i An update to this article is included at the end

Cover Story

Optimizing radiation safety in dentistry

Clinical recommendations and regulatory considerations

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Supplemental material is available online.

ABSTRACT

Background. The value of dental radiographs to oral health care decision making must be balanced with radiation safety to minimize patient exposure and occupational risk of oral health care providers. This review summarizes recommendations and regulatory guidance regarding dental radiography and cone-beam computed tomography. An expert panel presents recommendations on radiation safety, appropriate imaging practices, and reducing radiation exposure.

Types of Studies Reviewed. A systematic search run in Ovid MEDLINE, Embase, and Cochrane Database of Systematic Reviews identified relevant topical systematic reviews, organizational guidelines, and regulatory reviews published in the peer-reviewed literature since 2010. A supplemental search of the gray literature (eg, technical reports, standards, and regulations) identified topical nonindexed publications. Inclusion criteria required relevance to primary oral health care (ie, general or pediatric dentistry).

Results. A total of 95 articles, guidance documents, and regulations met the inclusion criteria. Resources were characterized as applicable to all modalities, operator and occupational protection, dose reduction and optimization, and quality assurance and control.

Practical Implications. Understanding factors affecting imaging safety and applying fundamental principles of radiation protection consistent with federal, state, and local requirements are essential for limiting patient ionizing radiation exposure, in conjunction with implementing optimal imaging procedures to support prudent use of dental radiographs and cone-beam computed tomographic imaging. The regulatory guidance and best practice recommendations summarized in this article should be followed by dentists and other oral health care providers.

Key Words. Dental radiography; radiography; dentistry; radiation protection; computer tomography; CBCT; x-ray; panoramic; digital radiograph; radiographic film.

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In 2012, the American Dental Association (ADA) and the US Food and Drug Administration (FDA) published *Dental Radiographic Examinations: Recommendations for Patient Selection and Limiting Radiation Exposure*,[1] and the ADA Council on Scientific Affairs issued an advisory statement on the use of cone-beam computed tomography (CBCT) in dentistry.[2] This article provides updated evidence-based recommendations, consistent with ADA methodology, on components of the 2012 publications related to dental radiation safety, appropriate imaging practices, recommendations to reduce radiation exposure to patients and personnel, and adherence to relevant regulatory requirements.

These recommendations are based on a comprehensive review of dental radiation safety research, guidance from national and international agencies, and regulatory standards. These broadly applicable recommendations aim to help clinicians develop and implement safety practices that will provide optimal diagnostic value while minimizing radiation risks to patients or personnel. This

This article has an accompanying online continuing education activity available at: http://jada.ada.org/ce/home.

article also provides an overview of regulatory standards that clinicians may need to consult when conducting radiographic imaging studies in clinical practice, including installation and use of imaging equipment, and training of staff members. The recommendations were developed for dental practitioners and their support teams, public health dentists, dental staff members (including dental hygienists and dental assistants), dental students, and community oral health coordinators.

METHODS

A library informationist (K.K.O.) developed a search strategy to identify systematic reviews, organizational guidelines, and regulatory reviews addressing dental imaging modalities (2-dimensional radiographs [bite-wing, periapical, occlusal, panoramic] and 3-dimensional images [CBCT]) used in general dentistry or recognized dental specialties, with a primary focus on digital imaging modalities. The strategy was built in Ovid MEDLINE, and searches were run in August 2020 in Ovid MEDLINE 1946-, Embase 1947-, and Cochrane Database of Systematic Reviews. The Scottish Intercollegiate Guidelines Network systematic reviews filter was modified to include guideline language and applied to the MEDLINE and Embase searches.[3]

Publications to be included were limited to articles published from 2010 onward. The original search was augmented with an updated search in April 2022, and an EndNote file of 1,476 records was exported into DistillerSR (DistillerSR Inc) and duplicates were removed. After duplicate removal and screening at the abstract and full-text level, 95 articles were included. Further manual screening for duplicates and exclusion criteria resulted in 74 articles available for qualitative synthesis. The full search strategies are provided in the Appendix, available online at the end of this article.

Concurrent with the primary search, nonindexed publications were identified with a systematic search of the gray literature and regulatory literature to retrieve technical reports, white papers, position and consensus statements, and regulations (primarily federal, eg, *Code of Federal Regulations* [CFR]) addressing dental imaging considerations and other documents from professional organizations or government agencies in the United States or internationally. A total of 22 citations were identified using this methodology. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram of the search strategy and article screening process is presented in the eFigure, available online at the end of this article.[4]

An expert panel composed of general, public health, and pediatric dentists (M.A.K., A.K.M., M.-L.D.); oral and maxillofacial radiologists (E.B., T.A., A.B.); and a patient representative (M.J.A.-B.) was convened by the ADA Council on Scientific Affairs. A designated writing group composed of expert panel members, including 3 oral and maxillofacial radiologists (E.B., T.A., A.B.), 1 health physicist (D.S.), and 2 ADA Science and Research Institute staff members (J.R.K., R.T.C.), was charged with developing the imaging safety recommendations presented in this report, which was subsequently reviewed and approved by the expert panel.

