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.[Gelskey and Baker, 1984] 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. [Hechler, 2008] 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. [van Vlijmen, *et al.*, 2012] 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. [Hechler, 2008; Silva, *et al.*, 2008; Mah, *et al.*, 2010] 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. [International Commission on Radiological Protection (ICRP), 1991] 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.” [International Commission on Radiological Protection, 1991] 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).[Valentin, 2007] These modifications have resulted in substantial increases in radiation effective doses for specific maxillofacial radiographic procedures ranging from 32% to 422%.[Ludlow, *et al.*, 2008a]

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; Cevidanes, *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;]

Koyama, *et al.*, 2007; Ahmad, *et al.*, 2009; Dworkin and LeResche, 1992; Schiffman, *et al.*, 2010a and b; Truelove, *et al.*, 2010; Bryndhal, *et al.*, 2006)

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 accurarately 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-Elfetouh, *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

Hatcher, 2010; Tso, *et al.*, 2009; Strauss and Burgoyne, 2008; Osorio, *et al.*, 2008; Ogawa, *et al.*, 2005; Aboudara, *et al.*, 2003; Sera, *et al.*, 2003

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 [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. [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 7th Biological Effects of Ionizing Radiation report (BEIR VII report).[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.[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.
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> **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 [Cha, *et al.*, 2007; Pliska, *et al.*, 2011; Pazera, *et al.*, 2011] and some are critical to the health of the patient. [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. [(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.[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.

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REFERENCES

Aboudara CA, Hatcher D, Nielsen IL, Miller A. A three-dimensional evaluation of the upper airway in adolescents. Orthod Craniofac Res 2003;6 Suppl 1:173-5.

Abou-Elfetouh A, Barakat A, Abdel-Ghany K. Computed-guided rapid-prototyped templates for segmental mandibular osteotomies: a preliminary report. Int J Med Robot 2011;7:187-92.

Abramson Z, Susarla SM, Lawler M, Bouchard C, Troulis M, Kaban LB. Three-dimensional computed tomographic airway analysis of patients with obstructive sleep apnea treated by maxillomandibular advancement. J Oral Maxillofac Surg 2011;69:677-86.

Agarwal R. Anthropometric evaluation of complete unilateral cleft lip nose with cone beam CT in early childhood. J Plast Reconstr Aesthet Surg 2011;64:e181-2.

Ahmad M, Hollender L, Anderson Q, Kartha K, Ohrbach RK, Truelove EL, John MT, Schiffman EL. Research diagnostic criteria for temporomandibular disorders (RDC/TMD): development of image analysis criteria and examiner reliability for image analysis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;107:844-60.

Alexiou K, Stamatakis H, Tsiklakis K. Evaluation of the severity of temporomandibular joint osteoarthritic changes related to age using cone beam computed tomography. Dentomaxillofac Radiol 2009; 38:141-7.

AlHadidi A, Cevidanes LH, Mol A, Ludlow J, Styner M. Comparison of two methods for quantitative assessment of mandibular asymmetry using cone beam computed tomography image volumes. Dentomaxillofac Radiol 2011;40:351-7.

Almeida RC, Cevidanes LH, Carvalho FA, Motta AT, Almeida MA, Styner M, Turvey T, Proffit WR, Phillips C. Soft tissue response to mandibular advancement using 3D CBCT scanning. Int. J Oral Maxillofac Surg 2011;40:353-9.

American Academy of Oral and Maxillofacial Radiology. Letter to the Editor of Cancer Concerning the Manuscript entitled "Dental X-Rays and Risk of Meningioma, EB Claus et al, Cancer, 2012 https://www.aaomr.org/resource/resmgr/docs/letter_to_the_editor_of_canc.pdf Accessed June 21, 2012.

American Dental Association. ADA Press Release. Recent study questions safety of dental X-rays, April 10, 2012, http://www.ada.org/6972.aspx Accessed June 20, 2012

American College of Radiology. ACR Appropriateness Criteria®. Radiation Dose Assessment Introduction. 2011. Available at: http://www.acr.org/~/media/ACR/Documents/AppCriteria/RRLInformation.pdf Accessed 22 May 2012.

American College of Radiology. ACR Appropriateness Criteria®. Rating Round Information. 2011. Available at: http://www.acr.org/SecondaryMainMenuCategories/quality_safety/app_criteria/Rating-Round-Information.aspx Accessed 23 September 2011

American College of Radiology. The Quality Improvement Registry for CT Scans in Children. 2010. Available at: https://nrdr.acr.org/Portal/QuIRCC/Main/page.aspx Accessed 21 December 2011.

