Significant reduction in dental cone beam computed tomography (CBCT) eye dose through the use of leaded glasses

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Objective. In light of the increased recognition of the potential for lens opacification after low-dose radiation exposures, we investigated the effect of leaded eyeglasses worn during dental cone-beam computerized tomography (CBCT) procedures on the radiation absorbed dose to the eye and suggest simple methods to reduce risk of radiation cataract development.

Study design. Dose measurements were conducted with the use of 3 anthropomorphic phantoms: male (Alderson radiation therapy phantom), female (CIRS), and juvenile male (CIRS). All exposures were performed on the same dental CBCT machine (Imtec, Ardmore, OK) using 2 different scanning techniques but with identical machine parameters (120 kVp, 3.8 mA, 7.8 s). Scans were performed with and without leaded glasses and repeated 3 times. All measurements were recorded using calibrated thermoluminescent dosimeters and optical luminescent dosimetry.

Results. Leaded glasses worn by adult and pediatric patients during CBCT scans may reduce radiation dose to the lens of the eye by as much as 67% (from 0.135 \pm 0.004 mGy to 0.044 \pm 0.002 mGy in pediatric patients).

Conclusions. Leaded glasses do not appear to have a deleterious effect on the image quality in the area of clinical significance for dental imaging. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:502-507)

Cone-beam computerized tomography (CBCT) is becoming a widely used imaging tool in many dental facilities. CBCT units offer excellent bone image resolution and are lighter in weight, less expensive, and designed to have a smaller operating “footprint” than multidetector CT (MDCT) machines. CBCT scanners offer 3-dimensional (3D) diagnostic information with better spatial resolution and less distortion than panoramic radiography machines. More importantly, from the point of view of patient safety, CBCT differs from MDCT in the shape of the x-ray beam and number of rotations and typically results in lower radiation exposures. CBCT uses a cone-shaped x-ray beam rather than the typical fan-shaped x-ray beam used in MDCT. The CBCT’s detector rotates, along with the x-ray source, once around a patient’s head, and a computer algorithm converts the series of 2-dimensional basic images into a 3D reconstruction. Depending on machine type and manufacturer, typical scanning times range from \sim 10 to 40 seconds.

CBCT units are primarily designed to demonstrate osseous structures as opposed to soft tissue anatomy. They are commonly used to image dental impactions, maxillofacial skeletal and dental discrepancies, assessment of facial trauma, and tumors. Dental CBCT units are also increasingly used in treatment planning for dental implants, and orthognathic and general maxillofacial surgery. Although there are no current standardizations for CBCT dosimetry, and there is no consensus among dental and medical physics health professionals regarding patient- or organ-specific radiation doses in dental CBCT imaging procedures, there is a European project (www.sedentexct.eu) in place seeking to address this issue. Additionally, effective doses can vary by orders of magnitude when different machine models, systems, and manufacturers are compared.

It is important to justify all uses of ionizing radiation in health care and, when appropriate, maintain image quality while reducing radiation doses as low as rea-
sonably achievable.\textsuperscript{8} CBCT doses, although usually an order of magnitude smaller than those of MDCT, are still greater than traditional panoramic radiography.\textsuperscript{9,10} Recently, governmental and regulatory agencies have begun to address this issue. For example, only within the last year did the U.K. Health Protection Agency release guidelines for the safe use of CBCT units in dentistry.\textsuperscript{11} Although these guidelines address the use of patient shields to protect the body and thyroid gland from scattered radiation dose, they do not address reduction of radiation dose to the lens of the eye, which is a very radiosensitive tissue.\textsuperscript{12-14} Ionizing radiation exposure to the lens causes characteristic dose-related changes, including opacification (cataract) and resultant potential visual disability.\textsuperscript{15-17}

An association between radiation exposure and cataractogenesis is well documented, having been studied in a variety of populations, including, for example, atomic bomb survivors,\textsuperscript{13} Chernobyl clean-up workers,\textsuperscript{18} radiotherapy patients,\textsuperscript{19,20} x-ray technicians,\textsuperscript{21} interventional radiologists,\textsuperscript{22} and cardiologists.\textsuperscript{23,24}