RESULTS

Radiation exposure and use of ionizing radiation in dentistry

Radiographic imaging procedures used in dental practice are collectively among the most frequently performed in the United States in healthy people[5] and one of the most common radiographic examinations performed worldwide.[6,7] In a 2023 report, a scientific committee of the National Council on Radiation Protection and Measurements (NCRP) estimated that 320 million dental imaging procedures (including intraoral, panoramic, and CBCT) were conducted in the United States in 2016, comprising more than 46% of diagnostic imaging and nuclear medicine procedures nationwide.[5]

Exposure to any amount of ionizing radiation can increase the risk of adverse health effects.[8-14] Adverse effects associated with ionizing radiation exposure are commonly grouped in 2 categories: tissue reactions (also known as deterministic effects [eg, skin burns, cataracts, or cellular death after an acute radiation exposure $\geq$100 mGy]) and stochastic (random) effects.[7,15] Although direct association between low-dose cumulative exposure and eventual adverse outcomes has remained elusive,[13,16-20] tissue reactions from exposure to ionizing radiation may occur in patients who receive an acute exposure at high doses (ie, > 100 mGy threshold level).[15] Although dental imaging exposure levels are typically well below this threshold, patients often undergo multiple radiographic examinations throughout life,[21,22] and studies have shown that cumulative low-level

ABBREVIATION KEY

ADA:	American Dental Association.
ALARA:	As low as reasonably achievable.
CBCT:	Cone-beam computed tomography.
CT:	Computed tomographic.
CDC:	Centers for Disease Control and Prevention.
CFR:	*Code of Federal Regulations*.
FDA:	US Food and Drug Administration.
FOV:	Field of view.
NCRP:	National Council on Radiation Protection and Measurements.
OSHA:	Occupational Safety and Health Administration.
PSP:	Photo-stimulable phosphor.
QA:	Quality assurance.
QC:	Quality control.

Table 1. Effective dose and equivalent background radiation exposure time for selected dental and medical radiographic examinations and procedures.

TYPE OF EXAMINATION	EFFECTIVE DOSE, AVERAGE OR RANGE,* μSv	AVERAGE BACKGROUND RADIATION EQUIVALENT, D†
Dental Radiograph Examination Exposure		
Full-mouth series—18 images, adult[34,35]		
PSP‡ or F-speed film and rectangular collimation	34.9	4
PSP or F-speed film and round collimation	170.7	20
Full-mouth series—12 images, pediatric[36]		
PSP or F-speed film and rectangular collimation	44 (44-85)	5
PSP and round collimation	89.0	11
Bite-wing		
Digital, single[37]	0.3 (premolar), 1.4 (molar)	< 1
4 images with PSP or F-speed film and rectangular collimation[34,37]	3.4-5.0	< 1§
Extraoral radiographs		
Panoramic charge-coupled device[34,37]	14.2-30.0	2-3.5
Panoramic PSP[37]	19.0-75.0	2-9
Cephalometric[34,38]	2.0-10.0	< 1-1.3§
Cone-beam computed tomography—adult[35]		
Small FOV¶	19-652	2-77
Medium FOV	45-860	5-101
Large FOV	68-1,073	8-126
Cone-beam computed tomography—pediatric[31,39]		
Small FOV	7-521	1-61§
Medium or large FOV	13-769	1.5-91§
Comparative Effective Dose From Medical Examinations		
Conventional head CT scan#,[35]	860-1,500	101-177
Low-dose protocol head CT scan[35]	180-534	21-63
Brain CT scan[38]	1,600	188§
Abdominal and pelvic CT[38]	7,700	905

* All values follow International Commission on Radiation Protection 103[34] methodology unless otherwise noted. † National Council on Radiation Protection and Measurements 177[35] estimates unless otherwise noted. ‡ PSP: Photo-stimulable phosphor. § Estimated per capita based on average natural background radiation 3.1 mSv per year. ¶ FOV: Field of view. # CT: Computed tomographic.

radiation exposure may be associated with triggering oxidative stress or potentially inducing damage to cellular DNA[23,24] or oral epithelium,[22,25] increasing the risk of carcinogenesis.[13,14,18,20-23] In addition, the risk for children may be augmented due to longer cumulative exposure over the life span[14,25-27] as well as higher organ radiosensitivity.[14,24,26-30]

Radiation Dose in Dental Imaging

The radiation doses associated with the main imaging modalities used in dental practices range from low-dose intraoral digital radiographs to higher-dose imaging procedures using CBCT. Typical effective doses associated with these modalities are generally low when compared with other medical diagnostic imaging. Table 1 presents a summary of typical effective dose values for dental imaging procedures as well as comparative effective doses from nondental radiographic procedures. The wide range of reported radiation doses from CBCT examinations is a result of differences among models or scanner types, field of view options, exposure parameters, and other protocols used.[31-33]

Recommendations to minimize exposure to ionizing radiation in dentistry

Ionizing radiation exposure is a known carcinogen. The risks associated with the use of ionizing radiation in dentistry, however, can be mitigated by following recommended procedures, in addition

to selection criteria and recall interval guidance as provided by professional societies such as the ADA and relevant specialty organizations. The guiding principle for the safe use of radiograph-based imaging states the needed clinical benefit should be obtained at a radiation dose level that is as low as reasonably achievable (ALARA)[40] and, following the increased use of CBCT, as low as diagnostically acceptable.[41]

Priority recommendations

To emphasize the significance of practice-level considerations to reduce exposure to ionizing radiation while optimizing diagnostic quality, recommendations of critical importance are listed as priority recommendations in Box 1. When these recommendations are followed, exposure to ionizing radiation can be reduced substantially for both patients and staff members.

Regulatory oversight and nongovernmental guidance

Distinguishing Between Regulations and Recommendations

Guidance and recommendations from the ADA and other organizations and agencies, such as the Centers for Disease Control and Prevention (CDC), provide a basis for professional clinical judgment and are not regulatory in nature. Federal, state, and local agencies or health departments may choose to enforce some aspects of clinical guidance. At the federal level, the Occupational Safety and Health Administration (OSHA) regulates the workplace environment (ie, dental health care professional staff members), and the FDA develops and enforces regulatory performance requirements for clinical medical and dental radiograph systems. Those requirements include the provision of device features that address safety for the patient and user, acceptable imaging performance at minimal radiation doses, and instructions for use that document relevant device performance characteristics, as specified in federal regulations. The FDA also promulgates various guidance documents to assist manufacturers and users and releases specific guidance on handheld dental radiograph devices.[42]

ADA policies (available to ADA members on ADA.org) recognize the importance of work practice controls, OSHA recommendations,[43] and guidance from the CDC that support safe delivery of care in dental settings.[44] Regulatory oversight of the use of ionizing radiation in dentistry is based on ALARA principles of radiation safety and image optimization,[45] and, therefore, the first general (and a priority) recommendation is that dentists adhere to all applicable federal, state, and local regulations (Box 1, recommendation 1.0.1). Table 2 lists additional federal and international guidance that is within the dentist's responsibility to be aware of in addition to local regulatory oversight.