American Dental Association Council on Scientific Affairs. The use of dental radiographs: update and recommendations. J Am Dent Assoc. 2006;137:1304-12.

Baumrind S, Miller D, Molthen R. The reliability of head film measurements. 3. Tracing superimposition. Am J Orthod 1976;70:617-44.

Becker A, Chaushu C, Casap-Caspi N. Cone-beam computed tomography and the orthosurgical management of impacted teeth. J Am Dent Assoc 2010;141;14S-18S.

Behnia H, Khojasteh A, Soleimani M, Tehranchi A, Atashi A. Repair of alveolar cleft defect with mesenchymal stem cells and platelet derived growth factors: a preliminary report. J Craniomaxillofac Surg 2012;40:2-7.

Botticelli S, Verna C, Cattaneo PM, Heidmann J, Melsen B. Two- versus three-dimensional imaging in subjects with unerupted maxillary canines. Eur J Orthod 2011;33:344-9

Bowlin J. Cone beam Technology: Legal Caveats. The Bulletin of the American Association of Orthodontists 2010;28:24-25.

Brenner DJ, Elliston CD, Hall EJ, Berdon WE. Estimated risks of radiation-induced fatal cancer from pediatric CT Am. J. Roentgenol 2001;176:289-96.

Bryndahl F, Eriksson L, Legrell PE, Isberg A. Bilateral TMJ disk displacement induces mandibular retrognathia. J Dent Res 2006;85:1118–1123.

Carrafiello G, Dizonno M, Colli V, Strocchi S, Pozzi Taubert S, Leonardi A, Giorgianni A, Barresi M, Macchi A, Bracchi E, Conte L, Fugazzola C. Comparative study of jaws with multislice computed tomography and cone-beam computed tomography. Radiol Med 2010;115:600-11.

Carter L, Farman A, Geist J, Scarfe W, Angelopoulos C, Nair M, *et al.* American Academy of Oral and Maxillofacial Radiology executive opinion statement on performing and interpreting diagnostic cone beam computed tomography. Oral Surg, Oral Med, Oral Path, Oral Radiol, Endod 2008;106:561-2.

Carvalho Fde A, Cevidanes LH, da Motta AT, Almeida MA, Phillips C. Three-dimensional assessment of mandibular advancement 1 year after surgery. Am J Orthod Dentofac Orthop 2010;137(4 Suppl): S53.e1-12.

Cascade PN. The American College of Radiology. ACR Appropriateness Criteria project. Radiology 2000;214 Suppl:3-46.

Cevidanes LH, Alhadidi A, Paniagua B, Styner M, Ludlow J, Mol A, Turvey T, Proffit WR, Rossouw PE. Three-dimensional quantification of mandibular asymmetry through cone-beam computerized tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111:757-70.

Cevidanes LHC, Tucker S, Styner M, Kim H, Chapuis J, Reyes M. Proffit W, Turvey T, Jaskolka M. Three-dimensional surgical simulation. Am J Orthod Dentofac Orthop 2010;138:361-71.

Cha, JY, Mah J, Sinclair P. Incidental findings in the maxillofacial area with 3 dimensional cone beam imaging. Am J Orthod Dentofacial Orthop 2007;132:7–14

Chaushu S, Chaushu G, Becker A. The role of digital volume tomography in the imaging of impacted teeth. World J Orthod 2004; 5: 120-132.

Claus EB, Calvocoressi L, Bondy ML, Schildkraut JM, Wiemels JL, Wrensch M. Dental x-rays and risk of meningioma. Cancer. 2012 Apr 10. http://dx.doi.org/10.1002/cncr.26625 Accessed June 7, 2012.

Conley RS. Evidence for dental and dental specialty treatment of obstructive sleep apnoea. Part 1: the adult OSA patient and Part 2: the paediatric and adolescent patient. J Oral Rehabil 2011;38:136-56.

Dalessandri D, Laffranchi L, Tonni I, Zoti F, Piancino MG, Paganelli C, Bracco P. Advantages of cone beam computed tomography (CBCT) in the orthodontic treatment planning of cleidocranial dysplasia patients: a case report. Head Face Med 2011;27:7-6.

Damstra J, Fourie Z, Ren Y. Evaluation and comparison of postero-anterior cephalograms and cone-beam computed tomography images for the detection of mandibular asymmetry. Eur J Orthod 2011 Mar 31. http://dx. doi:10.1093/ejo/cjr045 [Epub ahead of print]

Davies J, Johnson B, Drage NA. Effective doses from cone beam CT investigation of the jaws Dentomaxillofac Radiol 2012;41:30–36.

de Moraes ME, Hollender LG, Chen CS, Moraes LC, Balducci I. Evaluating craniofacial asymmetry with digital cephalometric images and cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2011;139:e523-31.

