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RESEARCH ARTICLE

Efficacy of lead foil for reducing doses in the head and neck: a simulation study using digital intraoral systems

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Objectives: To assess the efficacy of lead foils in reducing the radiation dose received by different anatomical sites of the head and neck during periapical intraoral examinations performed with digital systems.
Methods: Images were acquired through four different manners: phosphor plate (PSP; VistaScan® system; Dürr Dental GmbH, Bissingen, Germany) alone, PSP plus lead foil, complementary metal oxide semiconductor (CMOS; DIGORA® Toto, Soredex®, Tuusula, Finland) alone and CMOS plus lead foil. Radiation dose was measured after a full-mouth periapical series (14 radiographs) using the long-cone paralleling technique. Lithium fluoride (LiF 100) thermoluminescent dosemeters were placed in an anthropomorphic phantom at points corresponding to the tongue, thyroid, crystalline lenses, parotid glands and maxillary sinuses.
Results: Dosemeter readings demonstrated the efficacy of the addition of lead foil in the intraoral digital X-ray systems provided in reducing organ doses in the selected structures, approximately 32% in the PSP system and 59% in the CMOS system.
Conclusions: The use of lead foils associated with digital X-ray sensors is an effective alternative for the protection of different anatomical sites of the head and neck during full-mouth periapical series acquisition.
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Introduction

While the periapical series is regarded as an important auxiliary diagnostic tool in dentistry, the amount of radiation emitted during examination requires proper protection for both the patient and the professional, since high energy and great penetrating power of the X-rays are potentially damaging to any exposed human tissue.[1,2]

As a result of the interaction between ionizing radiations and living tissues, a wide range of molecular changes can occur depending on the area of exposure, on the type and stage of development of each tissue exposed, as well as on the dose and frequency of exposure. Excessive radiation is potentially harmful to the oral mucosa, salivary glands, taste buds, teeth, periodontal tissues, bone, muscle and joints.[3]

The term "dose" is used to describe the amount of energy absorbed per unit of mass in a region of interest. It is measured in gray (Gy) and is directly related to the radiation absorbed by the organs of a living body. The exposure can lead to two types of biological effects, deterministic and stochastic.[4]

Radiation doses needed for intraoral periapical radiographs are relatively small and well below the range that produces deterministic effects. The principles of radiation protection recommend that these examinations be clearly justified by clinical reasons and that the doses used be the lowest possible (the ALARA principle: "as low as reasonably achievable"). Even though minimal, radiation may still elicit stochastic effects,

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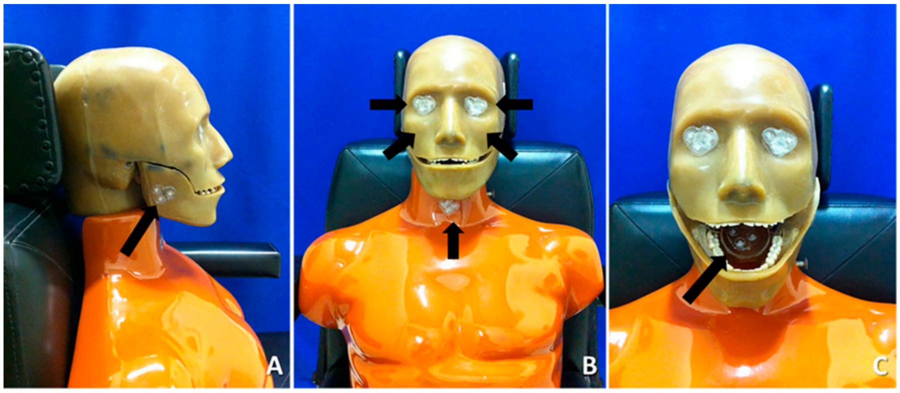

Figure 1 Image of the anthropomorphic phantom made of tissue-equivalent materials and the positioning of the dosemeters (arrows): (a) side view, (b) front view with closed mouth and (c) front view with open mouth.