NCRP and International Radiation Protection Agencies

The NCRP is a US-chartered scientific advisory agency that develops radiation safety recommendations used by US government agencies (eg, Environmental Protection Agency) and various professional organizations.[56] The NCRP also evaluates recommendations from the International Commission on Radiation Protection to consider their applicability to various domestic radiologic health activities. The International Commission on Radiation Protection and NCRP are not regulatory agencies, but both develop recommendations that serve as a basis for radiation protection standards and legislation. The International Atomic Energy Agency also provides a range of resources that promote optimization of patient protection in dental radiology.[7]

The NCRP developed several reports addressing radiation safety in dental imaging procedures.[56,57] NCRP report 177, *Radiation Protection in Dentistry and Oral and Maxillofacial Imaging*,[35] provides recommendations for practicing dentists that serve as a foundation for these recommendations, which were developed as a component of an update to the 2012 ADA-FDA recommendations for dental radiographic examinations.[1]

Occupational Radiation Safety

OSHA sets statutes, standards, and regulations pertaining to workplace safety and workers' rights. OSHA's Standard on Ionizing Radiation (29 CFR 1910.1096)[58] includes regulatory oversight of the storage, labeling, and testing of radiologic equipment as well as personnel monitoring (dosimetry) and recordkeeping. OSHA ionizing radiation standards relevant to the practice of dentistry are incorporated into NCRP report 177 recommendations[35] as well as the recommendations regarding

Box 1. Priority recommendations.*

RECOMMENDATION

1. Familiarity with and adherence to all applicable local, state, and federal laws (recommendation 1.0.1)
2. Radiographs should be ordered based on diagnostic and treatment planning needs, and dentists shall make a good-faith attempt to obtain radiographs from previous dental examinations (recommendation 3.0.1)
3. Use digital receptors instead of film for intraoral, panoramic, and cephalometric imaging (recommendation 3.1.1.0)
4. Use rectangular collimation whenever possible for intraoral imaging (recommendation 3.1.2)
5. Use cone-beam computed tomography only when lower-exposure options will not yield the needed diagnostic information (recommendation 3.2.1)

*See Box 2 for a full list of recommendations.

occupational protection we present (Box 2, Section 2). OSHA also regulates hazard communication and infection control in the workplace.

Infection Control

OSHA's Bloodborne Pathogens Standard[47] provides regulatory guidance in workplace infection control. The CDC provides nonregulatory infection control protocols for the dental setting, which includes specific recommendations for radiographic equipment.[46] Infection control in radiography is beyond the scope of this article, which is focused on radiation protection, but is included in Section 5.3 of NCRP report 177.[35]

Recommendations applicable to all radiographic modalities (Box 2, Section 1)

Section 1 of Box 2 contains recommendations applicable to all radiographic imaging modalities and patients. In addition to following local, state, and federal regulations, protective measures should be implemented carefully before, during, and after the provision of dental and maxillofacial imaging procedures, including proper radiographic equipment installation, structural shielding, periodic testing of radiographic imaging equipment, and proper training of personnel qualified to operate radiographic equipment. It is also necessary to follow the manufacturer's instructions for the operation and maintenance of equipment, in addition to following recommendations for safe and optimal use. Manufacturers who market radiographic systems in the United States are required to provide that user documentation. Structural considerations and barrier protection, typically regulated by state and local agencies, are beyond the scope of this article.

Recommendations for occupational and operator use of ionizing radiation (Box 2, Section 2)

Recommendations for the reduction of radiation exposure to dental staff members and operators of radiographic equipment can be found in Box 2, Section 2. Every dental practice should have a radiation protection program that specifies occupational radiation exposure limits and includes requirements for barrier shielding where possible and guidance regarding personnel dosimeters for monitoring to minimize the risk of exceeding the limits. These recommendations are supported by NCRP report 177.[35] Barrier protection and structural shielding are covered in detail in NCRP report 147[49] (Table 3 in that NCRP report). When barrier protection is not available, the operator shall stand at least 2 meters from the primary beam path (recommendation 2.0.1). NCRP report 177 further recommends standing at an angle of 90 to 135° to the beam path.[35]

Dosimetry

Dental staff members who may be exposed to an annual effective dose that may exceed 1 mSv, or as otherwise determined by state or local guidance, should consider wearing dosimeters. Using data from United Nations Scientific Committee on the Effects of Atomic Radiation,[59] NCRP report 177 noted that a dental health care worker receives on average an effective dose of 0.06 mSv per year, which is 6% of the recommended threshold for radiation monitoring.[35] Although it is unlikely that