Dworkin SF, LeResche L. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations, and specifications, critique, J Craniomandib Disord 1992;6:301–355.

Ebner FH, Kürschner V, Dietz K, Bültmann E, Nägele T, Honegger J. Craniometric changes in patients with acromegaly from a surgical perspective. Neurosurg Focus 2010;29:E3.

Edwards SP. Computer-assisted craniomaxillofacial surgery. Oral Maxillofac Surg Clin North Am 2010;22:117-34.

El AS, El H, Palomo JM, Baur DA. A 3-dimensional airway analysis of an obstructive sleep apnea surgical correction with cone beam computed tomography. J Oral Maxillofac Surg 2011;69:2424-36.

El H, Palomo JM. Measuring the airway in 3 dimensions: a reliability and accuracy study. Am J Orthod Dentofacial Orthop 2010;137(4 Suppl):S50.e1-9; discussion S50-2.

European Commission. Radiation Protection 136. European guidelines on radiation protection in dental radiology. 2004. pp. 115. ISBN 92-894-5958-1

Gateno J, Xia JJ, Teichgraeber JF. New 3-dimensional cephalometric analysis for orthognathic surgery. J Oral Maxillofac Surg 2011;69:606-22.

Gavala S, Donta C, Tsiklakis K, Boziari A, Kamenopoulou V, Stamatakis HC. Radiation dose reduction in direct digital panoramic radiography. Eur J Radiol 2009;71:42-8.

Gelskey DE, Baker CG.The ALARA concept. Population exposures from x rays in dentistry--as low as reasonably achievable? J Can Dent Assoc 1984;50:402-3.

Hechler SL. Cone-Beam CT: Applications in orthodontics. Dent Clin N Am 2008;52:753–759.

Helenius LM, Hallikainen D, Helenius I, Meurman JH, Könönen M, Leirisalo-Repo M, Lindqvist C. Clinical and radiographic findings of the temporomandibular joint in patients with various rheumatic diseases: A case control study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;99: 455-463.

Heymann GC, Cevidanes L, Cornelis M, De Clerck HJ, Tulloch JFC. Three-dimensional analysis of maxillary protraction with intermaxillary elastics to miniplates. Am J Orthod Dentofac Orthop 2010;137:274-84.

Hofmann E, Medelnik J, Fink M, Lell M, Hirschfelder U. Three-dimensional volume tomographic study of the imaging accuracy of impacted teeth: MSCT and CBCT comparison - an in vitro study. Eur J Orthod 2011 Mar 4. http://dx.doi.10.1093/ejo/cjr030 [Epub ahead of print].

International Commission on Radiological Protection, 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60. Ann ICRP 1991;21:1-3.

Isaacson KG, Thom AR, Horner K, Whaites E. Orthodontic radiographs— guidelines for the use of radiographs in clinical orthodontics. 3rd ed. London: British Orthodontic Society; 2008.

Iwasaki T, Saitoh I, Takemoto Y, Inada E, Kanomi R, Hayasaki H, Yamasaki Y. Evaluation of upper airway obstruction in Class II children with fluid-mechanical simulation. Am J Orthod Dentofacial Orthop 2011;139:e135-45.

Janssens A, Horner K, Rushton V, Walker A, Tsiklakis K, Hirschmann PN, van der Stelt PF, Glenny A-M, Velders XL, Pavitt S. Radiation protection: European guidelines on radiation protection in dental radiology—the safe use of radiographs in dental practice, 2003. At: www.sefm.es/docs/otros/raddigUE.pdf. Accessed: April 20, 2012.

Jayaratne YS, Zwahlen RA, Lo J, tam SC, Cheung LK. Computer-aided maxillofacial surgery: an update. Surg Innov 2010;17:217-25.

Jayaratne YSN, Zwahllen RA, Lo J, Cheung LK. Three-dimensional color maps: A novel tool for assessing craniofacial changes. Surg Innov 2010;17:198-205.

Johnston LE Jr. A few comments on an elegant answer in search of useful questions. Semin Orthod 2011;17:13-14.

Kapila S, Conley RS, Harrell WE Jr. The current status of cone beam computed tomography imaging in orthodontics. Dentomaxillofac Radiol 2011;40:24-34.

Katheria BC, Kau CH, Tate R, Chen J-W, English J, Bouquot J. Effectiveness of impacted and supernumerary tooth diagnosis from traditional radiography versus cone beam computed tomography. Ped Dent 2010;32:304-309.