which require no threshold dose to occur. Thus, care should be taken during radiographic imaging of the head and neck region since critical organs such as the thyroid gland and the crystalline lens may be exposed to radiation.[5]

The amount of radiation created by an imaging device or by the environment can be measured with relative ease by one of the several types of radiation detectors available. The most commonly used detectors for individual monitoring are dosimetric films and thermoluminescent dosemeters (TLDs). Some of the compounds used in TLDs include lithium fluoride (LiF), $CaSO_4$ (calcium sulfate) and CaF_2 (calcium fluoride).[1,6]

Radiographic examination is an important component of the diagnostic process in dentistry; still, the possible deleterious effects of ionizing radiation on biological tissues must not be ignored. Digital systems are gradually replacing conventional radiographic films with the advantages of lower radiation doses, as well as time- and storage-saving properties.[7] Lead sheets or foils are part of conventional radiographs and function as absorbers of residual X-ray beams. Digital systems have eliminated lead foils, and one may ponder whether that could lead to a certain loss of radiation protection. Thus, the present study evaluated the efficacy of lead foil for reducing the radiation dose received by different anatomical sites of the head and neck during periapical intraoral examinations performed with digital systems.

Methods and materials

An anthropomorphic phantom made of tissue-equivalent materials was used as a substitute patient in all experiments.[8] Dosemeters were placed on the anatomical regions equivalent to the tongue, thyroid gland, crystalline lenses (bilaterally), parotid glands (bilaterally) and maxillary sinuses (bilaterally) (Figure 1).

All dosemeters were arranged in triplets and wrapped in plastic to make handling easier and to protect against moisture and/or impurities (Figure 2). To obtain the results, the average of the readings measured in each triplet was used.

An intraoral GE 1000® X-ray device (General Electric Co., Milwaukee, WI) with acquisition parameters set to 65 kVp and 10 mA, and a circular collimation was used to obtain a full-mouth periapical series (composed of 14 radiographs) through the long-cone paralleling technique. To control for the variations in electrical current that could affect proper determination of the doses, tests were performed at three distinct times during the day so that the best

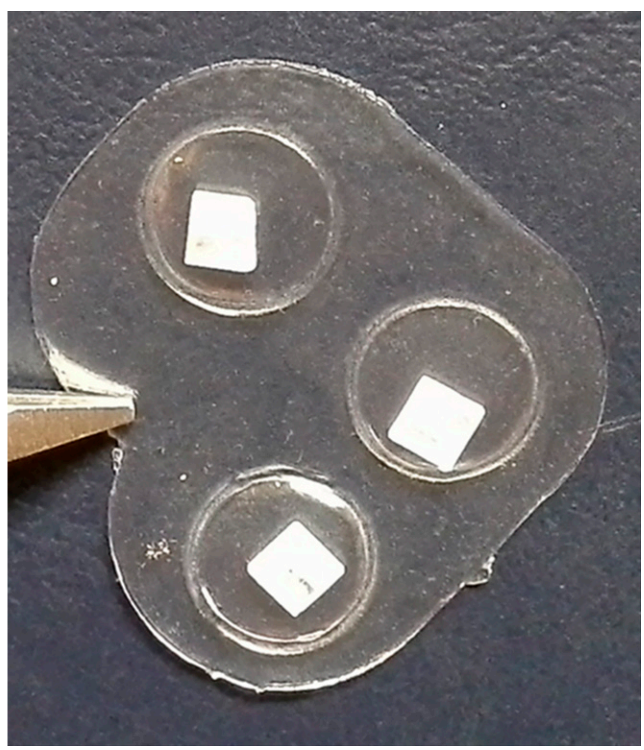

Figure 2 Image of the dosemeters arranged in triplets and wrapped in plastic.

Figure 3 Image of the phosphor plate digital periapical system used and the location where the lead foil was placed.

time for measurements could be established. After performing the tests, the afternoon time period was chosen, as this time period presented the most stable electrical current during testing.