Table 2. List of external resources.*

EXTERNAL RESOURCE	TYPE	AUDIENCE
Infection Control		
Centers for Disease Control and Prevention, Summary of infection prevention practices in dental settings: basic expectations for safe care[46]	Health guidance	Dental office staff members
United States Department of Labor, Occupational Safety and Health Administration, Standard 1910.1030: bloodborne pathogens[47]	Regulatory	Dental office staff members
Occupational Risks		
United States Nuclear Regulatory Commission, Standards for Protection Against Radiation: Subpart C—Occupational Dose Limits. Code of Federal Regulations 10 CFR part 20[48]	Regulatory	Industry
Structural Shielding and Protection		
National Council on Radiation Protection and Measurements Report 147, *Structural Shielding Design for Medical X-Ray Imaging Facilities*[49]	Guidance	Facility-level
Quality Control and Quality Assurance		
National Council on Radiation Protection and Measurements Report 177, *Radiation Protection in Dentistry and Oral & Maxillofacial Imaging: Recommendations of the National Council on Radiation Protection and Measurements*[35]	Guidance	Dental office staff members
American National Standards Institute and American Dental Association Standard No. 1094, *Quality Assurance for Digital Intra-Oral Radiographic Systems*[50]	Standards	Dental office staff members
American National Standards Institute and American Dental Association Standard No. 1099, *Quality Assurance for Digital Panoramic and Cephalometric Radiographic Systems*[51]	Standards	Dental office staff members
American Association of Physicists in Medicine Report No. 175, *Acceptance Testing and Quality Control of Dental Imaging Equipment*[52]	Guidance	Quality assurance and quality control experts
Conference of Radiation Control Program Directors, Technical white paper: cone beam computed tomography (CBCT) for dental applications[53]	Guidance	State and local governments, regulators, inspectors
International Guidance		
International Atomic Energy Agency, *Radiation Protection in Dental Radiology*[7]	Guidance	Dental office staff members; national, local and professional agencies
International Electrotechnical Commission International Standard 60601-2-63:2012, Medical electrical equipment, part 2-63: particular requirements for the basic safety and essential performance of dental extra-oral x-ray equipment[54]	Standards	Manufacturers
International Electrotechnical Commission International Standard 61223-3-7:2021, Evaluation and routine testing in medical imaging departments, part 3-7: acceptance and constancy tests—imaging performance of X-ray equipment for dental cone beam computed tomography[55]	Standards	Manufacturers

* Consult local and state regulatory agencies for local radiation protection standards. Additional external guidance is referred to in the article.

a dental health care worker will approach the exposure limit of 1 mSv per year, it is recommended that operators of radiographic equipment who are pregnant firmly adhere to shielding procedures as specified in the facility's radiation protection documentation and always use dosimeters to monitor exposure.

Recommendations for patient safety and protection (Box 2, Section 3)

General Recommendations to Limit Radiation Exposure to Patients

The ADA recommends that clinicians should perform radiographic imaging, including CBCT, only after reaching the professional judgment that there is a clear clinical benefit from the imaging examination and that this benefit outweighs the risks associated with exposure to ionizing radiation.[2] The benefits and associated risks of the dental imaging examination should be discussed clearly with the patient. Justification also should be based on consultation of evidence-based selection and recall criteria balanced with risks of exposure.[7,8,25,33,35,60-63]

Before performing a radiographic examination, dentists should perform a clinical examination of the patient and consider the patient's medical and dental history. In addition, when previous radiographs and images exist, a good-faith effort should be made to obtain them. CBCT examinations

Box 2. Recommendations for the safe and appropriate use of ionizing radiation in dentistry.

1. General Recommendations for All Modalities

1.0 Regulatory and Industry Oversight

1.0.1 The practice shall comply with all applicable local, state, and federal regulatory requirements regarding the safe and effective use of radiography-based imaging modalities, including installation, usage, optimization, patient and operator protection, infection control, maintenance and training for radiographic equipment and procedures.

1.0.2 New facilities, or facilities installing or relocating radiographic and CBCT* equipment must follow state and local regulations pertaining to radiation safety in effect at the time of construction or renovation.

1.0.3 Follow manufacturer's provided documentation for safe and proper operation, maintenance, and infection control procedures for radiographic, CBCT, and related radiographic imaging equipment.

1.1 Radiation Safety Programs and Training

1.1.1 The dental practice shall develop and implement a radiation safety program that provides all staff members with instructions and guidance for maintaining a safe radiographic imaging program. The program should be consistent with nationally established recommendations for the radiation protection of both patients and staff members and adhere to all applicable state and local requirements, be developed and implemented under the guidance of a qualified expert, and should be regularly reviewed and updated to be current with applicable established guidance and regulations.

1.1.2 Personnel performing radiography-based dental and maxillofacial imaging shall have the qualifications, education, training, and licensure as required by relevant federal, state, and local regulations.

2. Occupational and Operator Use of Ionizing Radiation

2.0 Operator Training Requirements and Performance

2.0.1 When barrier protection or shielding is not available for intraoral imaging, the operator shall stand at least 2 meters from the tube head and out of the primary beam path.

2.0.2 Access to radiation-producing devices shall be restricted, and handheld and portable devices shall be safely secured to prevent unauthorized use.

2.1 Dosimetry

2.1.1 Dental staff members who may be exposed to an annual effective dose that may exceed 1 mSv, or as otherwise determined by state or local guidance, should consider wearing dosimeters.

2.1.2 Pregnant dental personnel who operate radiographic imaging equipment shall adhere to the relevant recommendations set forth in the facility's radiation safety program, including the limitation of occupational exposure, and the use of protective barriers and personal dosimeters regardless of anticipated exposure levels.

3. Patient Safety and Protection

3.0 General Recommendations for Patient Safety and Protection

3.0.1 Before conducting any type of radiographic examination, clinicians should complete a comprehensive clinical examination and patient assessment, with consideration of the patient's oral and medical histories, including previous radiographs as well as the patient's specific oral disease risk.

3.0.2 Clinicians should prescribe dental radiographs and CBCT scans only when they expect that the diagnostic yield will benefit patient care, enhance patient safety, or substantially improve clinical outcomes.

*CBCT: Cone-beam computed tomography.

Box 2. Continued.

3.0.3 The clinical prescription of radiographic imaging, including CBCT, should be supported by professional judgment that is based on current, established selection and recall criteria to ensure that the benefit of the radiographic imaging procedure outweighs the associated radiation risk.

3.0.4 Where possible the x-ray imaging equipment shall be configured to optimize imaging and dosimetric performance specific to the size and age of the patient.

3.0.5 Abdominal and thyroid shielding during diagnostic intraoral, panoramic, cephalometric, and CBCT imaging is no longer recommended, and the use of these forms of protective shielding should be discontinued as routine practice.

3.1 Radiation Dose Minimization and Image Optimization for Traditional Modalities

3.1.1.1 Digital rather than film-based imaging should be used because digital imaging allows for lower patient radiation exposure.