Current regulatory guidelines from the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements limit the lens equivalent dose to 150 mSv/y.\textsuperscript{25,26} At present, both organizations consider radiation cataract to be a deterministic event with a relatively high dose threshold dose of 5-8 Gy after chronic, prolonged, or fractionated exposures. In fact, however, the ICRP report\textsuperscript{8} noted that “recent studies have suggested that the lens of the eye may be more radiosensitive than previously considered.” It added that “new data on the radiosensitivity of the eye with regard to visual impairment are expected” and concluded, “Because of the uncertainty concerning this risk, there should be particular emphasis on optimization in situations of exposure of the eyes.” In support of this assertion, in recent years new evidence has emerged that suggests that lens opacification may occur at far lower exposures, <1 Gy, than previously expected and that development of radiation cataract may be consistent with the absence of a dose threshold.\textsuperscript{12,27-31} In addition, recent experimental work suggests that individual genetic differences in radiosensitivity may play an important role in explaining the wide variation in reported time of cataract onset, degree of opacification, and subsequent progression to visual disability, among various individuals exposed to ionizing radiation.\textsuperscript{32,33}

In light of the increased recognition of the potential for lens opacification after low-dose radiation exposures, we investigated the extent of the effect of leaded eyeglasses worn during dental CBCT procedures on the radiation absorbed dose to the eye and suggest simple methods to reduce risk of radiation cataract development.

MATERIAL AND METHODS

Three different anthropomorphic phantoms were used to assess eye radiation doses from dental CBCT procedures. The adult female phantom (model 702; Computerized Reference Imaging System (CIRS), Norfolk, VA) represents an average woman that is 160 cm in height and 55 kg in weight. The 5-year-old phantom (CIRS model 705) represents a pediatric patient that is 110 cm in height and 19 kg in weight. These full-body phantoms are manufactured to ICRP 23 and ICRU 48 specifications and consist of 25-mm contiguous sections containing 21 specific inner organs.\textsuperscript{24} The adult male phantom (Alderson Radiation Therapy Phantom; Radiology Support Devices, Long Beach, CA) represents an adult man that is 175 cm in height and 73.5 kg in weight and is manufactured to ICRU 44 specifications. Optically stimulated luminescent dosimeters (OSLs; NanoDot; Landauer, Glenwood, IL) and thermoluminescent dosimeters (TLDs; TLD-100; Harshaw Chemical Co., Solon, OH) were used to assess radiation dose to the eye and the brain. OSL dosimeters were also placed on the surface of each phantom eye to measure the lens dose.

All scans were performed using an Iluma CBCT machine (Imtec, Ardmore, OK) in the Memorial Sloan-Kettering Cancer Center Oral Surgery Department. Two scanning techniques were used. The full scan had no collimation, representing a full facial scan, and the collimated scan (collimated to just the maxilla-mandibular area, not including the eyes) used a collimator to simulate a maxilla-mandibular scan. Both scanning techniques used the same machine parameters (120 kVp, 3.8 mA, 7.8 s). Three complete (scout and volume acquisition) scans were conducted for each procedure. To compute the exposure for each scan, the procedure dosimeter measurements were divided by 3. Organ dose data points are an average of dose measurement for all dosimeters within that organ. Basic statistical evaluation (mean, standard deviation, etc.) was conducted using Excel (Microsoft Corp., Redmond, WA).

Sport wraparound leaded glasses (LG-600 Rayshield; Aadco Medical, Randolph, VT) were used to assess the reduction in ocular and brain dose from wearing eye protection during the 2 different scanning techniques. Glasses were placed over the eyes on the bridge of the nose before each scan (Figs. 1 and 2).

Dosimeter measurements were performed by the authors. Before use, the TLD-100s were annealed at 400°C for 1 hour, then 2 hours at 100°C, and then allowed to cool at room temperature. TLD read-outs were performed on a Harshaw Model 3500 reader.
(Thomas Scientific, Waltham, MA). All of the TLDs were preheated for 10 seconds at 50°C and finally at 300°C for 10 seconds of annealing time before read out. Calibration of the TLDs at 120 kVp was performed using a calibrated RadCal MDH model 1015 dosimeter (RadCal Corp., Monrovia, CA). OSL dosimeters were read out in accordance with the manufacturer’s protocol and calibrated with a manufacturer-provided calibration set.

