and mimicking the anatomical structures of the head and neck of adult male. Three-dimensional anthropomorphic anatomy of the phantom head includes brain, bone, larynx, trachea, sinus cavities, teeth, and nasal cavity. TLD-100 (LiF2:Mg, Ti; Model 100, Harshaw Chemical, Solon, Ohio) crystals which includes lithium fluoride (LiF2) were used for dose measurements.

Dosimeters were irradiated by an X-ray source which its amount of radiation was known. After the exposed dosimeters were calibrated by using WinREMS software in TLD-reader device, they were grouped in threes. Then, each group of dosimeters in locked bags were placed to the surfaces of following organs on phantom head:

- Thyroid gland
- Right and left eyes
- Larynx
- Trachea
- Right and left parotid glands
- Right and left submandibular salivary glands
- Sublingual salivary gland

During the study, the same dosimeters always placed in exactly the same region in every single exposure. The phantom head loaded with dosimeters was exposed respectively by following systems and devices:

- Conventional full-mouth intraoral radiographic series [7 maxillary periapical radiographs, 7 mandibular periapical radiographs and 2 bite-wing radiographs) exposed by Evolution X300-2C (new life radiology SRL, Italy] X-ray device.
- Digital full-mouth intraoral radiographic series exposed by Belmont Phot-X II model 303-H (Takara Belmont Corp, Japan) X-ray device.
- Conventional panoramic radiographs exposed by Proline CC (Planmeca, Finland) conventional panoramic and cephalometric imaging device.
- Digital panoramic radiographs exposed by Orthophos XG 5 DS/ceph (Sirona, USA) digital panoramic and cephalometric imaging device.
- Conventional extraoral radiographs for orthodontic purpose (panoramic, lateral and posteroanterior cephalometric radiographs) exposed by same device as conventional panoramic radiographs are exposed.
- Digital extraoral radiographs for orthodontic purpose exposed by same device as digital panoramic radiographs are exposed.
- Multi-slice computed tomography (MSCT) exposed by Somatom Sensation 16-sliced CT device (Siemens, Germany).
- Cone beam computed tomography exposed by ILUMA ultra CBCT device (Imtec Corp 3M, USA).

All the exposures were repeated twice and obtained values were averaged. In this way, absorbed doses of organs included in the experiment were measured and effective doses were calculated by using the tissue weighting factors defined in 2007 ICRP recommendations. Results were comparatively evaluated. When the contribution of salivary glands to the effective dose was calculated; absorbed doses measured from all salivary glands were averaged, the resultant value was multiplied with tissue weighting factor given for salivary gland and effective dose for salivary gland was found. When the contribution of esophagus to the effective dose was calculated; the absorbed doses obtained for larynx and trachea were averaged and the resultant value was multiplied with tissue weighting factor given for esophagus. When the contribution of bone marrow to the effective dose was calculated; the absorbed doses for parotid glands and sublingual salivary gland were averaged, thus, a mean absorbed dose for mandible was obtained. Then, mean effective dose for bone marrow was calculated as given by ICRP in 2007.

## RESULTS

Technical features of imaging devices and exposure techniques were the factors affecting radiation dose during study. Table 3 shows the features of imaging devices set and used in our study.

The effective doses for organs included in our study are shown in Table 5. Effective doses were calculated with given formula $E = \sum W_T \times H_T$. According to this formula, measured organ absorbtion doses (Table 4) multiplied with tissue weighting factors for appropriate organs which were rearranged by ICRP in 2007 (Table 2) and total effective doses were found (Table 5). As a result, highest effective dose was found as 114 μSv with multi-slice CT and lowest effective dose was found as 35.6 μSv with lateral cephalometric imaging device.

## DISCUSSION

In today's dentistry, radiological examination is a requirement for diagnosis and treatment planning. As a result of technological development in dental imaging, both digital imaging and 3D imaging techniques have been started to use routinely. In our study, all imaging devices including conventional intraoral imaging device up to multi-slice CT so as to apply every imaging method were used to present effective doses together.

Average dose absorbed by tissue or organ should be known to calculate the effective dose. Measurement of organ dose is very difficult on patient during radiological applications.[6] Additionally, same patient must be exposed by several imaging devices because of need for comparable results. So, unnecessary irradiation makes using patient impossible for radiation dose studies. For that reason, all the exposures in our study performed on hard and soft tissue equivalent phantom head as all the other related articles.

