CLINICAL RECOMMENDATIONS FOR THE APPROPRIATE USE OF CONE BEAM COMPUTED TOMOGRAPHY (CBCT) IN ORTHODONTICS

Joint Position Statement by the American Association of Orthodontists and the American Academy of Oral and Maxillofacial Radiology

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ABSTRACT

The American Association of Orthodontists (AAO) and American Academy of Oral and Maxillofacial Radiology (AAOMR) Joint Task Force committee reviewed the current literature on the clinical efficacy and radiation dose associated with cone-beam computed tomography (CBCT) to develop a position statement. The AAO/AAOMR Joint Task Force Committee position statement provides both general recommendations and specific criteria for CBCT use based on specific clinical scenarios and most appropriate scan field of view. Appropriate CBCT imaging is selection criteria based. The use of the American College of Radiology Relative Radiation Level to assess radiation dose risk for orthodontic patients is recommended. Dose minimization and professional use strategies are provided. The use of CBCT must be justified based on individual clinical presentation and is not appropriate for routine diagnostic use nor as a substitute for non-ionizing radiation techniques to record the dentition or maxillofacial complex.

STATEMENT OF INTENT

The American Association of Orthodontists (AAO) and American Academy of Oral and Maxillofacial Radiology (AAOMR) jointly developed this position statement. It provides research-based, consensus-derived clinical guidance for practitioners on the appropriate use of cone beam computed tomography (CBCT) in orthodontics. This document is to be revised periodically to reflect new evidence and, without reapproval, becomes invalid after 5 years.

INTRODUCTION

Malocclusions and craniofacial anomalies adversely affect quality of life. Orthodontics and dentofacial orthopedic treatment addresses the correction of malocclusions and facial
disproportions due to dental/skeletal discrepancies to provide esthetic, psychosocial, and functional improvements. For almost a century, two-dimensional (2D) plain radiographic imaging and cephalometry has been used to assess the interrelationships of the dentition, maxillofacial skeleton and soft tissues in orthodontics in all phases of the management of orthodontic patients, including diagnosis, treatment planning, evaluation of growth and development, assessment of treatment progress and outcomes, and retention. However, the limitations of 2D imaging have been realized for decades as many orthodontic and dentofacial orthopedic problems involve the lateral or “third dimension.” Baumrind, et al., 1976; Moyers and Bookstein, 1979; Johnston, 2011 For instance, relapse of, and unfavorable responses to, orthodontic therapy remain poorly understood despite implications that considerations in the transverse plane are important factors in stability. Little, et al., 1981 For years, multiple images were obtained using different radiographic projections to attempt to display complex anatomic relationships and surrounding structures; however correlating and interpreting multiple-image inputs is challenging. With the increasing availability of multi-slice computed tomography (CT) and most recently cone-beam computed tomography (CBCT), visualization of these relationships in three dimensions is now feasible.

Based on considerations of appropriate use, and radiation dose involved with CBCT in orthodontics, the purpose of this document is to provide practical, literature-based, consensus-derived, best-practice guidelines. Specifically we provide general and specific imaging selection criteria to assist professional clinical judgment and recommend the use of Relative Radiation Level (RRL) when considering imaging risk for a single imaging procedure or for multiple radiographic procedures over a course of orthodontic treatment.
BACKGROUND

Imaging Considerations in Orthodontic Therapy

The purpose of radiographic imaging in orthodontics is to supplement or support clinical diagnosis in the pre-treatment assessment of the orthodontic patient. Imaging may also be performed during treatment to assess the effects of therapy and post-treatment to monitor stability and outcome. Imaging for a specific orthodontic patient occurs in at least three stages: 1) selection of the most appropriate radiographic imaging technique, 2) acquisition of appropriate images, and 3) interpretation of the images obtained, sometimes followed by a repeat of these steps. Selection of the appropriate radiographic imaging techniques is based on the principle that practitioners who use imaging with ionizing radiation have a professional responsibility of beneficence—that imaging be performed to “serve the patient’s best interests.” This requires that each radiation exposure is justified clinically and that principles and procedures are applied that minimize patient radiation exposure while optimizing maximal diagnostic benefit. This concept is referred to as the “as low as reasonably achievable” (ALARA) principle. Justification of every radiographic exposure must be based principally on the individual patient’s presentation including considerations of the chief complaint, medical and dental history, and assessment of the physical status as determined with a thorough clinical examination and treatment goals.

The Evidence Base for CBCT Imaging in Orthodontics

A dramatic increase in the use of CBCT has occurred in dentistry over the last decade. In particular, this technology has found application in orthodontic treatment planning for both adult
and pediatric patients. Fundamental to evidence-based guideline development are systematic reviews of the published literature. Systematic reviews use well-defined and reproducible literature search strategies to identify evidence directed towards the use of a modality towards a specific clinical problem. Evidence can then be graded according to its level, methodological rigor (or quality), relevance and strength. Recently van Vlijmen, et al., attempted to analyze the orthodontic literature from six databases in relation to CBCT. They identified only 55 articles from a total of 550 that satisfied specific inclusion and exclusion criteria. They used a subjective method to qualitatively rate methodological soundness and found variable and, in most cases, only moderate methodological rigor. Evaluation of the existing orthodontic literature according to established systematic review criteria (e.g. Cochrane Collaborative) is warranted.

Clinical radiographic imaging recommendations are usually based on the quantity, quality and level of evidence base; consistency of evidence; clinical impact compared with available imaging modalities; and radiation dose. However, the highest level of evidence for CBCT in orthodontics that currently exists consists of observational studies of diagnostic performance and efficacy. Given the paucity of well-designed, clinically relevant studies on the use of CBCT for specific orthodontic applications, it is clear that a need still exists for rigorous investigation on the clinical efficacy of CBCT imaging for all aspects of orthodontics. Despite these limitations, the AAO/AAOMR Joint Task Force Committee developed a four tier hierarchical level of consensus recommendations regarding the suitability of CBCT imaging for specific clinical situations (Table 1), based on previously published criteria. U.S. Preventive Services Task Force Ratings, 2003; National Health and Medical Research Council of Australia, 1999; Scottish Intercollegiate Guidelines Network, 2011; American College of Radiology, 2011; European Commission, 2004; Cascade, 2000
The potential of extracting additional diagnostic information from volumetric imaging and the technical ease in obtaining scans has led some clinicians and manufacturers to advocate the replacement of current conventional imaging modalities by CBCT for standard orthodontic diagnosis and treatment. Based on the analysis of the current peer-reviewed, published research there is no evidence to support this position.