3.1.1.2 If film is used, only E- or F-speed film shall be used because they require substantially lower patient radiation exposure compared with D-speed film. D-speed film shall be eliminated from clinical use.

3.1.1.3 If film is used for panoramic or cephalometric imaging, rare-earth screens and high-speed film of 400 are recommended.

3.1.2 The x-ray beam should be collimated to the receptor size and shape wherever possible, and rectangular collimation should be used for intraoral imaging.

3.1.3 The intraoral radiograph system shall be configured so that the distance from the x-ray tube focal spot to the skin entrance surface (source-to-skin distance) is not < 20 cm.

3.1.4 Intraoral radiography units should be operated at a minimum of 60 kV and not exceed 80 kV.

3.1.5 Intraoral image receptor holders including beam-guiding devices should be used when possible.

3.1.6 Handheld radiographic devices for intraoral imaging must be cleared by the US Food and Drug Administration, used according to manufacturer's instructions, and restricted to use only by authorized operators with appropriate training in device use.

3.2 Radiation Dose Minimization and Image Optimization for CBCT

3.2.1 CBCT imaging should not be used routinely. CBCT examinations shall not be used as the primary or initial imaging modality when a lower dose alternative is adequate for diagnosis and treatment planning.

3.2.2 Use the smallest field of view necessary for imaging the specific anatomical area of interest consistent with the diagnostic and treatment planning needs.

3.2.3 CBCT shall be conducted using technique factors and imaging protocols that are optimized to produce diagnostically acceptable images with the lowest radiation dose to the patient.

3.3 Special Considerations for Pediatric Patients for All Modalities

3.3.1 Pediatric patients shall be imaged using radiographic device configurations as labeled by the manufacturer and optimized specifically for such patients.

4. Quality Assurance and Quality Control

4.0 General Recommendations for Staff Members and Equipment

4.0.1 Staff members of facilities using radiographic imaging equipment shall establish a quality assurance and quality control program, implemented and monitored by a qualified expert and following updated quality assurance and quality control guidance (see Table 2 for list of external guidance).

4.0.2 A qualified expert should survey all conventional radiography units at the time of installation, and should survey the equipment at least every 4 years, after any changes that may affect the radiation exposure to patients and staff members, or in accordance with state and local law, whichever is more stringent.

Box 2. Continued.

4.1	**Equipment- and Modality-Specific Image Quality and Dose Optimization**
4.1.1	The operator's manual for all radiographic systems including applicable computer hardware and software systems must be readily available to the user. All imaging equipment shall be operated and maintained following the manufacturer's instructions, including any appropriate adjustments for optimizing dose and image quality and quality control and quality assurance testing frequency.
4.1.2	CBCT imaging and dosimetry performance shall be evaluated by a qualified expert at least every 2 years, but preferably annually.
4.1.3	Special considerations for receptors
4.1.3.1	Image receptor devices for film-based and digital systems shall undergo initial acceptance testing and be evaluated either monthly (film-based) or annually (digital), as recommended by relevant American National Standards Institute and American Dental Association standards.
4.1.3.2	The film processor and phosphor plate scanners should be evaluated at initial installation and regularly afterward, according to the manufacturer's instructions.
4.1.3.3	Film shall be processed with active, properly replenished chemicals. Chemical solutions should be replenished daily and replaced when depleted. Film processor performance should be checked daily before developing the first patient radiograph, and each type of film should be evaluated monthly or when a new box or batch of film is opened.
4.2	**Technique Charts**
4.2.1	A radiograph exposure factors chart shall be developed for each type of intraoral image receptor and radiograph unit combination and posted near the control panel of the radiographic unit. The charts and recommended exposure factors shall be updated when a different type of receptor or new radiograph unit are used.
4.2.2	Technique charts for intraoral radiography should list the exposure settings based on the type of examination, the type of receptor, and the patient size (small, medium, large) for adults and pediatric settings.

should not be merely routine and should not be for screening purposes.[1] The size and age of the patient need to be considered when applying selection criteria and selecting dose-optimization procedures.[2,7,35,64,65]

Dose Reduction and Optimization

Using digital sensors instead of film for intraoral imaging (3.1.1.0, a priority recommendation) can decrease substantially radiation dose per acquired image. The level of dose reduction varies according to the imaging modality used. If film is used, use the fastest speed possible (E or F). High-speed film can provide a dose reduction similar to digital imaging,[66-68] with F-speed film showing a 60% reduction in dose compared with (now obsolete) D-speed film.[35,69] NCRP report 177 indicates that D-speed film shall not be used for intraoral imaging.[35] Rare-earth, high-speed film is recommended for panoramic and cephalometric radiographs.

Collimating the x-ray beam to the specific region of interest, including using rectangular collimation whenever possible (3.1.2, a priority recommendation),[7,35] has been shown to reduce dose consistently by more than 40%.[66,70] Additional intraoral radiographic measures can reduce radiation exposure substantially, including the use of long position-indicating devices to maximize the distance between the radiation source and the skin of patient to decrease the divergence of the beam, using appropriate operating potentials (60-80 kVp) (3.1.4), and, when digital images are not possible, using E-speed or faster film (3.1.1.2) and using a receptor holder with a beam-guiding device (3.1.5).[35]

Handheld dental intraoral radiographic devices must be FDA-cleared (meaning the FDA has found the device to be substantially equivalent to another legally marketed device that already has FDA clearance). These devices are cleared for a specific clinical intended use and should be used only in accordance with that declaration. Special considerations should be given to the use of handheld intraoral radiographic devices, and the operator should review referenced guidance

documents.[42] Due to the portable nature of handheld devices, they should be stored securely, outside of public reach. Because the operator is essentially holding a radiographic system while it is producing x-rays, facility staff members should be trained in proper holding of these devices to maximize protection from the backscatter shield.[35]