Ionizing radiation sensitivity of different tissues in the human body is also different. International commission on radiological protection defined the effective dose as prior unit in order to compare the risk arising for different radiological examinations in 1991.[7] The use of effective dose is oriented for radiation protection. In 2007, ICRP updated effective dose calculation method in the light of the latest scientific data about radiation physics and biological effects of radiation.[4] Salivary glands, brain, oral mucosa and extrathoracic airway were included in current table for the first time. These changes that containing maxillofacial region shows that there is a significant potential to affect cancer risk estimates during dental examinations. In fact, there are studies showing the association between incidence of head and neck cancer and dental radiography.[8,9] Also, if effective doses are calculated with 2007 factors, the results will be 32 to 422% higher than that calculated with 1990 factors.[10] The 2007 ICRP tissue weighting factors reflect more current data on cancer incidence and mortality. Data on the incidence of cancer, especially for cancer types

**Table 3:** Technical features of imaging devices used in our study

| *Device* | *kVp* | *mA* | *Time (sec)* | *mAs* | *Filtration* | *Focal spot-object* |
|---|---|---|---|---|---|---|
| Conventional full-mouth | 70 | 8 | 7.2 | 57.6 | 2 mm Al | 200 mm |
| Digital full-mouth | 70 | 7 | 2.56 | 17.92 | 2 mm Al | 200 mm |
| Conventional panoramic | 68 | 8 | 18 | 144 | 2.5 mm Al | 250 mm |
| Digital panoramic | 69 | 15 | 14.1 | 211.5 | 2.5 mm Al | 250 mm |
| Conventional ceph | 70 | 12 | 0.8 | 9.6 | 2.5 mm Al | 1500 mm |
| Conventional PA | 78 | 12 | 1.2 | 14.4 | 2.5 mm Al | 1500 mm |
| Digital ceph | 73 | 15 | 14.8 | 222 | 2.5 mm Al | 1714 mm |
| Digital PA | 80 | 14 | 9.1 | 127.4 | 2.5 mm Al | 1714 mm |
| CBCT | 120 | 3.8 | 40 | 152 | 1.3 mm Cu | 600 mm |
| Multi-slice CT | 100 | 6.7 | 15 | 100 | 6.3 mm Al | 700 mm |

**Table 4:** Organ absorbtion doses measured for dental imaging devices (mGy)

| *Organ/tissue* | *Conventional full-mouth* | *Digital full-mouth* | *Conventional panoramic* | *Digital panoramic* | *Conventional ceph + PA* | *Digital ceph + PA* | *CBCT* | *Multi-slice CT* |
|---|---|---|---|---|---|---|---|---|
| Thyroid | 0.574 | 0.378 | 0.446 | 0.379 | 0.481 | 0.412 | 0.863 | 0.714 |
| Right eye | 2.080 | 1.047 | 0.362 | 0.338 | 0.349 | 0.322 | 3.165 | 3.367 |
| Left eye | 2.853 | 0.786 | 0.419 | 0.468 | 0.462 | 0.437 | 3.409 | 4.028 |
| Right parotid gland | 0.593 | 0.367 | 0.779 | 0.611 | 0.405 | 0.413 | 3.190 | 4.416 |
| Left parotid gland | 0.530 | 0.462 | 0.764 | 0.542 | 0.488 | 0.382 | 3.061 | 4.000 |
| Right submandibular gland | 1.911 | 0.748 | 0.512 | 0.592 | 0.353 | 0.453 | 2.594 | 4.050 |
| Left submandibular gland | 2.065 | 0.957 | 0.492 | 0.554 | 0.356 | 0.485 | 2.638 | 3.793 |
| Sublingual gland | 3.372 | 1.375 | 0.636 | 0.607 | 0.413 | 0.399 | 2.636 | 3.105 |
| Larynx | 0.925 | 0.527 | 0.485 | 0.495 | 0.374 | 0.281 | 1.209 | 1.222 |
| Trachea | 0.840 | 0.405 | 0.487 | 0.452 | 0.433 | 0.437 | 0.991 | 0.929 |

**Table 5:** Calculated effective doses for imaging devices used in our study (μSv)

| *İmaging device* | *Effective dose* |
|---|---|
| Conventional full-mouth | 77.4 |
| Digital full-mouth | 42.2 |
| Conventional panoramic | 44.3 |
| Digital panoramic | 40.4 |
| Conventional ceph + PA | 39.9 |
| Digital ceph + PA | 35.6 |
| CBCT | 109.5 |
| Multi-slice CT | 114 |

that the survival rate is high, reveals a more complex explanation. Especially, salivary glands and brain are shown as organs which have increased weighting factors due to evidences of increased risk of cancer in 2007. In our study, 2007 ICRP tissue and organ weighting factors were used to calculate effective doses of critical organs in head and neck.