**Radiation Dose Considerations in Orthodontics**

There are two broad potential harmful effects of the use of ionizing radiation in orthodontics. The direct death of cells, referred to as deterministic effects, require a high dose over a short period of time and usually only present after a level has been reached (threshold) below which no clinical changes have been reported to occur. These levels are never reached in the diagnostic range encountered in conventional oral and maxillofacial radiology. However they can be seen in dental patients who undergo radiotherapy to the head and neck region for the treatment of cancer. One example of this is the presentation of radiation induced oral mucositis. The second effect, called a stochastic effect, is irreversible alteration of the cell, usually from damage to cellular DNA resulting in cancer, leukemia and occasionally genetic damage. The long-term risks to the patient associated with diagnostic radiographic imaging are related to radiation-induced carcinogenesis. Unlike, deterministic effects, stochastic effects can result from very low levels over an extended period of time.

Assessment of the risks associated with the use of ionizing radiation for diagnostic imaging is an important public health issue. Recent reports have increased concerns over the potential association between radiation exposure and cancer. Claus, *et al.*, found a relationship between increased risk of intracranial meningioma and reported episodes of dental radiographic
procedures performed in the past. Claus, et al., 2012 These results are highly controversial as preliminary responses have highlighted limitations in the data collection and consistency of the study that may render the conclusions invalid. Lam and Yang, 2012; American Academy of Oral and Maxillofacial Radiology, 2012; American Dental Association, 2012 Most recently, the results of a retrospective cohort study by Pearce, et al., provide more direct evidence of a link between exposure to radiation from computed tomography (CT) and cancer risk in children. Pearce, et al., 2012 They found that children and young adults who received radiation doses from the equivalent of 2 or 3 CT scans of the head have almost triple the risk of developing leukaemia or brain cancer later in life. Medical CT head scans may have an effective dose of up to 2,000 µSv, Smith-Bindman, et al., 2009 however substantial reductions to less than 1,000 µSv have been reported for low dose protocol CT examinations. Ludlow, et al., 2006; Ludlow, et al., 2008a Most CBCT examinations are reported to impart a fraction of medical CT effective dose, however, doses vary considerably between CBCT units.

The actual risk of cancer induction for low dose radiographic procedures currently considered to be below about 100,000 µSv, including as maxillofacial CBCT, is difficult to assess. Radiation epidemiologists and radiobiologists internationally are in consensus that for stochastic risks such as carcinogenesis, from a radiation safety perspective, the risk should be considered to be linearly related to dose, all the way down to the lowest doses. Valentin, 2007; Preston, et al., 2003; United Nations Scientific Committee on the Effects of Atomic Radiation, 2008; National Research Council of the National Academies, 2006 However assessment of risk is confounded in that we are already naturally exposed daily to background radiation and other sources of radiation such as flights and/or living at high altitude places. In this paper, the AAO/AAOMR Joint Task Force Committee reviewed information on the potential health effects of exposure to diagnostic ionizing radiation. There is neither convincing evidence for carcinogenesis at the level of dental exposures, nor the absence of such
damage. This situation is unlikely to change in the foreseeable future. In the absence of evidence of a threshold dose, it is prudent to assume that such a risk exists. This implies that there is no safe limit or “safety zone” for ionizing radiation exposure in diagnostic imaging. Every exposure cumulatively increases the risk of cancer induction. Consequently, to be cautious, the Committee’s recommendations are focused on minimizing or eliminating unnecessary radiation exposure in diagnostic imaging.

The overall biological effect of exposure to ionizing radiation, expressed as the risk of cancer development over a lifetime, is determined from absorbed radiation dose to specific organs in combination with other factors that account for differences in exposed-tissue sensitivity and other patient susceptibility factors such as gender and age. The AAO/AAOMR Joint Task Force Committee accepts the International Commission on Radiological Protection (ICRP) effective dose \( E \) methodology for the estimate of whole body dose and measure stochastic radiation risk to patients based on evidence of biological effect currently available. \( E \) is calculated by multiplying actual organ doses in specific susceptible tissues by "risk weighting factors" (which give each organ's relative radiosensitivity to developing cancer) and adding up the total of all the numbers —the sum of the products is the "effective whole-body dose" or just "effective dose." The estimated risk weighting factors for specific tissues have recently been revised, and a number of additional tissues found in the head and neck region have been included (most importantly the salivary glands, lymphatic nodes, muscle and oral mucosa). These modifications have resulted in substantial increases in radiation effective doses for specific maxillofacial radiographic procedures ranging from 32% to 422%.
The effective dose for CBCT radiographic imaging used for orthodontic records is of particular concern, especially as the modal age for initiating orthodontic treatment represents a pediatric population. For pediatric patients, the radiation risk to ionizing radiation is greater than that of adults for four reasons: 1) In the developing child, the relative greater cellular growth and rate of organ development is responsible for greater radiosensitivity of tissues than in adults. 2) Younger patients have a longer expected lifetime for the effects of radiation exposure to manifest as cancer. 3) Specific organ and effective doses for children in CBCT imaging, particularly the salivary glands, are, on average, 30% higher than for adolescents with the same exposure, Theodorakou, et al., 2012 and 4) unless specific, pediatric, exposure-reduction techniques are incorporated in imaging protocols, the radiation doses for small patients and children may exceed typical adult radiation levels. Not all currently available CBCT units are capable of implementing exposure-reduction techniques. Therefore, in consideration of 1) to 4), children may be two to ten times or more sensitive to radiation carcinogenesis than mature adults. Brenner, et al., 2001; Smith-Bindman, et al., 2009 International Commission on Radiological Protection, 1991; National Research Council (US), 2006

Reflective of the importance in considering the increased risks associated with exposing children to ionizing radiation, the American College of Radiology (ACR) has incorporated pediatric, effective-dose estimates in Relative Radiation Level (RRL) designations for specific imaging procedures (Table 2). American College of Radiology, 2011 In addition, there are at least two national radiation safety initiatives to raise awareness of using lower radiation doses to image children: Image Gently™ The Alliance for Radiation Safety in Pediatric Imaging, 2011 and the National Children’s Dose Registry. American College of Radiology, 2010
For all imaging procedures using ionizing radiation, the clinical benefits should be balanced against the potential radiation risks, the relative radiosensitivity of those being imaged, and the ability of the operator to control radiation exposures.