RESULTS

Absorbed dose to the eye and brain were assessed for 3 different anthropomorphic phantoms (Table I). The relative differences between doses among the 3 phantoms were small for full scans without collimation.

Use of machine collimation significantly reduced the dose to the eye for the pediatric (46% dose reduction) and adult female (84% dose reduction) phantoms. The male phantom was not included in the eye dose reduction comparison for the collimated scan. Likewise, the brain also received a large radiation dose reduction for both the pediatric (63%) and the adult female (81%) phantoms.

Wearing leaded glasses provided significant reduction in absorbed dose to the eye and, to a lesser extent, the brain (Fig. 3; Table II). Eye doses for all 3 phantoms undergoing the full scan were reduced by >60%. Eye dose for the pediatric phantom undergoing the collimated scan was also reduced by 60%, whereas the adult female phantom eye dose was reduced to a somewhat lesser extent (38%). Comparison of dose reduction to the brain for the adult female phantom undergoing the collimated scan with and without glasses was negligible (~1%). Machine collimation limited the primary scanning field of view, presumably explaining the minimal gain in dose reduction after use of leaded glasses in this case.
DISCUSSION

Machine collimation significantly reduces the radiation dose to portions of the body not directly in the dental professional’s primary area of concern. Machine collimators are generally made of lead and reduce the total area of the x-ray beam. Most new machines allow the user to collimate the x-ray area from the user terminal after taking the initial scout image, while older machines allow for manual collimation in the form of knobs and/or dials. X-ray beam collimation reduces the radiation beam to a specific field size and limits the radiation exposure of tissues outside the primary x-ray beam field-of-view. Therefore, a collimated CBCT x-ray beam reduces the effective dose and organ-specific absorbed doses. The present paper, however, is the first to demonstrate that use of leaded glasses significantly reduces exposure from CBCT scans to the adult and pediatric eye lens, inferring that the subsequent risk for radiation cataract development is reduced.

Variation in the absorbed doses among the phantoms for each scanning procedure arises primarily from differences in radiation attenuation. Attenuation of photon radiation is a function of the photon energy and the atomic numbers of the different tissues present in the scanning field. Even though the atomic numbers of each of the different tissues are the same among the phantoms, the density of the tissue varies, with that of a pediatric phantom being less than an adult phantom’s (i.e., the pediatric bone density is less than the adult bone density). Therefore, a pediatric phantom will result in lower attenuation of the scattered beam, resulting in a more scattered radiation being absorbed by each organ, giving a higher absorbed dose, as the CBCT scans completely around the phantom.

Earlier studies have measured lens x-ray exposures arising from a variety of dental radiographic procedures and techniques. The earliest comprehensive survey of lens exposure after conventional dental radiographic examination of specific anatomic sites or after a complete intraoral survey was published in 1989. The increasing use of higher-resolution, but also higher x-ray dose, modalities, such as conventional and spiral CT, led to increased scrutiny of lens exposure. Lower patient radiation doses to the infraorbital foramen, lateral orbit, and presumably lens, were noted for spiral compared with conventional CT after dental implant pretreatment evaluation. Another study compared 3 forms of panoramic radiography with CT during dental implant evaluation and noted as much as a 100-fold greater lens exposure arising from CT examinations compared with radiologic cephalometric examinations. When different types of CBCT systems were compared with each other as well as with conventional CT, using an Alderson phantom, significant differences in absorbed dose to the lens, ranging from 0.06 to 5.76 mGy, were noted. In cases where examination of only limited dental regions were needed, such as the lower jaw, spiral tomography resulted in significantly less lens exposure that spiral CT. Similarly, organ doses after preoperative radiographic examination of the lower molars by CT were higher than those obtained by conventional radiography or conventional radiography with spiral tomography. Most recently, lens radiation doses were compared in Alderson radiation therapy