Kim YI, Park SB, Son WS, Hwang DS. Midfacial soft-tissue changes after advancement of maxilla with Le Fort I osteotomy and mandibular setback surgery: comparison of conventional and high Le Fort osteotomies by superimposition of cone-beam computed tomography volumes. J Oral Maxillofac Surg 2011;69:e225-33.

Kook YA, Kim Y. Evaluation of facial asymmetry with three-dimensional cone-beam computed tomography. J Clin Orthod 2011;45:112-5.

Koyama J, Nishiyama H, Hayashi T. Follow-up study of condylar bony changes using helical computed tomography in patients with temporomandibular disorder. Dentomaxillofac Radiol 2007;36:472-477.

Kwong, JC, Palomo, JM, Landers, MA, Figueroa, A, Hans, MG. Image quality produced by different CBCT settings. Am J Orthod Dentofacial Orthop 2008;133:317-27.

Lam E, Yang J. AAOMR Response to Recent Study on Dental X-ray Risks. 2012 www.aaomr.org/resource/resmgr/.../aaomr_response_to_study2.pdf Accessed June 20, 2012.

Lenza MG, Lenza MM, Dalstra M, Melsen B, Cattaneo PM. An analysis of different approaches to the assessment of upper airway morphology: a CBCT study. Orthod Craniofac Res 2010;13:96-105.

Leung CC, Palomo L, Griffith R. Hans MG. Accuracy and reliability of cone-beam computed tomography for measuring alveolar bone height and detecting bony dehiscences and fenestrations. Am J Orthod Dentofac Orthop 2010;137(4 Suppl):S109-119.

Leuzinger M, Dudic A, Giannopoulou C, Killaridis S. Root-contact evaluation by panoramic radiography and cone-beam computed tomography of super-high resolution. Am J Orthod Dentofac Orthop 2010;137:389-392.

Liedke GS, Dias de Silveira HE, Dias de Silveira HL, Dutra V, Poli de Figueiredo JA. Influence of voxel size in the diagnostic ability of cone beam tomography to evaluate simulated external root resorption. J Endod 2009;35:233-235.

Little RM, Wallen TR, Riedel RA. Stability and relapse of mandibular anterior alignment-first premolar extraction cases treated by traditional edgewise orthodontics. Am J Orthod. 1981;80:349-65.

Liu D, Zhang W, Zhang z, Wu Y, Ma X. Localization of impacted maxillary canines and observation of adjacent incisor resorption with cone-beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105:91-98.

Liu D, Zhang W, Zhang z, Wu Y, Ma X. Three-dimensional evaluations of supernumerary teeth using cone-beam computed tomography for 487 cases. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:403-411.

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.

Loubele M, Van Assche N, Carpentier K, Maes F, Jacobs R, Van Steenberghe D, Suetens P. Comparative localized linear accuracy of small-field cone-beam CT and multislice CT for alveolar bone measurements. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105: 512-518.

Ludlow JB, Brooks SL, Davies-Ludlow LE, Howerton B. Dosimetry of 3 CBCT units for oral and maxillofacial radiology. Dentomaxillofac Radiol 2006 35: 219-226.

Ludlow JB, Davies-Ludlow LE, White SC. Patient risk related to common dental radiographic examinations: the impact of 2007 International Commission on Radiological Protection recommendations regarding dose calculation. J Am Dent Assoc. 2008a;139:1237-43.

Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT Devices and 64-slice CT for oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008b;96:930-938.

Mah JK, Huang JC, Choo H. Practical applications of cone-beam computed tomography in orthodontics. J Am Dent Assoc 2010;141 Suppl 3:7S-13S.

Matteson SR, Joseph LP, Bottomley W, Finger HW, Frommer HH, Koch RW, *et al.*: The selection of patients for x-ray examinations: dental radiographic examinations. In: Center for Devices and Radiological Health, ed: U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration, 1987.

Merrett SJ, Drage NA, Durning P. Cone beam computed tomography: a useful tool in orthodontic diagnosis and treatment planning. J Orthod 2009;36:202-10.

Molen AD. Considerations in the use of cone-beam computed tomography for buccal bone measurements. Am J Orthod Dentofac Orthop 2010;137(4 Suppl):S130-5.

Moyers RE, Bookstein FL. The inappropriateness of conventional cephalometrics. Am J Orthod 1979;75:599-617.