RECOMMENDATIONS FOR CBCT IN ORTHODONTICS

The choice of modality used for imaging an orthodontic patient is based on clinical judgment as to whether the examination is likely to provide a clinical benefit for the patient as well as an assessment of the risk. Best practice in orthodontics requires a judicious approach to imaging based on the use of imaging selection criteria. These criteria are based on an appreciation of evidence-based benefits of the procedure and considerations for minimizing radiation risk.

Imaging guidelines for the use of CBCT in contemporary orthodontic practice include:

1. Image Appropriately According to Clinical Condition
2. Assess the Radiation Dose Risk
3. Minimize Patient Radiation Exposure
4. Maintain Professional Competency in Performing and Interpreting CBCT Studies

1. Image Appropriately According to Clinical Condition

Currently in the United States, there is no clinical guideline directing practitioners on the type, timing, or number of radiographs suggested for orthodontic therapy. Based on considerations of the ALARA principle, acknowledging the increased sensitivity of pediatric patients to ionizing radiation and recognizing that patients present with varying degrees of
orthodontic complexity, the Committee makes the following general recommendations for the use of CBCT in Orthodontics:

**Recommendation 1.1.** Base the decision to order a CBCT scan on the patient’s history, clinical examination, and the presence of an appropriate clinical condition and assure the benefits to diagnosis and/or the treatment plan outweigh the potential risks of exposure to radiation, especially in the case of a child or young adult.

**Recommendation 1.2.** Use CBCT only when the clinical question for which imaging is required cannot be answered adequately by lower dose conventional dental radiography or alternate non-ionizing imaging modalities.

**Recommendation 1.3.** Do not use CBCT solely to facilitate the placement of orthodontic appliances such as aligners and computer-bent wires or to produce virtual orthodontic models.

**Recommendation 1.4.** Design CBCT protocols to be task specific and to incorporate the imaging goal for the patient’s specific presenting circumstances. The protocol includes considerations of exposure (mA and kVp), minimum, image-quality parameters (e.g. number of basis images, resolution), and restriction of the field of view (FOV) to visualize adequately the region of interest.

**Recommendation 1.5.** Do not perform a CBCT if only 2D projected images derived from CBCT are to be used for diagnostic purposes.

**Recommendation 1.6.** Do not take a conventional image if it is clear from the clinical examination that a CBCT study is indicated for proper diagnosis and/or treatment planning.
To assist clinicians in defining the scope of orthodontic conditions and the most appropriate CBCT imaging in each circumstance, the Committee proposes specific Imaging Selection Criteria for the Use of CBCT in Orthodontics (Table 3). The proposed Imaging Selection Criteria include the phase of treatment (pre-, during-, or post-treatment), the treatment difficulty and the presence of additional skeletal and dental conditions. The table rows list orthodontic phases of treatments and treatment difficulty categories and table columns list dental and skeletal clinical conditions. Within each cell the overall consensus suitability of the CBCT procedure (Table 1) and most appropriate field of view (FOV) are provided for practitioner guidance. Table 4 describes the three FOV ranges most commonly encountered in orthodontic imaging. The concerns in selecting a CBCT field of view (FOV) are the inclusion of the region of clinical importance and the collimation of the radiation beam to that specific region.

Rational for Orthodontic Image Selection Criteria

The foundational principle for the proposed orthodontic image selection criteria (Table 3) is that appropriateness of CBCT imaging depends on the level of complexity of orthodontic problems presented by the patient. To assess the level of complexity of orthodontic problems, image selection is performed after clinical examination but prior to acquisition of orthodontic records.

Considering the absence of evidence-based clinical research on indications for CBCT imaging in orthodontics, the current foundational knowledge for the proposed selection criteria is as follows:
1- Prior dentistry and orthodontic imaging selection criteria guidelines:

In 1987 a panel of representatives from general dentistry and various academic disciplines in the United States, convened by the Food and Drug Administration (FDA), published broad selection criteria for intraoral radiographic examinations Matteson, et al., 1987 that were later updated in 2004. American Dental Association Council on Scientific Affairs, 2006; U.S. Department of Health and Human Services, 2004 These broad guidelines suggested that for monitoring growth and development of children and adolescents, “clinical judgment be used in determining the need for, and type of radiographic images necessary for, evaluation and/or monitoring of dentofacial growth and development.”

In both the European Union Janssens, et al., 2003; Sedentex Project Radiation Protection, 2011 and in the United Kingdom Isaacson, et al., 2008 orthodontic imaging guidelines state that there is neither an indication for taking radiographs routinely before clinical examinations nor for taking a standard series of radiographic images for all orthodontic patients. The latter document provides clinical decision algorithms based on the ages of the patients (less than or over 9 years of age) and clinical presentation (delayed or ectopic eruption, crowding, antero-posterior discrepancies—such as anterior overjet or overbite, etc.).