Special Considerations for CBCT

Dentists should never use CBCT routinely, when any other lower-dose radiographic modality may yield adequate diagnostic information[2,8,11,32,33,35,61,71-81] (recommendation 3.2.1). CBCT can deliver a substantially higher dose than traditional radiography (as much as 10-15 times the dose)[25,30,31,35,61,62,82,83] but provides 3-dimensional images of teeth and surrounding structures that can be valuable for certain indications.[7,8,35,39,76,78,81,84-89] CBCT should be used only after a determination is made that other lower-dose imaging methods would not be expected to provide the required diagnostic information. Most newer systems provide clinical scanning protocols that include lower-dose settings[87,88,90,91]; however, operators also can reduce patient radiation dose via using the smallest possible field of view needed for the clinical purpose (recommendation 3.2.2) and manually adjusting the combination of tube output and scan time where possible (recommendation 3.2.3).[12,75,77,79,86,87,92-94]

Special Considerations for Pediatric Patients

Children and young adults are more susceptible to the effects of radiation exposure due to a higher sensitivity of organs as well as the longer expected life span, resulting in a greater cumulative effect.[7,12,27,29,30,95] In accordance with recommendation 3.0.4, the size and age of the patient, especially eruption sequence and spacing in children (recommendation 3.3.1), must be taken into account when prescribing radiographic examinations.

Radiographic imaging using any modality should be justified clinically.[2,7,8,25,35,64,95,96] Of particular concern is exposure of the thyroid to the x-ray beam,[11,29] and, therefore, careful patient positioning and application of dose-reduction measures, including rectangular collimation for intraoral radiographs, are essential.

Patient Protection and Shielding

Although the ADA had previously recommended that the thyroid gland should be shielded with a protective collar during intraoral radiography in children,[1] thyroid collars are no longer recommended for any imaging modality.[97] Thyroid collars and abdominal (gonadal) shielding can introduce artifacts by blocking the primary beam,[33,98] potentially resulting in additional radiographs being taken, and do not protect against internal scatter radiation.[97] Patient radiation doses can be minimized most effectively with proper use of rectangular collimation, optimal patient positioning during imaging procedures,[35,97] and implementing appropriate dose-reduction procedures as presented in Box 2 (eg, sections 3.1 and 3.2).

In dentistry, appropriate selection of patients for imaging[1] and rectangular collimation when taking intraoral radiographs[99] offer the best protection against radiation exposure to the thyroid, when combined with guiding principles of radiation safety.[35,100] Patient thyroid shielding during diagnostic intraoral, panoramic, cephalometric, and CBCT imaging no longer should be used in routine practice for pediatric or adult patients. As necessary, federal, state, and local regulations and guidance should be revised to remove any actual or implied requirement for routine protective shielding for intraoral, panoramic, cephalometric, and CBCT imaging.

Quality assurance and quality control (Box 2, Section 4)

Quality assurance (QA) in dental and maxillofacial radiography are the specific steps taken to produce images with necessary diagnostic information with the lowest radiation exposure to the patient, in accordance with manufacturer and regulatory guidance for device use.[35,101] Quality control (QC) is the component of QA focused on tests and measurements of radiographic devices, image receptors, scanners, display devices, and other technical components and parameters.[98] The primary goal of QC is to ensure that the complete imaging system remains at an acceptable level of performance as established by QA activities. American Association of Physicists in Medicine report 175, NCRP report 177, and American National Standards Institute/ADA standard no. 1094 provide detailed guidance on QA and QC procedures for dental and maxillofacial imaging systems, equipment performance evaluation,

and shielding design.[35,50,52] They underscore the responsibility of the dentist to establish and implement protocols for the safe and effective use of diagnostic radiographic equipment in the office. This includes optimization and maintenance of dental imaging equipment and QC of the components of digital imaging systems and film processing (for those using film).[35] For CBCT imaging devices, the European Federation of Organizations for Medical Physics and the International Atomic Energy Agency have established a detailed quality-control protocol for CBCT, available online.[101]

Dental facilities should have a designated, locally licensed clinician who is responsible for the radiation safety program.[35] The program should include procedures that limit patient exposure, guidance about application of appropriate dose-reduction techniques, protective devices that minimize radiation exposure to the patient, and QA practices as well as protocols for ensuring the proper functioning, calibration, and use of dental imaging equipment.[35,98] For CBCT, the FDA requires manufacturers to provide QA and QC recommendations, including a schedule of the frequency that various tests should be performed and who should perform them (21 CFR 1020.33).[102]

The NCRP recommendations strongly encourage dentists to establish and implement robust QA and QC processes as part of a complete quality program of radiographic imaging. Although clinical staff members should ensure that radiographic equipment produce consistent output of clinically acceptable images, a qualified physics professional such as a medical or health physicist should conduct periodic evaluations of the complete program of radiographic imaging to ensure the production of high-quality dental images at the lowest possible patient radiation dose and that risks of radiation-induced injury to personnel are mitigated.[35] The QA program should specify a complete physics survey at recommended intervals that includes assessment of patient radiation dose, clinical image quality, and x-ray output levels as appropriate to evaluate compliance with manufacturer-recommended values.[35,71,103] In addition to recommendation 1.0.3, the dental practice should follow the manufacturer's instructions and guidance for routine maintenance of imaging equipment and infection-control procedures for radiographic, CBCT, and related radiographic imaging equipment. Recommendations for QA and QC are presented in Box 2, Section 4.

DISCUSSION

This review of radiation safety and protection recommendations and regulatory oversight has established several critical recommendations that significantly reduce patient dose and occupational risk from radiographic and CBCT imaging. These priority recommendations include adherence to local, state, and federal regulations; a good-faith attempt to obtain images from previous examinations; using digital receptors rather than film; using rectangular collimation; and using CBCT only as an adjunct.