National Health and Medical Research Council of Australia. A Guide to the Development, Implementation and Evaluation of Clinical Practice Guidelines. 1999.

http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/cp30.pdf accessed September 23, 2011

National Research Council (U.S.), Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation. Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII – Phase 2. The National Academies Press 2006 Washington DC ISBN: 0-309-53040-7, pp. 424

National Research Council of the National Academies, Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation. Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII – Phase 2. The National Academies Press Washington, DC, USA ISBN: 0-309-53040-7, 2006, pp. 424.

Oberoi S, Knueppel S.Three-dimensional assessment of impacted canines and root resorption using cone beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011 Jun 24 doi:10.1016/j.tripleo.2011.03.035 [Epub ahead of print]

Ogawa T, Enciso R, Memon A, Mah JK, Clark GT. Evaluation of 3D airway imaging of obstructive sleep apnea with cone-beam computed tomography. Stud Health Technol Inform 2005;111:365-8.

Oh KM, Hong JS, Kim YJ, Cevidanes LS, Park YH. Three-dimensional analysis of pharyngeal airway form in children with anteroposterior facial patterns. Angle Orthod 2011;81:1075-82.

Orentlicher G, Goldsmith D, Horowitz A. Applications of 3-dimensional virtual computerized tomography technology in oral and maxillofacial surgery: current therapy. J Oral Maxillofac Surg 2010;68:1993-59.

Osorio F, Perilla M, Doyle DJ, Palomo JM. Cone beam computed tomography: an innovative tool for airway assessment. Anesth Analg 2008;106:1803-7.

Palomo, JM, Rao, PS, Hans, MG. Influence of CBCT exposure conditions on radiation dose. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105:773-82.

Pauwels R, Beinsberger J, Collaert B, Theodorakou C, Rogers J, Walker A, Cockmartin L, Bosmans H, Jacobs R, Bogaerts R, Horner K; The SEDENTEXCT Project Consortium. Effective dose range for dental cone beam computed tomography scanners. Eur J Radiol. 2012;81:267-271.

Pazera P, Bornstein MM, Pazera A, Sendi P, Katsaros C. Incidental maxillary sinus findings in orthodontic patients: a radiographic analysis using cone-beam computed tomography (CBCT). Orthod Craniofac Res 2011;14:17-24.

Pearce MS, Salotti JA, Little MP, McHugh K, Lee C, Kim KP, Howe NL, Ronckers CM, Rajaraman P, Craft AW, Parker L, Berrington de González A. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study, The Lancet, http://dx.doi.org/10.1016/S0140-6736(12)60815-0 Accessed June 10, 2012.

Pliska B, DeRocher M, Larson BE. Incidence of significant findings on CBCT scans of an orthodontic patient population. Northwest Dent 2011;90:12-6.

Popat H, Richmond S. New developments in: three-dimensional planning for orthognathic surgery. J Orthod 2010;37:62-71.

Preston DL, Shimizu Y, Pierce DA, Suyama A, Mabuch K. Studies of mortality of atomic bomb survivors. Report 13: Solid cancer and non-cancer disease mortality: 1950-1997. Radiat Res 2003;160:381-407.

Rogers SA, Drage N, Durning P. Incidental findings arising with cone beam computed tomography imaging of the orthodontic patient. Angle Orthod 2011;81:350-5.

Rungcharassaeng K, Caruso JM, Kan JY, Kim J, Taylor G. Factors affecting buccal bone changes of maxillary posterior teeth after rapid maxillary expansion. Am J Orthod Dentofacial Orthop 2007;132: 428.e1-8.

Schendel S, Powell N, Jacobson R. Maxillary, mandibular, and chin advancement: treatment planning based on airway anatomy in obstructive sleep apnea. J Oral Maxillofac Surg 2011;69:663-76.

Schendel SA, Hatcher D. Automated 3-dimensional airway analysis from cone-beam computed tomography data. J Oral Maxillofac Surg 2010;68:696-701.

Schendel SA, Lane C. 3D orthognathic surgery simulation using image fusion. Semin Orthod 2009;15:48-56.

Schiffman EL, Ohrbach R, Truelove EL, Tai F, Anderson GC, Pan W, Gonzalez YM, John MT, Sommers E, List T, Velly AM, Kang W, Look JO. The research diagnostic criteria for temporomandibular disorders. V: methods used to establish and validate revised Axis I diagnostic algorithms. J Orofac Pain 2010;24:63-78.

Schiffman EL, Truelove EL, Ohrbach R, Anderson GC, John MT, List T, Look JO. The research diagnostic criteria for temporomandibular disorders. I: overview and methodology for assessment of validity. J Orofac Pain 2010;24:7-24.