2 - Selection of Clinical Conditions for Indications of CBCT use:

Indications for CBCT use in orthodontics are currently based on observational studies of diagnostic performance and efficacy: Advantages of CBCT have been noted in cases that involve assessment of root morphology and resorption, dental spatial relationships (including impactions and dentoalveolar discrepancies); characterization of craniofacial morphology (such as skeletal discrepancies); and depiction of the temporomandibular joint and airway space. Kapila, et al., 2011; Mah, et al., 2010 In addition, CBCT has been reported as
particularly useful in assessing treatment outcomes in cases involving orthognathic surgery, grafting procedures, in cases for which non-surgical devices (e.g. orthodontic temporary anchorage devices, maxillary expanders) are used to affect vertical or transverse discrepancies. Kapila, et al., 2011; Mah, et al., 2010; Merrett, et al., 2009 White and Pae, 2009 proposed that the use of CBCT examination is potentially indicated as part of the diagnostic process for the following specific clinical assessments: 1) severe facial asymmetry or facial disharmony, 2) sleep apnea, 3) impacted maxillary cuspids, 4) mini-dental implant placement, 5) rapid maxillary expansion, and 6) persistent temporomandibular joint symptoms. In their analysis of the orthodontic literature in relation to CBCT, van Vlijmen, et al., identified 5 topic domains for the use of CBCT including temporary anchorage devices, cephalometry, combined orthodontic and surgical treatment, airway measurements, root resorption and tooth impactions, cleft lip and palate, and miscellaneous. van Vlijmen, et al., 2012 Research in the areas of craniofacial growth and development as well as assessments on of the short and long term influence outcomes of various treatment regimens has the potential to benefit from CBCT assessments of longitudinal changes and diagnostic characterization of tooth and facial morphology of hard and soft tissues. Studies on the morphological basis for craniofacial growth and response to treatment can help elucidate clinical questions on variability of outcomes of treatment, as well as clarify treatment effects and areas of bone remodeling and displacement.

The column headings in Table 3 are the most common clinical dental and skeletal conditions that may present. These include:
Dental structural anomalies. This comprises variations in tooth morphology, hypodontia, retained primary teeth, supernumeraries/gemination/fusion, root abnormalities, and external and internal resorption. (Katheria, et al., 2010; Leuzinger, et al., 2010; Van Elslande, et al., 2010; Shemesh, et al., 2011; Sherrard, et al., 2010; Treil, et al., 2009; Liedke, et al., 2009; Liu, et al., 2007)

Anomalies in dental position. This comprises dental impactions (including maxillary canine impaction), presence of unerupted and impacted supernumeraries, determination of location of molars in relation to the inferior alveolar canal, anomalies in eruption sequence, and ectopic eruption (including teeth in clefts). (Katheria, et al. 2010; Tamimi and ElSaid, 2009; Becker, et al., 2010; Liu, et al. 2008; Chaushu, et al., 2004; Botticelli, et al., 2010; Walker, et al., 2005; Oberoi and Knueppel, 2011; Hofmann, et al., 2011)

Compromised dento-alveolar boundaries. The assessment of dento-alveolar volume (in addition to that which can be determined by clinical examination and study models) is needed when there is reduced buccal/lingual alveolar width, bimaxillary protrusion, compromised periodontal status, and/or clefts of the alveolus. (Molen, 2010; Yagci, et al., 2012; Timock, et al., 2011; Leung, et al., 2010; Loubele, et al., 2008; Rungcharassaeng, et al., 2007)

Asymmetry. Clinically, asymmetry presents as chin or mandibular deviation, dental midline deviation, and/or occlusal cant discrepancies as well as other dental and craniofacial asymmetries. (Sievers, et al. 2011; AlHadidi, et al., 2011; de Moraes, et al. 2011; Damstra, et al., 2011; Veli, et al., 2011; Kook and Kim, 2011; Cevidanes, et al., 2011)
Anterior-posterior discrepancies. These are skeletally based Class II and Class III malocclusions. Almeida, et al., 2011; Cevidanis, et al., 2010; Gateno, et al., 2011; Heymann, et al., 2010; Kim, et al., 2011; Lloyd, et al., 2011; Orentlicher, et al., 2010; Tucker, et al., 2010

Vertical discrepancies. Initial clinical or radiographic (e.g. cephalometric) assessment indicates either increased or decreased vertical facial height. Presentations include anterior open bite, deep overbite, and facial patterns suggesting skeletal discrepancies such as vertical maxillary deficiency or excess.

Transverse discrepancies. These anomalies may be present as either skeletal lingual or buccal crossbites or discrepancies without the presence of crossbites in which there is excessive dental compensation of the buccolingual inclination of posterior teeth.

TMJ signs and/or symptoms. TMJ pathologies that result in alterations in the size, form, quality and spatial relationships of the osseous joint components may lead to skeletal and dental discrepancies in the three planes of space. In affected condyles, perturbed resorption and/or apposition can lead to progressive bite changes and compensations in the maxilla. In addition, tooth position, occlusion and the articular fossa of the non-affected side of the mandible can become involved. The sequelae of these changes are unpredictable orthodontic outcomes. Such TMJ conditions include developmental disorders such as condylar hyperplasia, hypoplasia or aplasia; arthritic degeneration; persistently symptomatic joints; bite changes including progressive bite opening and limitation or deviation upon opening or closing. (Alexiou, et al., 2009; Helenius, et al., 2005;
Additional conditions:

Dentofacial deformities and craniofacial anomalies: Clinicians use CBCT to analyze facial asymmetry and antero-posterior, vertical and transverse discrepancies. Clinicians also use virtual treatment simulations to plan orthopedic corrections and orthognathic surgeries. Computer-aided jaw surgery is increasingly in use clinically because virtual plans accurately represent surgical procedures in the operating room. (Agarwal, 2011; Behnia, et al., 2011; Dalessandri, et al., 2011; Ebner, et al., 2010; Edwards, 2010; Jayaratne, et al., 2010; Kim, et al., 2011; Abou-Elloutouh, et al., 2011; Lloyd, et al., 2011; Gateno, et al., 2011; Almeida, et al., 2011; Scolozzi and Terzic, 2011; Heymann, et al., 2010; Cevidanes, et al., 2010; Tucker, et al., 2010; Orentlicher, et al., 2010; Jayaratne, et al., 2010a and b; Popat and Richmond, 2010; Carvalho, et al., 2010; Schendel and Lane, 2009)