Dental practice continues to evolve, with use of electronic dental records, precision dental medicine, imaging equipment advancements, and artificial intelligence applications driving the way dentistry is practiced. Trends in technology use likely are affected not only by its availability but also the frequency with which patients seek routine care as well as available treatment options. Nevertheless, foundational compliance with radiation-protection regulations and best-practice recommendations is a core component of quality dentistry. Regulatory compliance is essential, as is the appropriate and safe use of radiographic imaging systems.

Although CBCT can provide enhanced visualization of dental and related structures beyond that provided with conventional 2-dimensional imaging, its misuse results in ionizing radiation exposure to the patient that is not justified. It is incumbent on the influencers of clinical practice, including academics and journal editors, to consult the latest professional recommendations regarding the clinical indications for CBCT to ensure that such imaging is appropriate and justified.

CONCLUSIONS

The concept of ALARA, introduced in 1977,[40] is firmly entrenched as an overarching principle for radiation protection in dental and medical imaging guidance and regulatory standards. With the increasing availability of CBCT and digital-based imaging, the panel recommends that dental office staff members integrate the recommendations presented here, weigh the benefits of newer imaging technologies against radiation-specific risks (particularly for children), and conduct imaging procedures with an aim of obtaining optimal image quality at radiation doses that are as low as diagnostically acceptable.[41] ■

DISCLOSURES

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SUPPLEMENTAL DATA

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APPENDIX: LIBRARY SEARCH STRATEGIES

Ovid MEDLINE search strategy

1 exp Radiography, Dental/
2 ((radiograph$ or x-ray$ or radiation or radiology or radiolucency or radiopacity or radiopaque or radiolucent or imaging or bitewing or CBCT or "Cone-beam CT" or "cone beam computed tomography" or "Computerized tomography" or panoramic or orthopantomograph$) adj5 (dent$ or tooth or teeth or orthodont$ or mouth or maxillofacial or endodont$ or periodont$ or root or maxillary or gingiv$ or intraoral or periapical or alveolar or molar or premolar or cuspid or incisor or canine or temporomandibular or furcation or 'intrabony defect' or 'dental caries' or 'carious lesion')).ab,kw,ti.
3 1 or 2
4 adverse effects.fx.
5 exp Risk Factors/
6 Safety/
7 exp Risk Assessment/
8 radiation effects.fx.
9 exp Radiation Protection/
10 exp Radiation Effects/
11 (risk or exposure or damage or radiosensitivity or safe or safety or mortal$ or threat$ or "adverse effect" or "adverse effects" or "adverse event" or "adverse events" or "side effect" or "side effects" or protection$ or protect or dosimetry or regulatory or regulation or regulations or rules or "as low as reasonably achievable" or ALARA or ALADA or dose or doses or dosing or phantom or phantoms).ab,kw,ti.
12 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11
13 3 and 12
14 Meta-Analysis as Topic/
15 meta analy$.tw.
16 metaanaly$.tw.
17 Meta-Analysis/
18 (systematic adj (review$1 or overview$1)).tw.
19 exp "Review Literature as Topic"/
20 review.pt.
21 14 or 15 or 16 or 17 or 18 or 19 or 20
22 cochrane.ab.
23 embase.ab.
24 (psychlit or psyclit).ab.
25 (psychinfo or psycinfo).ab.
26 (cinahl or cinhal).ab.
27 science citation index.ab.
28 bids.ab.
29 cancerlit.ab.
30 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29
31 reference list$.ab.
32 bibliograph$.ab.
33 hand-search$.ab.
34 relevant journals.ab.
35 manual search$.ab.
36 31 or 32 or 33 or 34 or 35
37 exp guideline/
38 (guideline or guidelines).ab,kw,ot,ti.
39 ('consensus statement' or 'consensus statements').ab,kw,ot,ti.
40 37 or 38 or 39

41 selection criteria.ab.
42 data extraction.ab.
43 41 or 42
44 "Review"/
45 43 and 44
46 Comment/
47 Letter/
48 Editorial/
49 exp Animals/
50 exp Humans/
51 49 and 50
52 49 not 51
53 46 or 47 or 48 or 52
54 21 or 30 or 36 or 40 or 45
55 54 not 53
56 13 and 55