Then, two types of digital image receptors (PSP and CMOS) were divided into four groups:

(1) phosphor plate (PSP) digital periapical system (VistaScan® system; Dürr Dental GmbH, Bissingen, Germany) at 0.30 s of exposure
(2) PSP plus lead foil at 0.30 s of exposure (Figure 3)
(3) CMOS digital periapical system (DIGORA® Toto, Soredex®, Tuusula, Finland) at 0.18 s of exposure
(4) complementary metal oxide semiconductor (CMOS) plus lead foil at 0.18 s of exposure (Figure 4).

Exposure times were determined based on image quality. All lead foils used were those removed from conventional periapical films Insight (Eastman Kodak Co., Rochester, NY).

Measurement of the dose received by the selected anatomical sites described above was performed with LiF 100 TLDs supplied by the FFCLRP/USP Center for Instrumentation, Dosimetry and Radiation Protection (CIDRA). After exposure, the dosemeters were sent to CIDRA for a reading of the radiation absorbed. Values obtained for each anatomical region were expressed in milligrays and tabulated. The normality of the sample was verified using the Kruskal–Wallis test and then compared using descriptive and variance analyses with *post hoc* Tukey's test set at the 5% significance level.

Results

The average readings obtained from LiF 100 TLDs showed a statistically significant decrease in the dose received by all the selected anatomical sites when lead foil was added to PSP and CMOS systems (Tables 1 and 2). The regions with the largest reduction in radiation absorption were the tongue with PSP plus lead foil (2.39–0.82 mGy), and the right crystalline lens with CMOS plus lead foil (1.67–0.38 mGy).

Discussion

Studies that investigated the amount of radiation produced or absorbed during dental radiographic examinations have commonly used ion chambers and/or TLDs to determine radiation levels.[9–11] The authors of this study chose LiF 100 TLDs owing to their high sensitivity to the low doses of radiation commonly seen in dental radiography.

Figure 4 Image of the complementary metal oxide semiconductor (CMOS) digital periapical system (DIGORA® Toto, Soredex®, Tuusula, Finland) used and the location where the lead foil was placed.

Table 1 Measurements of doses received by the critical organs in phosphor plate (PSP) system (VistaScan® system; Dürr Dental GmbH, Bissingen, Germany) (in mGy)

Digital intraoral system	*Tongue Mean ± SD*	*Thyroid gland Mean ± SD*	*Right parotid gland Mean ± SD*	*Left parotid gland Mean ± SD*	*Right crystalline lens Mean ± SD*	*Left crystalline lens Mean ± SD*	*Right maxillary sinus Mean ± SD*	*Left maxillary sinus Mean ± SD*
PSP (mGy)	2.39 ± 0.56a	3.38 ± 0.81a	0.19 ± 0.04a	0.14 ± 0.01a	0.28 ± 0.06a	0.30 ± 0.09a	2.94 ± 0.69a	2.95 ± 0.55a
PSP + lead foil (mGy)	0.82 ± 0.21b	2.36 ± 0.76b	0.09 ± 0.02b	0.06 ± 0.01b	0.12 ± 0.03b	0.16 ± 0.05b	2.43 ± 0.58b	2.45 ± 0.59b

SD, standard deviation.
Different letters within the same column represent statistically significant differences $p < 0.05$.

The main purpose of periapical radiography is the study of a single tooth or a group of teeth by providing a detailed two-dimensional view of the dental anatomy and of the neighbouring structures.[12] Notwithstanding the newer, more advanced imaging tools, periapical radiography remains the technique of choice in dental practices throughout the world.[7,13] Thus, this study was designed to simulate and assess the amount of radiation produced by a full-mouth periapical series of 14 radiographs.

The development of digital radiography has triggered many changes in the field of diagnostic imaging. Features such as a higher dynamic range and greater sensitivity of digital sensors can reduce the amount of radiation to which patients are exposed and that is perceived as the main reason for the current move from conventional to digital radiography in dentistry.[7,14,15] Since digital radiography is currently less of a trend and more of a reality, the present study tested two digital systems: CMOS and PSP.