Scolozzi P, Terzic A. "Mirroring" computational planning, navigation guidance system, and intraoperative mobile C-arm cone-beam computed tomography with flat-panel detector. J Oral Maxillofac Surg 2011 69:1697-707.

Scottish Intercollegiate Guidelines Network. Key to evidence statements and grades of recommendations. 2011. http://www.sign.ac.uk/guidelines/fulltext/50/annexb.html. Accessed January 17 2012.

SedentexCT Project Radiation Protection: Cone Beam CT for Dental and Maxillofacial Radiology. Evidence Based Guidelines, 2011 (v2.0 Final) www.sedentexct.eu/files/guidelines_final.pdf Accessed 11/12/11.

Sera T, Fujioka H, Yokota H, Makinouchi A, Himeno R, Schroter RC, Tanishita K. Three-dimensional visualization and morphometry of small airways from microfocal X-ray computed tomography. J Biomech 2003;36:1587-94.

Shemesh H, Cristescu RC, Wesslink PR, Wu M-K. The use of cone-beam computed tomography and digital periapical radiographs to diagnose root perforations. J Endod 2011;37:513-516.

Sherrard JF, Rossouw PE, Benson BW, Carrillo R, Buschang PH. Accuracy and reliability of tooth and root lengths measured on cone-beam computed tomographs. Am J Orthod Dentofac Orthop 2010;137(4 Suppl):S100-S108.

Sievers MM, Larson BE, Gaillard PR, Wey A. Asymmetry assessment using cone-beam CT a Class I and Class II patient comparison. Angle Orthod 2011 Oct 6. doi: http://dx.doi.org/10.2319/041711-271.1 [Epub ahead of print]

Silva MA, Wolf U, Heinicke F, Bumann A, Visser H, Hirsch E. Cone-beam computed tomography for routine orthodontic treatment planning: A radiation dose evaluation. Am. Am J Orthod Dentofacial Orthop 2008;133:640.e1-5.

Smith-Bindman R, Lipson J, Marcus R, Kim KP, Mahesh M, Gould R, Berrington de González A, Miglioretti DL. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med. 2009;169:2078-86.

Strauss RA, Burgoyne CC. Diagnostic imaging and sleep medicine. Dent Clin North Am 2008;52:891-915.

Tamimi D, ElSaid K. Cone beam computed tomography in the assessment of dental impactions. Semin Orthod 2009;15:57-62.

The Alliance for Radiation Safety in Pediatric Imaging. Image Gently™. 2011 http://www.imagegently.org Accessed December 21, 2011.

Theodorakou C, Walker A, Horner K, Pauwels R, Bogaerts R, Jacobs R; SEDENTEXCT Project Consortium. Estimation of paediatric organ and effective doses from dental cone beam CT using anthropomorphic phantoms. Brit J Radiology 2012;85:153-60.

Timock AM, Cook V, McDonald T, Leo MC, Crowe J, Benninger BL, Covell DA Jr. Accuracy and reliability of buccal bone height and thickness measurements from cone-beam computed tomography imaging. Am J Orthod Dentofacial Orthop 2011;140:734-44.

Treil J, Braga J, Loubes J-M, Maza E, Inglese J-M, Casteigt J, Waysenson B. 3D tooth modeling for orthodontic assessment. Semin Orthod 2009;15:42-47.

Truelove E, Pan W, Look JO, Mancl LA, Ohrbach RK, Velly AM, Huggins KH, Lenton P, Shiffman EL. The research diagnostic criteria for temporomandibular disorders. III: validity of axis I diagnoses. J Orofac Pain 2010;24:35-47.

Tso HH, Lee JS, Huang JC, Maki K, Hatcher D, Miller AJ. Evaluation of the human airway using cone-beam computerized tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:768-76.

Tucker S, Cevidanes LHS, Styner M, Kim H, Reyes M, Proffit W, Turvey T. Comparison of actual surgical outcomes and 3-dimensional surgical simulations. J Oral Maxillofac Surg 2010;68:2412-21.

U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration; and American Dental Association, Council on Dental Benefit Programs, Council on Scientific Affairs. The selection of patients for dental radiographic examinations. Rev. ed. 2004. Available at: "www.ada.org/prof/resources/topics/radiography.asp". Accessed May 26, 2012.

U.S. Preventive Services Task Force Ratings: Grade Definitions. Guide to Clinical Preventive Services, Third Edition: Periodic Updates, 2000-2003. http://www.uspreventiveservicestaskforce.org/3rduspstf/ratings.htm Accessed September 23, 2011;

United Nations Scientific Committee on the Effects of Atomic Radiation. Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation - UNSCEAR 2006 Report, Volume 1 - Report to the General Assembly, with Scientific Annexes A and B. United Nations, New York, New York, USA 2008 pp. 360.