Conditions that affect airway morphology. While it is possible to measure airway dimensions in CBCT images, CBCT is not warranted solely for the purpose of assessing the airway. Although a number of studies have measured airways and changes in airways overtime (particularly with regard to obstructive sleep apnea), but such measurements present a number of challenges. The boundaries of the nasopharynx with the maxillary/paranasal sinuses and the boundaries of the oropharynx with the oral cavity are not consistent among subjects and image acquisitions, and airway shapes and volumes vary markedly with dynamic processes such as breathing and head postures. (El and Palomo, 2011; Oh, et al., 2011; Abramson, et al., 2011; Schendel, et al., 2011; Iwasaki, et al., 2011; Conley, 2011; Lenza, et al., 2010; El & Palomo, 2010; Schendel and
3- Definition of Orthodontic Treatment Difficulty Criteria:

**Mild.** Patients present with dental malocclusions, with or without minimal anterior-posterior, vertical, or transverse skeletal discrepancies. These patients are usually treated with conventional biomechanics (with or without extraction). **CBCT is not indicated for these patients unless they present with the additional clinical conditions noted in Table 3.**

**Moderate.** Patients present with dental and skeletal discrepancies that are treated orthodontically and/or orthopedically only. These discrepancies include bimaxillary proclination, open bite, and compensated Class III malocclusion. **CBCT is indicated for many of these patients as shown in Table 3.**

**Severe.** Patients present with skeletal conditions including, but not limited to complicated skeletal discrepancies, craniofacial anomalies (e.g. cleft lip and palate, craniofacial synostosis, etc.), sleep apnea, speech disorders, and post oncology/trauma/resection/pathology. For patients in this group, a team approach to treatment is used including speech therapy, clinical psychology, orthodontic and surgical interventions. **Advanced imaging, including CBCT, may be indicated for many of these patients (Table 3).**

4- Selection of Field of View:

There is also limited published research on the many and varied technical issues associated with CBCT imaging in orthodontics including optimal fields of view (image sizes) for specific diagnostic tasks, optimal exposure settings (some tasks require lower exposures than others), and variations in the levels of ionizing radiation used (for similar
tasks) with various CBCT systems. More specific and additional issues and controversies related to CBCT use include: 1) the necessary diagnostic quality of images; Kwong, et al., 2008 2) imperfect superimposition of CBCT and surface-scan data; 3) differing levels of exposure needed to determine root and bone morphology related to appliance construction or for the diagnosis of pathology; 4) indications for use of multiple CBCT scans; 5) lack of and utility of 3D norms; 6) impact of CBCT for the assessment of treatment outcome; 7) responsibility for the diagnosis of pathology; and 8) responsibility for calibration and maintenance of the equipment. Palomo, et al., 2008

5- Assessment of Progress and Treatment Outcomes:

In complex cases, follow-up CBCT acquisitions for growth observation, assessment of treatment progress, and post-treatment analysis may be helpful. Any imaging protocol for the longitudinal quantitative assessment of the craniofacial complex requires methods to: 1) minimize the radiation dose from sequential multiple CBCT exposures; 2) construct accurate 3D surface models; 3) reliably register images (non-rigid, elastic and deformable; or rigid registration) using stable structures of reference for cranial base or regional superimpositions; and 4) quantify changes over time.

6- Age Considerations:

The appropriateness of radiographic imaging of a patient with clinically determined dental and/or skeletal modifying factors is dependent on the stage of growth of the individual and age-related presentation of the condition; therefore, recommendations for CBCT for some dental/skeletal conditions are age dependent. These conditions include:
Tooth Structural Anomalies. A possible indication for a supplementary CBCT examination is when other diagnostic modalities indicate a problem with root morphology or resorption in the mixed and permanent dentitions.

Tooth Positional or Eruption Anomalies. A possible indication for a supplementary CBCT examination (in addition to periapical, occlusal and/or panoramic images) is when interceptive orthodontics is being considered for children between the ages of 5 to 11. In such cases, a small field of view should be used. Another possible indication for a CBCT examination (usually restricted or small field of view) is in children more than 11 years of age if surgical exposure is being considered as a treatment option and the location of the crown cannot be determined clinically or with conventional two-dimensional images (e.g. panoramic, occlusal and/or periapical images).

Craniofacial Anomalies. An additional possible indication for CBCT is in children (0 to 4 years) prior to mandibular distraction or other craniofacial surgical treatments if the children can remain motionless during the scans. For children between 5 to 11 years of age, CBCT is useful for locating developing teeth prior to alveolar bone grafting and Phase I orthodontic treatment for children with oral clefts. For these cases, limited fields of views may suffice. For patients older than 11 if comprehensive orthodontic treatments are required in preparation for craniofacial surgical procedures, the patients may benefit from having CBCT at the diagnostic stage of orthodontic treatment as well as immediately before the surgical procedures. Such decisions are case specific.
2. Assess the Radiation Dose Risk

Orthodontists must be knowledgeable of the radiation risk of performing CBCT and be able to communicate this risk to their patients. Radiation risk has most often been estimated by calculating the Effective Dose \textsuperscript{International Commission on Radiological Protection, 1991} of a CBCT scan and comparing this to other imaging modalities (e.g. multiples of typical panoramic images or a multi-slice medical CT), to background equivalent radiation time (e.g. days of background), or to radiation detriment [e.g. probability of x cancers per million scans (stochastic-cancer rate)]. Often the base unit of comparisons for these determinations (typical panoramic dose, background radiation, weighted probabilities of fatal and nonfatal cancers) is variable and not absolute. This means, for example, that depending on the panoramic image dose used for the comparison (e.g. equipment manufacturer and model, film vs. digital acquisition) the risk for CBCT can be reported either conservatively or liberally compared to panoramic radiography.

To standardize comparison of radiation dose risk between various imaging procedures, the AAO/AAOMR Joint Task Force Committee recommends the use of RRLs (Tables 2, 5 and 6). The RRL for various imaging examinations used either individually (Table 5) or for a course of orthodontic treatment (Table 6) can be assessed for adults and children using published effective dose calculations. \textsuperscript{Ludlow, et al., 2008b; Silva et al., 2008; Gavala, et al., 2009; Pauwels, et al., 2010 Carrafiello, et al., 2010; Davies, et al., 2012} Calculations of RRL levels in millisieverts (mSv; 1mSv = 1,000μSv) are made with methods described by Valentin, 2007 and data from the 7\textsuperscript{th} Biological Effects of Ionizing Radiation report (BEIR VII report).\textsuperscript{NAS, 2008} The estimate in the report, and the basis for subsequent levels of radiation risk, is that approximately 1 in 1,000 individuals develop cancer from an exposure of 10,000 μSv.\textsuperscript{Valentin, 2007} Relative Radiation Level assignments are based on
reviews of current literature. These assignments are revised periodically, as practice evolves and further information becomes available.