Radiation doses of dental imaging methods are always determined as low when compared with other medical radiological examinations. Therefore, the radiation dose used in dental radiology related issues are not observed as important as needed. However, dental radiological applications are one of the most common areas that X-rays are used within all dental applications.[11,12] Also, the most frequently used radiographic technique within all dental radiographic techniques is intraoral radiography. But, a very large portion of dental radiological applications are performed in dental clinics without a standard quality assurance program or radiological applications are performed by practitioners who are not properly trained.[13] Consequently, patients can be exposed unnecessarily because of inadequate or defective equipment or improper application techniques.[14] In our study, all the exposures were performed as well-trained staff do as in routine clinical applications. Results showed that the highest effective dose was calculated with multi-slice CT as 114 μSv and the lowest effective dose was calculated with digital lateral cephalometric and anteroposterior imaging as 35.6 μSv. Digital 2D extraoral imaging methods produced lower effective doses than conventional ones as expected but, no significant difference was detected between these two results. As a reason, the parameters, such as kVp and mAs in digital imaging might be adjusted more than the required, moreover, the practitioner might not notice or check the imaging protocol. So, this circumstance resulted to higher radiation. Hereby, effective doses of digital 2D imaging methods were found close to effective doses of conventional methods. Also, practitioner might not be aware that the patient is exposed over than required in routine digital radiological applications.[15] The increase in amount of irradiation does not cause a significant difference in image details. In contrast, decrease of irradiation causes digital image with excessive moire, and this event results with repetition of exposure. In both cases, patient dose increases.[16] As mentioned previously, radiologist or authorized person must be careful when adjusting the imaging protocol especially in digital systems, because, practitioner's faults, such as over-adjustment of imaging parameters can result to higher radiation in patient dose even in a radiology clinic of dentistry faculty experimented in this study.

Effective doses for full-mouth examination in digital and conventional intraoral imaging devices were calculated as 42.2 and 77.4 μSv, respectively. Thus, in opposition to 2D extraoral imaging methods, total effective dose for conventional intraoral examination was approximately two times higher than that for digital intraoral examination. The results showed that, total effective dose obtained for digital imaging was decreased 2 times when reducing the exposure time about 3 times according to conventional intraoral imaging exposure time while other settings for both intraoral imaging devices were almost the same. The difference found between absorption and effective doses of conventional and digital intraoral imaging methods was an expected result. Study was based on the parameters used in routine clinical practice. But it has been shown that using rectangular collimation and a high-speed film or digital sensor results 10-fold reduction in risk of fatal cancer.[10] Therefore, any adjustment was not performed intended for reducing radiation dose. Because effective doses were asked to determine under routine conditions in our study. In order to explain such a situation, the new studies are required, demonstrating the relationship between radiation dose, imaging technique and image quality so as to have optimum images.

Effective doses of digital 2D extraoral imaging device calculated in our study were approximately 3 or 4 times higher than that calculated in the literature.[10,17,18] Reason for this difference may be related to exposure settings of devices. The increase in mAs value results with increase in effective dose. Thus, total effective doses of digital panoramic, lateral cephalometric and posteroanterior imaging devices were calculated as relatively higher in consequence of higher mAs values of these imaging devices in our study.

In general, CBCT is a technique which uses lower doses in scanning the maxillofacial region when compared with multi-slice CT.[19,20] There are some studies supporting this opinion in the literature.[21-25] Also, CBCT is a diagnostic tool as effective as multi-slice CT. This condition makes frequent usage of the CBCT technique as innocent with valid medical reasons. But, cumulative radiation dose increases while the frequency of use increases. In 2007, a published study showed that 1.5 to 2% of all cancers in United States are associated with the use of CT scans.[26] Although this is a controversial, the amount of radiation received per person by sources of ionizing radiation has been increased from 3.6 to 6.2 mSv in the last 20 years period, and this has been largely attributed to increased use of CT scans.[27] On the other hand, some CBCT devices are used in similar or even higher radiation doses when compared with CT scans.[28] Therewithal, radiation dose levels close to those produced by CBCT devices can be obtained with using low dose protocol of CT devices.[29] Our results showed closer radiation dose levels of CBCT and multi-slice CT devices in support of this situation. As a reason, the mA value of multi-slice CT device was very low in our study. Thus, we obtained much lower radiation doses with multi-slice CT than that of the literature which has been measured as 474 μSv for mandible with the same CT device.[21] Additionally, there is no need to use higher mA values for purposes of dental imaging. The mAs value of CBCT device was very high and field-of-view (FOV) area was large in our study. So, these parameters may be approached the radiation doses of CBCT device close to that of multi-slice CT device in our study. Especially, FOV area is an important tool affecting the radiation dose of CBCT device.[21]

In conclusion, the lowest possible dose for dental imaging technique should be chosen to provide optimum image quality. Also, the technical properties of the imaging device should be set so as to obtain the image with lowest possible dose. Unnecessary exposures should always be avoided. The use of 3D imaging techniques in dentistry required a careful radiological indication. The effective doses of multi-slice CT scanners with low dose protocol are close to the effective doses of CBCT devices. Therefore, multi-slice CT devices can be used in dentistry when necessary. Cone beam computed tomography devices, which offering different scanning areas, resolutions and irradiation parameters, should be preferred. Although organ dosimetry studies present quite different results from one another, performing such studies with as much as possible different devices is valuable in terms of better understanding and revealing the importance of issue.

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