The use of collimation is one of the most effective ways to reduce the patient's exposure to radiation. Two shapes of collimators are available for intraoral radiography: circular and rectangular.[16] In this study, the authors have chosen to use a circular collimator because it is the most common collimator used in Brazil, and the purpose of the research was to reproduce a real clinical situation.

The ionizing nature of X-rays can damage organs and tissues regardless of the amount of exposure. Fortunately, different protective devices and techniques can be used to reduce the levels of radiation received by the patient. Filtering and collimation of the X-ray beam, use of lead aprons and lead collars for thyroid gland protection, in addition to techniques such as long-cone paralleling are all effective means of radiation protection during diagnostic imaging.[3–5,10] In our work, the dosemeters were placed in highly radiation-sensitive anatomical regions in the head and neck area in order to know if the addition of lead foil to digital sensors would bring significant differences in the absorption of radiation and could, therefore, be considered an effective tool for radiation protection.

The lead foil is one component of conventional radiographs and serves as an additional filter of secondary radiation. Owing to the shorter exposure time required for image acquisition with digital radiography systems, lead foils are not used along with digital sensors.[17] The dosimetric values obtained in this study revealed that, when lead foil was added to PSP and CMOS sensors, a statistically significant reduction in radiation absorption was evident for all different anatomical sites investigated. Taken together, the overall reduction in radiation absorption was approximately 32% in the PSP system and 59% in the CMOS system.

The results showed that for certain anatomical sites, such as the tongue, thyroid gland, and right and left maxillary sinus, the use of CMOS overall generates a lower effective dose than does PSP; but for other anatomical sites, such as the right and left parotid glands and crystalline lens, PSP delivers much lower dosages than CMOS. The authors believe that these differences are related to the positioning of the tongue, thyroid gland, and right and left maxillary sinus as they are closer to the irradiation field structures. These anatomical sites are more susceptible to direct radiation, in other words, primary radiation. As there is a reduction in the exposure time in the CMOS system when compared with the PSP, the dose received by the patient in these anatomical sites is lower in the CMOS system than in the PSP system. On the other side, organs such as the parotid glands and crystalline lenses are more distant from the radiation field and hence are

Table 2 Measurements of doses received by the critical organs in CMOS system (DIGORA® Toto, Soredex®, Tuusula, Finland) (in mGy)

Digital intraoral system	*Tongue Mean ± SD*	*Thyroid gland Mean ± SD*	*Right parotid gland Mean ± SD*	*Left parotid gland Mean ± SD*	*Right crystalline lens Mean ± SD*	*Left crystalline lens Mean ± SD*	*Right maxillary sinus Mean ± SD*	*Left maxillary sinus Mean ± SD*
CMOS (mGy)	1.69 ± 0.53a	2.80 ± 0.80a	1.67 ± 0.52a	1.61 ± 0.49a	1.67 ± 0.51a	1.61 ± 0.51a	1.20 ± 0.32a	1.30 ± 0.38a
CMOS + lead foil (mGy)	0.74 ± 0.19b	1.82 ± 0.63b	0.42 ± 0.15b	0.35 ± 0.13b	0.38 ± 0.14b	0.37 ± 0.14b	0.72 ± 0.18b	0.75 ± 0.20b

CMOS, solid sensor; SD, standard deviation
Different letters within the same column represent statistically significant differences $p < 0.05$.

more susceptible to secondary radiation than the primary radiation. The PSP produces a smaller amount of secondary radiation than does CMOS, probably owing to a smaller sensor thickness. Thus, the effective doses in these organs were lower in PSP than in CMOS.

Therefore, the addition of lead foil to intraoral digital radiography systems promoted superior radiation protection to the patient during routine diagnostic imaging. Manufacturers should consider modifying their sensors in order to improve radiation protection, as this study has demonstrated that the benefits to be derived from this modification is in the interest of manufacturers, patients and dentistry professionals.

Conclusions

In this study, the addition of lead foil to intraoral digital systems was able to reduce the effective dose absorbed by anatomical sites of the head and neck.

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