Based on these considerations, the Committee makes the following specific recommendations to calculate patient radiation dose risk for CBCT in orthodontics:

**Recommendation 2.1.** Use a relative radiation level (RRL) when considering imaging risk for a single imaging procedure or for multiple radiographic procedures over a course of orthodontic treatment. Table 5 contains the RRLs for specific orthodontic protocols and various modalities.

**Recommendation 2.2.** Since the use of CBCT exposes the patient to ionizing radiation that may pose elevated risks to some patients (pregnant patients or younger patients), clinicians should explain by disclosure, patient education, and documentation in the patients’ records the radiation exposure risks, benefits and imaging modality alternatives.

**Calculation of Relative Radiation Level for Orthodontic Imaging**

Table 6 provides three orthodontic imaging protocols and provides an example of assessment of the RRL American College of Radiology, 2011a, b using published effective doses for each episode of orthodontic imaging. For example, if a typical imaging protocol for an episode of orthodontic treatment for a child (<18 years) incorporates three digital (Planmeca PM Proline 2000 [low dose]) panoramic images (initial diagnostic, mid- and post-treatment; 12 µSv Carrafiello, et al., 2010 for each exposure = 36µSv) and two digital (photo-stimulable storage phosphor) lateral cephalometric images (initial and post-treatment; 5.6 µSv Ludlow, et al., 2008a for each exposure = 11.2 µSv) then the equivalent dose for the orthodontic series can be calculated to be 47.2 µSv. This represents an RRL of ☐ ☐. This level can be compared to that from an imaging protocol for
an orthodontic series for a child (<18 years) incorporating a large FOV CBCT (i-CAT Next Generation – Portrait) image (initial; 83 µSv, Pauwels, et al., 2010), two digital (Planmeca PM Proline 2000 [low dose]) panoramic images (mid- and post-treatment; 12 µSv, Carrafiello, et al., 2010 for each exposure = 24 µSv) and one digital (photo-stimulable storage phosphor) lateral cephalometric image (post-treatment; 5.6µSv, Ludlow, et al., 2008a) then the equivalent dose for this orthodontic imaging series can be calculated to be 112.6 µSv. While this is a little over twice the absolute dose, radiation risk for a child as estimated by RRL level remains the same (⩾⩾).

3. Minimize Patient Radiation Exposure

Depending on the equipment type and operator preferences, operators can adjust various exposure (e.g. milliamperage, kilovoltage), image quality (e.g. number of basis images, resolution, arc of trajectory) and radiation beam collimation settings (e.g. field of view [FOV]). Kwong, et al., 2008; Palomo, et al., 2008 Alteration of these parameters can affect radiation dose to the patient. Currently available CBCT units from different manufacturers vary in dose by as much as 10-fold for an equivalent FOV examination, Ludlow, et al., 2008a In addition, adjustments of exposure factors to improve image quality are available in many CBCT units and can cause as much as 7-fold differences in patient doses, Ludlow, et al., 2008b If CBCT imaging is warranted, appropriate selection of the FOV to match the region of interest (ROI) may provide a substantial dose savings.

Based on these considerations, the Committee makes the following specific recommendations to minimize patient radiation exposure for CBCT in orthodontics:

**Recommendation 3.1.** Perform CBCT imaging with acquisition parameters adjusted to the nominal settings consistent with providing appropriate images of task-specific
diagnostic quality for the desired diagnostic information required; 1) Use a pulsed exposure mode of acquisition, 2) Optimize exposure settings (mA, kVp), 3) Reduce the number of basis projection images, and 4) Employ dose reduction protocols (e.g. reduced resolution) when possible.

**Recommendation 3.2.** When other factors remain the same, reduce the size of the FOV to match the ROI; however, selection of FOV may result in automatic or default changes in other technical factors (e.g. mAs) that should be considered because these concomitant changes can actually result in an increase in dose.

**Recommendation 3.3.** Use patient protective shielding such as lead torso aprons and thyroid shields, when possible, to minimize exposure to radiosensitive organs outside the field of view of the exposure.

**Recommendation 3.4.** Ensure that all CBCT equipment is properly installed, routinely calibrated and updated, and meets all governmental requirements and regulations.

### 4. Maintain Professional Competency in Performing and Interpreting CBCT Studies

Orthodontists must be able to exercise judgment by applying professional standards to all aspects of CBCT. Any radiographic image prescribed and/or performed by a dental practitioner may contain information that is important to the management or general health of the patient. Incidental findings in CBCT images of orthodontic patients are common\(^\text{Cha, et al., 2007; Pliska, et al., 2011}\) and some are critical to the health of the patient.\(^\text{Rogers, et al., 2011}\) Clinicians who order or perform CBCT for orthodontic patients are responsible for interpreting the entire image volumes, just as they are responsible for interpreting all regions of other radiographic images that they order.\(^\text{Carter, et al., 2008}\) Counsel for the American Association of Orthodontists Insurance
Company suggests that an orthodontist who interprets a patient’s CBCT images has accepted a greater duty to the patient than the orthodontist would otherwise be obligated to and failure to detect conditions within a dataset is a breach of this duty. \textsuperscript{Bowlin, 2010}

Based on these considerations, the Committee makes the following specific recommendations related to performing and interpreting CBCT studies:

**Recommendation 4.1.** Clinicians have an obligation to attain and improve their professional skills through lifelong learning in regards to performing CBCT examinations as well as interpreting the resultant images. Therefore orthodontic practitioners are advised to regularly attend American Dental Association Continuing Education Recognition Program (ADA CERP) courses to maintain familiarity with the technical and operational aspects of CBCT and to maintain current knowledge of scientific advances and health risks associated with the use of CBCT.