### Table I. Eye and brain organ absorbed doses for full field-of-view and collimated scans

<table>
<thead>
<tr>
<th>Scan type</th>
<th>Organ</th>
<th>Pediatric (mGy)</th>
<th>Adult female (mGy)</th>
<th>Adult male (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full scan w/o glasses</td>
<td>Eye</td>
<td>0.135 ± 0.004</td>
<td>0.133 ± 0.002</td>
<td>0.133 ± 0.001</td>
</tr>
<tr>
<td>Full scan w/glasses</td>
<td>Eye</td>
<td>0.044 ± 0.002</td>
<td>0.051 ± 0.002</td>
<td>0.045 ± 0.001</td>
</tr>
<tr>
<td>Collimated scan w/o glasses</td>
<td>Eye</td>
<td>0.073 ± 0.005</td>
<td>0.021 ± 0.002</td>
<td></td>
</tr>
<tr>
<td>Collimated scan w/glasses</td>
<td>Eye</td>
<td>0.029 ± 0.001</td>
<td>0.013 ± 0.003</td>
<td></td>
</tr>
</tbody>
</table>

### Table II. Percentage reduction in organ-specific absorbed dose resulting from the use of leaded glasses during the scanning procedure

<table>
<thead>
<tr>
<th>Scan type</th>
<th>Organ</th>
<th>Pediatric</th>
<th>Adult female</th>
<th>Adult male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full scan</td>
<td>Eye</td>
<td>67%</td>
<td>62%</td>
<td>66%</td>
</tr>
<tr>
<td>Collimated scan</td>
<td>Eye</td>
<td>60%</td>
<td>38%</td>
<td></td>
</tr>
</tbody>
</table>
phantoms after conventional spiral tomography, spiral CT, and CBCT. As expected from earlier studies, spiral CT resulted in an order of magnitude higher lens doses than spiral tomography, when either maxillary or mandibular scans were used. CBCT lens doses, as measured in the present study and in other literature reports, were similar to those of conventional spiral tomography.

Leaded glasses are rarely used in dental radiographic imaging procedures. The increasing use of higher-dose imaging modalities by dental professionals, including conventional CT, spiral CT, and CBCT, raises concerns about patient exposure to radiosensitive organs and tissues, including the lens. Whereas CBCT x-ray units provide as much as an order of magnitude lower radiation doses compared with MDCT x-rays units, the radiation dose to the lens of the eye, and to a lesser extent the brain, can be further reduced significantly by wearing leaded glasses during the scanning procedure. Among the 3 phantoms, the greatest dose reduction was observed in the pediatric model.

Pediatric patients are the most at risk from cumulative ionizing radiation exposure due to medical and dental diagnostic scanning procedures. The BEIR (Biological Effects of Ionizing Radiation) VII report noted that children are at greater risk for carcinogenesis after low-dose radiation exposure than adults. This is especially relevant because tissue weighting factors, used in effective dose calculations, were recently revised and overall effective dose for dental procedures using multidetector CT and CBCT has now increased. It is also generally assumed that the pediatric population is at higher risk for radiation cataract due to increased latency and presumed greater radiosensitivity.

Dental professionals should be actively involved in the image acquisition process and should seek to reduce patient radiation exposure by a combination of machine techniques (reduction of photon energy and quantity), collimation, and use of protective shields (e.g., leaded glasses, thyroid collar). Leaded glasses are advantageous because they provide significant dose reduction to the lens of the eye during CBCT procedures not being used for cephalometric analysis while having no apparent deleterious effect on the quality of the dental image in the region of concern (Fig. 2). Further research needs to be performed to characterize the image quality when leaded glasses are worn.

**CONCLUSIONS**

Effective doses from CBCT are much lower than normal MDCT scans. Similarly to other uses of ionizing radiation in diagnosis and treatment, use of CBCT should always be justified by a dentist or physician. Operators should optimize CBCT scanning protocols, using machine settings and collimation, to reduce overall dose while still maintaining appropriate diagnostic image quality. In keeping with the “as low as reasonably achievable” principle, leaded glasses can be used to reduce the amount of absorbed radiation to the lens of the eye during CBCT scans. Because leaded glasses are relatively inexpensive and can be purchased from many different manufacturers, they should be worn by patients during all CBCT scanning procedures (both limited-volume scans that do not include the eyes and full-head scans) to limit the radiation absorbed dose to the lens of the eye and reduce the risk of radiation cataract development. This study focused on noncephalometry studies, and although we did not notice a detrimental effect from the leaded eyeglasses on CBCT image quality, additional studies are required to fully characterize this aspect.

**REFERENCES**