Valentin J. The 2007 Recommendations of the International Commission on Radiological Protection. Publication 93. Ann ICRP 2007;37:1-332,

Van Elslande D , Heo G, Flores-Mir C, Carey J, Major PW. Accuracy of mesiodistal root angulation projected by cone-beam computed tomographic panoramic-like images. Am J Orthod Dentofac Orthop 2010;137(4 Suppl):S94-S99.

van Vlijmen OJC, Kuijpers MAR, Berge SJ, Schols JGJH, Maal TJJ, Beruning H, Juijpers-Jagtman AM. (2012) Evidence supporting the use of cone-beam computed tomography in orthodontics. J Am Dent Assoc 2012;143:241-252.

Veli I, Uysal T, Ozer T, Ucar FI, Eruz M. Mandibular asymmetry in unilateral and bilateral posterior crossbite patients using cone-beam computed tomography. Angle Orthod 2011;81:966-74.

Walker L, Enciso R, Mah J. Three-dimensional localization of maxillary canines with cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2005;128: 418-423.

White SC, Pae E-K. Patient image selection criteria for cone beam computed tomography imaging. Semin Orthod 2009;15:19-28.

Yagci A, Veli I, Uysal T, Ucar FI, Ozer T, Enhos S. Dehiscence and fenestration in skeletal Class I, II, and III malocclusions assessed with cone-beam computed tomography. Angle Orthod 2012;82:67-74.

Table 1. Consensus Recommendations Supporting the Use of CBCT Imaging

Recommendation	Consensus Level	Definition
Likely Appropriate	I	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.
Possibly Appropriate	II	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.
Likely Inappropriate	III	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.
Not Supported	IV	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.

Table 2. Estimations of Relative Radiation Level Designations for Children and Adults for Orthodontic Imaging (*with permission from* ACR*, 2011).

Relative Radiation Level	***Effective Dose Estimate Range (µSv)***	
	Adult	***Child***
0	0	0
☢	< 100	< 30
☢☢	100 – 1,000	30 - 300
☢☢☢	1,000 – 10,000	300 – 3,000
☢☢☢☢	10,000 – 30,000	3,000 – 10,000

* 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.

Presentation		***Dental and Skeletal Clinical Conditions***								
Primary	***Treat-ment Diffi-culty***	***None***	***Dental structure anomalies***	***Anomalies in dental position***	***Compromised dento-alveolar boundaries***	***Asymmetry***	***Anterior posterior discrepancies***	***Vertical discrepancies***	***Transverse discrepancies***	***TMJ Signs and/or Symptoms***
Pre-treatment	*Mild*	*IV*	FOV_S (I)	FOV_S (I)	$FOV_{s, m}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{s, m}$ (III)
	Moderate	$FOV_{m,l}$ (II)	FOV_S (I)	FOV_S (I)	$FOV_{s, m}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)
	Severe	FOV_l (II)	FOV_S (I)	FOV_S (I)	$FOV_{s, m}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)
During treatment *		IV	FOV_S (III)	FOV_S (II)	$FOV_{s, m}$ (II)	Presurgical $FOV_{m,l}$ (I)	Presurgi-cal $FOV_{m,l}$ (II)	Presurgi-cal $FOV_{m,l}$ (II)	Presurgical $FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)
Post treatment *		IV	FOV_S (III)	FOV_S (III)	$FOV_{s, m}$ (III)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)	$FOV_{m,l}$ (II)

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.

Field of View	Abbreviation	Definition
Small	$\mathbf{FOV_s}$	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.
Medium	$\mathbf{FOV_m}$	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 > 10 cm and $\leq$ 15 cm.
Large	$\mathbf{FOV_l}$	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 > 15 cm.

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.