**Recommendation 4.2.** Clinicians must be aware of their legal responsibilities when operating CBCT equipment and interpreting images and comply with all governmental and third party payer (e.g. Medicare) regulations.

**Recommendation 4.3.** Clinicians should inform patients/guardians that CBCT images cannot be relied upon to show soft-tissues, that some images may contain artifacts that can make interpretation difficult or inconclusive, and that patient movement during the scan process may compromise the images or render them useless.

**SUMMARY**

The choice of radiographic examination in orthodontics, and CBCT in particular, should be based on initial clinical evaluation and must be justified based on individual need. The
benefits to the patient of each exposure must outweigh the radiation risks. CBCT is a supplement to two-dimensional radiographic imaging in most situations. Exposure of patients to ionizing radiation must never be considered as “routine.” A CBCT examination should never be performed without initially obtaining a thorough clinical examination. The AAO/AAOMR Joint Task Force Committee provides numerous general and specific recommendations for CBCT in orthodontic practice categorized under four guidelines: 1) Image appropriately by applying imaging selection criteria, 2) Assess the radiation dose risk, 3) Minimize patient radiation exposure and, 4) Maintain professional competency in performing and interpreting CBCT studies.

ACKNOWLEDGMENT

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REFERENCES


Lloyd TE, Drage NA, Cronin AJ. The role of cone beam computed tomography in the management of unfavourable fractures following sagittal split mandibular osteotomy. J Orthod 2011;38:48-54.


### Table 1. Consensus Recommendations Supporting the Use of CBCT Imaging

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Consensus Level</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likely Appropriate</td>
<td>I</td>
<td>The use of CBCT imaging is indicated in most circumstances for this clinical condition. There is an adequate body of evidence to indicate a favorable benefit from the procedure relative to the radiation risk in the majority of situations.</td>
</tr>
<tr>
<td>Possibly Appropriate</td>
<td>II</td>
<td>The use of CBCT imaging may be indicated in certain circumstances for this clinical condition. There is a sufficient body of evidence to indicate a possible favorable benefit from the procedure relative to the radiation risk in many situations.</td>
</tr>
<tr>
<td>Likely Inappropriate</td>
<td>III</td>
<td>The use of CBCT imaging is not indicated in the majority of circumstances for this clinical condition. There is an insufficient body of evidence to indicate a benefit from the procedure relative to the radiation risk in most situations.</td>
</tr>
<tr>
<td>Not Supported</td>
<td>IV</td>
<td>The use of CBCT imaging has not demonstrated a consistent clinical benefit for this clinical condition and cannot be recommended at this time. There is either lack of, weak or inconclusive body of evidence to indicate a benefit from the procedure relative to the radiation risk in this situation.</td>
</tr>
</tbody>
</table>
Table 2. Estimations of Relative Radiation Level Designations for Children and Adults for Orthodontic Imaging (*with permission from ACR*, 2011).

<table>
<thead>
<tr>
<th>Relative Radiation Level</th>
<th>Effective Dose Estimate Range (µSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adult</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>☐</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>☐ ☐</td>
<td>100 – 1,000</td>
</tr>
<tr>
<td>☐ ☐ ☐</td>
<td>1,000 – 10,000</td>
</tr>
<tr>
<td>☐ ☐ ☐ ☐</td>
<td>10,000 – 30,000</td>
</tr>
</tbody>
</table>

* Some of the information in this document was provided with permission from the American College of Radiology (ACR) and taken from the ACR Appropriateness Criteria. The ACR is not responsible for any deviations from original ACR Appropriateness Criteria content.
Table 3. Imaging Selection Criteria for the Use of Cone Beam Computed Tomography in Orthodontics.

<table>
<thead>
<tr>
<th>Presentation</th>
<th>Dental and Skeletal Clinical Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary: Treatment Difficulty</td>
</tr>
<tr>
<td></td>
<td>Pre-treatment Mild</td>
</tr>
<tr>
<td></td>
<td>Moderate FOV$_{m,l}$ (II)</td>
</tr>
<tr>
<td></td>
<td>Severe FOV$_{s,m}$ (II)</td>
</tr>
<tr>
<td></td>
<td>During treatment *</td>
</tr>
<tr>
<td></td>
<td>Post treatment *</td>
</tr>
</tbody>
</table>

CBCT, cone beam computed tomography; Field of View (FOV): FOV$_s$ = Small field of view CBCT imaging; FOV$_m$ = Medium field of view CBCT imaging; FOV$_l$ = Large field of view CBCT imaging. Consensus Recommendations: I = Likely Appropriate; II =Possibly Appropriate; III = Likely Inappropriate; IV = Not Supported.
Table 4. Definition of CBCT Field of View Ranges for Orthodontic Imaging.

<table>
<thead>
<tr>
<th>Field of View</th>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>$\text{FOV}_s$</td>
<td>A region of radiation exposure limited to a few teeth or a quadrant within a dental arch which include spherical volume diameters or cylinder heights $\leq 10$ cm.</td>
</tr>
<tr>
<td>Medium</td>
<td>$\text{FOV}_m$</td>
<td>A region of radiation exposure incorporating the dentition of at least one arch up to both dental arches which include spherical volume diameters or cylinder heights $&gt; 10$ cm and $\leq 15$ cm.</td>
</tr>
<tr>
<td>Large</td>
<td>$\text{FOV}_l$</td>
<td>A region of radiation exposure incorporating anatomic landmarks necessary for quantitative cephalometric and/or airway assessment including the TMJ articulations with spherical volume diameters or cylinder heights $&gt; 15$ cm.</td>
</tr>
</tbody>
</table>
Table 5. Adult and Child Relative Radiation Level (§) and Selected Published Effective Doses (µSv) (ICRP, 2007) for Specific Equipment used in Various Radiographic Examinations in Orthodontics.