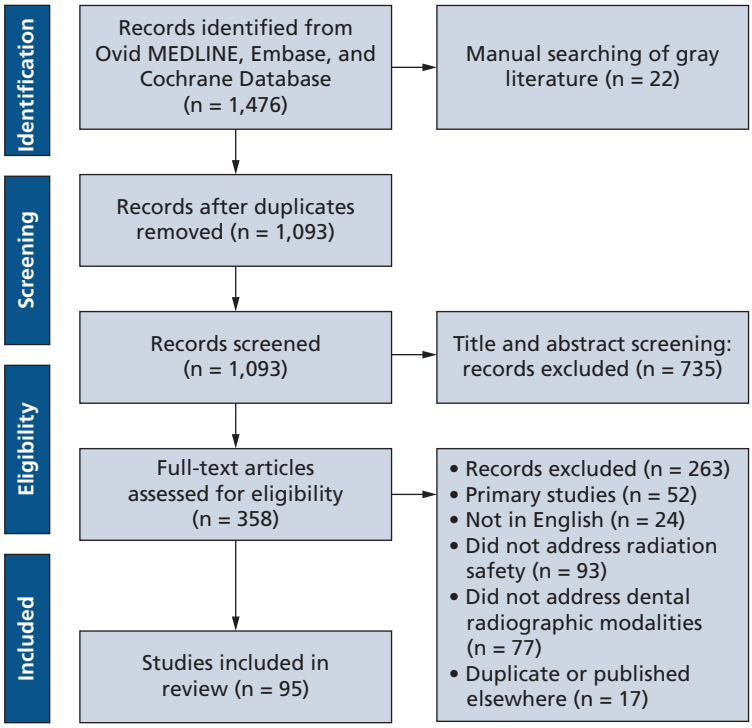
Embase search strategy

1 'dental x ray system'/exp
2 'dental radiology'/exp
3 ((dent* OR tooth OR teeth OR orthodont* OR mouth OR maxillofacial OR endodont* OR periodont* OR root OR maxillary OR gingiv* OR intraoral OR periapical OR alveolar OR molar OR premolar OR cuspid OR incisor OR canine OR temporomandibular OR furcation OR 'intrabony defect' OR 'dental caries' OR 'carious lesion') NEAR/5 (radiograph* OR 'x ray*' OR radiation OR radiology OR radiolucency OR radiopacity OR radiopaque OR radiolucent OR imaging OR bitewing OR cbct OR 'cone-beam ct' OR 'cone beam computed tomography' OR 'computerized tomography' OR panoramic OR orthopantomograph*)):ab,ti,kw
4 #1 OR #2 OR #3
5 'adverse event'/exp
6 'adverse drug reaction':lnk
7 'unexpected outcome of drug treatment':lnk
8 'adverse device effect':lnk
9 'risk factor'/exp
10 'safety'/exp
11 'risk assessment'/exp
12 'radiation response'/exp
13 'radiation protection'/exp
14 'radiation injury'/exp
15 risk:ti,ab,kw OR exposure:ti,ab,kw OR damage:ti,ab,kw OR radiosensitivity:ti,ab,kw OR safe:ti,ab,kw OR safety:ti,ab,kw OR mortal*:ti,ab,kw OR threat*:ti,ab,kw OR 'adverse effect':ti,ab,kw OR 'adverse effects':ti,ab,kw OR 'adverse event':ti,ab,kw OR 'adverse events':ti,ab,kw OR 'side effect':ti,ab,kw OR 'side effects':ti,ab,kw OR protection*:ti,ab,kw OR protect:ti,ab,kw OR dosimetry:ti,ab,kw OR regulatory:ti,ab,kw OR regulation:ti,ab,kw OR regulations:ti,ab,kw OR rules:ti,ab,kw OR 'as low as reasonably achievable':ti,ab,kw OR alara:ti,ab,kw OR alada:ti,ab,kw OR dose:ti,ab,kw OR doses:ti,ab,kw OR dosing:ti,ab,kw OR phantom:ti,ab,kw OR phantoms:ti,ab,kw
16 #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15
17 #4 AND #16
18 'meta analysis'/exp OR 'review'/exp OR 'review':it OR 'systematic review'/exp OR 'systematic review':it
19 (meta NEXT/1 analy*) OR metaanalys*
20 systematic* NEAR/5 (review* OR overview*)
21 #18 OR #19 OR #20
22 guideline:ti,ab,kw OR guidelines:ti,ab,kw

23 'practice guideline'/exp
24 'consensus statement':ti,ab,kw OR 'consensus statements':ti,ab,kw
25 #22 OR #23 OR #24
26 'cancerlit':ab
27 'cochrane':ab
28 'embase':ab
29 'psychlit':ab OR 'psyclit':ab
30 'psychinfo':ab OR 'psycinfo':ab
31 'cinahl':ab OR 'cinhal':ab
32 'science citation index':ab
33 'bids':ab
34 #26 OR #27 OR #28 OR #29 OR #30 OR #31 OR #32 OR #33
35 'reference lists':ab
36 'bibliograph*':ab
37 'hand-search*':ab
38 'manual search*':ab
39 'relevant journals':ab
40 #35 OR #36 OR #37 OR #38 OR #39
41 'letter':it
42 'editorial':it
43 'animal'/exp
44 'human'/exp
45 #43 NOT (#43 AND #44)
46 #41 OR #42 OR #45
47 #21 OR #25 OR #34 OR #40
48 #47 NOT #46
49 #17 AND #48

Cochrane Database of Systematic Reviews search strategy

1 MeSH descriptor: [Radiography, Dental] explode all trees
2 ((radiograph* OR x-ray* OR radiation OR radiology OR radiolucency OR radiopacity OR radiopaque OR radiolucent OR imaging OR bitewing OR CBCT OR "Cone-beam CT" OR "cone beam computed tomography" OR "Computerized tomography" OR panoramic OR orthopantomograph*) NEAR/5 (dent* OR tooth OR teeth OR orthodont* OR mouth OR maxillofacial OR endodont* OR periodont* OR root OR maxillary OR gingiv* OR intraoral OR periapical OR alveolar OR molar OR premolar OR cuspid OR incisor OR canine OR temporomandibular OR furcation OR 'intrabony defect' OR 'dental caries' OR 'carious lesion')):ti,ab,kw
3 #1 OR #2
4 MeSH descriptor: [] explode all trees and with qualifier(s): [adverse effects - AE]
5 MeSH descriptor: [Risk Factors] explode all trees
6 MeSH descriptor: [Safety] explode all trees
7 MeSH descriptor: [Risk Assessment] explode all trees
8 MeSH descriptor: [] explode all trees and with qualifier(s): [radiation effects - RE]
9 MeSH descriptor: [Radiation Protection] explode all trees
10 MeSH descriptor: [Radiation Effects] explode all trees
11 (risk OR exposure OR damage OR radiosensitivity OR safe OR safety OR mortal* OR threat* OR "adverse effect" OR "adverse effects" OR "adverse event" OR "adverse events" OR "side effect" OR "side effects" OR protection* OR protect OR dosimetry OR regulatory OR regulation OR regulations OR rules OR "as low as reasonably achievable" OR ALARA OR ALADA OR dose OR doses OR dosing OR phantom OR phantoms):ti,ab,kw
12 #4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11
13 #3 AND #12



eFigure. Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram of the search strategy and article screening process.[4]

Update

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CORRECTION

Check for updates

In the April JADA article titled "Optimizing Radiation Safety in Dentistry: Clinical Recommendations and Regulatory Considerations" (Benavides E, Krecioch JR, Connolly RT, et al. *JADA*. 2024;155[4]:280-293.e4), the name of the second expert consultant member in the acknowledgments should be "Kitrina Cordell." The online version of this article has been corrected. JADA regrets the error. ■

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