			Relative Radiation Level§	
Examination	***Make - Model***	***E (µSv)***	***Child***	***Adult***
Large FOV CBCT	NewTom3G – Large FOV	68[a]	☢☢	☢
	NewTom 9000	56.2[g]	☢☢	☢
	NewTom VG - Maxillofacial	83[b]	☢☢	☢
	CB Mercuray – Maximum/standard quality	1073/569[a]	☢☢☢	☢☢ - ☢☢☢
	i-CAT Next Generation - Portrait	74[a]; 83[b]; 78[g]	☢☢	☢
	Iluma –Ultra/Standard; Elite	498/98[a]; 368[b]	☢☢ - ☢☢☢	☢ - ☢☢
	KODAK 9500 - Maxillofacial	136[b]	☢☢	☢☢
	Skyview - Maxillofacial	87[b]	☢☢	☢
Medium FOV CBCT	i-CAT - Classic Standard/ Next Generation landscape	69/89[a]; 61[g]/110[c]; 77[f]	☢☢	☢ - ☢☢
	Galileos – Maximum/Default	128/70[a]	☢☢	☢ - ☢☢
	Galileos Comfort	84[b]	☢☢	☢
	Newtom VGi - Maxillofacial	194[b]	☢☢	☢☢
	Scanora 3D - Maxillofacial	68[b]	☢☢	☢
Small FOV CBCT	CB Mercuray - Max	407[a]	☢☢☢	☢☢
	Promax – Large adult/small adult	652/488[a]	☢☢☢	☢☢

Table 5 (cont.)

	Promax 3D - Standard dose/Low dose	122/28[b]	☢ - ☢☢	☢ - ☢☢
	PreXion – High resolution/standard exposure	388/189[a]	☢☢ - ☢☢☢	☢☢
	3D Accuitomo 170 - Max	54[b]	☢☢	☢
	i-CAT Next Generation - Man	45[b]	☢☢	☢
	KODAK 9500 - Dentoalveolar	92[b]	☢☢	☢
	Newtom VGi - Dentoalveolar	265[b]	☢☢	☢☢
	Picasso Trio – Standard dose/Low dose	123/81[b]	☢☢	☢ - ☢☢
	Scanora 3D – Max/Man/Both	46/47/45[b]	☢☢	☢
	Veraviewepocs 3D - Dentoalveolar	73[b]	☢☢	☢
	i-CAT Next Generation – Man 0.4mm/Man 0.2mm/Max 0.4mm/Max 0.2mm	58/113/32/60[f]	☢☢	☢ - ☢☢
	3D Accuitomo 170 – Man molar	43[b]	☢☢	☢
	KODAK 9000 3D – Max anterior/Man molar	19/40[b]	☢ - ☢☢	☢
	Pax-Uni3D – Max anterior	44[b]	☢☢	☢
MSCT	Siemens Somaton 64 (12 cm) – Default/ CARE	860/534[a]	☢☢☢	☢☢
	Toshiba Aquilion 64 (9 cm) - Optimized	990[c]	☢☢☢	☢☢
		429.7[g]	☢☢☢	☢☢

Table 5 (cont.)

	Siemens Somaton 64 (10 cm) – 120kVp/90ma			
Panoramic	Planmeca Promax - Film; CCD	26[e] / 24.3[d]	☢	☢
	Planmeca PM Proline 2000 (High /Low dose) - CCD	38/12[e]	☢ - ☢☢	☢
	Sirona Orthophos DS XG; XG[plus] - CCD	14.2[n]; 50[c]	☢ - ☢☢	☢
	Planmeca Promax PA	5.1[d]	☢	☢
Cephalometric	Lat Ceph - PSP	5.6[d]	☢	☢

§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.
[a] Ludlow, *et al*., 2008b; [b] Pauwels, *et al*., 2012; [c] Carrafiello, *et al*., 2010; [d] Ludlow, *et al*., 2008a; [e] Gavala, *et al*., 2009; [f] Davies, *et al*., 2012; [g] Silva, *et al*., 2008

Table 6. Examples of the Calculation of the Relative Radiation Level Associated with Specific Imaging Protocols used in Orthodontic Treatments.

		Stage of Treatment			*Dose (µSv)*		*Relative Radiation Level§*	
Protocol	***Modality***	***Initial Diagnostic***	***Mid-Treatment***	***Post-Treatment***	***Sub-total***	***Total***	***Child***	***Adult***
Conventional Imaging	Panoramic[a]	+	+	+	36	47.2	☢☢	☢
	Lateral Cephalogram[b]	+	-	+	11.2			
Conventional + Small FOV CBCT	Panoramic[a]	+	+	+	36	107.2	☢☢	☢
	Lateral Cephalogram[b]	+	-	+	11.2			
	Small FOV CBCT[c]	+	-	-	60			
Large FOV CBCT + conventional imaging	Panoramic[a]	-	+	+	24	112.6	☢☢	☢☢
	Lateral Cephalogram[b]	-	-	+	5.6			
	Large FOV CBCT[d]	+	-	-	83			
Large FOV CBCT	Large FOV CBCT[d]	+	+	+	249	249	☢☢	☢☢

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; ☢, Child (< 30 µSv), Adult (< 100µSv); ☢☢, Child (<30-300µSv), Adult (100-1000µSv).

[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