<table>
<thead>
<tr>
<th>Examination</th>
<th>Make - Model</th>
<th>$E$ (µSv)</th>
<th>Relative Radiation Level§</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large FOV CBCT</td>
<td>NewTom3G – Large FOV</td>
<td>68&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NewTom 9000</td>
<td>56.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NewTom VG - Maxillofacial</td>
<td>83&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CB Mercuray – Maximum/standard quality</td>
<td>1073/569&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>i-CAT Next Generation - Portrait</td>
<td>74&lt;sup&gt;a&lt;/sup&gt;; 83&lt;sup&gt;b&lt;/sup&gt;; 78&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iluma –Ultra/Standard; Elite</td>
<td>498/98&lt;sup&gt;a&lt;/sup&gt;; 368&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>KODAK 9500 - Maxillofacial</td>
<td>136&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Skyview - Maxillofacial</td>
<td>87&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Medium FOV CBCT</td>
<td>i-CAT - Classic Standard/ Next Generation landscape</td>
<td>69/89&lt;sup&gt;a&lt;/sup&gt;; 61&lt;sup&gt;b&lt;/sup&gt;/110&lt;sup&gt;c&lt;/sup&gt;;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Galileos – Maximum/Default</td>
<td>128/70&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Galileos Comfort</td>
<td>84&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Newtom VGi - Maxillofacial</td>
<td>194&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scanora 3D - Maxillofacial</td>
<td>68&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Small FOV CBCT</td>
<td>CB Mercuray - Max</td>
<td>407&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Promax – Large adult/small adult</td>
<td>652/488&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>
Table 5 (cont.)

<table>
<thead>
<tr>
<th>Machine</th>
<th>Type</th>
<th>Dosage</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promax 3D - Standard dose/Low dose</td>
<td>122/28^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PreXion – High resolution/standard exposure</td>
<td>388/189^a</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3D Accuitomo 170 - Max</td>
<td>54^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>i-CAT Next Generation - Man</td>
<td>45^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>KODAK 9500 - Dentoalveolar</td>
<td>92^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Newton VGi - Dentoalveolar</td>
<td>265^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Picasso Trio – Standard dose</td>
<td>123/81^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Scanora 3D – Max/Man/Both</td>
<td>46/47/45^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Veraviewepocs 3D - Dentoalveolar</td>
<td>73^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>i-CAT Next Generation – Man</td>
<td>58/113/32/60^f</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.4mm/Man 0.2mm/Max 0.4mm/Max 0.2mm</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3D Accuitomo 170 – Man molar</td>
<td>43^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>KODAK 9000 3D – Max anterior/Man molar</td>
<td>19/40^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pax-Uni3D – Max anterior</td>
<td>44^b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Siemens Somaton 64 (12 cm) – Default/ CARE</td>
<td>860/534^a</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Toshiba Aquilion 64 (9 cm) - Optimized</td>
<td>990^c</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>429.7^g</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 5 (cont.)

Siemens Somaton 64 (10 cm) – 120kVp/90ma

<table>
<thead>
<tr>
<th>Panoramic</th>
<th>Plannmeca Promax - Film; CCD</th>
<th>26°/24.3d</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Plannmeca PM Proline 2000 (High /Low dose) - CCD</td>
<td>38/12e</td>
<td>⊘ - ⊘ -</td>
<td>⊘</td>
<td></td>
</tr>
<tr>
<td>Sirona Orthophos DS XG; XG^{plus} - CCD</td>
<td>14.2^n; 50c</td>
<td>⊘ - ⊘ -</td>
<td>⊘</td>
<td></td>
</tr>
<tr>
<td>Plannmeca Promax PA</td>
<td>5.1d</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Cephalometric                    | Lat Ceph - PSP               | 5.6d      |  |  |

§American College of Radiology Relative Radiation Level; ⊘, Child (< 30 µSv), Adult (< 100µSv); ⊘ ⊘, Child (<30-300µSv), Adult (100-1000µSv); ⊘ ⊘ ⊘, Child (<300-3000 µSv), Adult (1,000-10,000µSv).

CBCT, cone beam computed tomography; PSP, photo-stimulable phosphor; CCD, Charged coupled device-based technology; Max, Maxillary; Man, Mandibular; MSCT, multi-slice computed tomography.

Ludlow, et al., 2008b; Pauwels, et al., 2012; Carrafiello, et al., 2010; Ludlow, et al., 2008a; Gavala, et al., 2009; Davies, et al., 2012; Silva, et al., 2008
Table 6. Examples of the Calculation of the Relative Radiation Level Associated with Specific Imaging Protocols used in Orthodontic Treatments.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Modality</th>
<th>Stage of Treatment</th>
<th>Dose (µSv)</th>
<th>Relative Radiation Level$^$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Imaging</td>
<td>Panoramic$^a$</td>
<td>Initial Diagnostic</td>
<td>+</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Lateral Cephalogram$^b$</td>
<td>Mid-Treatment</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post-Treatment</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Conventional + Small FOV CBCT</td>
<td>Panoramic$^a$</td>
<td>Initial Diagnostic</td>
<td>+</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Lateral Cephalogram$^b$</td>
<td>Mid-Treatment</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post-Treatment</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Small FOV CBCT$^c$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large FOV CBCT + conventional imaging</td>
<td>Panoramic$^a$</td>
<td>Initial Diagnostic</td>
<td>-</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Lateral Cephalogram$^b$</td>
<td>Mid-Treatment</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post-Treatment</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large FOV CBCT$^d$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large FOV CBCT</td>
<td>Large FOV CBCT$^d$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CBCT, cone beam computed tomography; FOV, field of view; CCD, charged coupled device technology; Sub-total, product of the times when the modality is used at each stage over a course of treatment by the average effective dose per modality exposure; Total, sum of subtotals for a particular orthodontic imaging protocol

§ American College of Radiology Relative Radiation Level: <30 µSv, Child (<30 µSv), Adult (<100 µSv); >30, Child (30-300 µSv), Adult (100-1000 µSv).

$^a$ Planmeca PM Proline 2000 (Low dose) – Charged coupled device (12 µSv) from Carrafiello, et al., 2010
$^b$ Photostimulable storage phosphor (5.6 µSv) from Ludlow, et al., 2008a
$^c$ i-CAT Next Generation – Maxilla 6cm field of view height, 0.2mm voxel resolution (60 µSv) from Pauwels, et al., 2010
$^d$ i-CAT Next Generation – Portrait (83 µSv) from Pauwels, et al., 2010