Cone Beam Computed Tomography in Implant Dentistry: A Systematic Review Focusing on Guidelines, Indications, and Radiation Dose Risks

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Purpose: *The aim of the paper is to identify, review, analyze, and summarize available evidence in three areas on the use of cross-sectional imaging, specifically maxillofacial cone beam computed tomography (CBCT) in pre- and postoperative dental implant therapy:* (1) *Available clinical use guidelines,* (2) *indications and contraindications for use, and* (3) *assessment of associated radiation dose risk.* ***Materials and Methods:*** *Three focused questions were developed to address the aims. A systematic literature review was performed using a PICO-based search strategy based on MeSH key words specific to each focused question of English-language publications indexed in the MEDLINE database retrospectively from October 31, 2012. These results were supplemented by a hand search and gray literature search.* ***Results:*** *Twelve publications were identified providing guidelines for the use of cross-sectional radiography, particularly CBCT imaging, for the pre- and/or postoperative assessment of potential dental implant sites. The publications discovered by the PICO strategy (43 articles), hand (12), and gray literature searches (1) for the second focus question regarding indications and contraindications for CBCT use in implant dentistry were either cohort or case-controlled studies. For the third question on the assessment of associated radiation dose risk, a total of 22 articles were included. Publication characteristics and themes were summarized in tabular format.* ***Conclusions:*** *The reported indications for CBCT use in implant dentistry vary from preoperative analysis regarding specific anatomic considerations, site development using grafts, and computer-assisted treatment planning to postoperative evaluation focusing on complications due to damage of neurovascular structures. Effective doses for different CBCT devices exhibit a wide range with the lowest dose being almost 100 times less than the highest dose. Significant dose reduction can be achieved by adjusting operating parameters, including exposure factors and reducing the field of view (FOV) to the actual region of interest.* Int J Oral Maxillofac Implants 2014;29 (Suppl):55–77. doi: 10.11607/jomi.2014suppl.g1.4

Key words: *cone beam computed tomography, contraindications, dental implants, effective dose, guidelines, indications, radiation dose.*

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Successful dental implant rehabilitation requires accurate preoperative surgical planning. The use of specific imaging to assist planning is based on the patient's need as determined by clinical presentation and professional judgment, which is defined by the individual clinician's need for information supplemental to that already obtained from clinical examination to formulate a diagnosis.[1,2] Specific considerations should include clinical complexity, regional anatomic considerations, potential risk of complications and esthetic considerations in the location of implants. The use of imaging modalities for presurgical dental implant planning should be adequate to provide information supporting the following three goals:

1. *Establish the morphologic characteristics of the residual alveolar ridge.* The morphology of the residual alveolar ridge (RAR) includes considerations of bone volume and quality. Vertical bone height, horizontal width, and edentulous saddle length determine the amount of bone volume available for implant placement. This information is necessary to correlate the available bone dimensions with the selection of the number and physical dimensions of the dental implant.
2. *Determine the orientation of the residual alveolar ridge.* The orientation and residual topography of the alveolar-basal bone complex should be assessed to determine deviations of the RAR that compromise alignment of the implant fixture with respect to the prosthetic plan.
3. *Identify local anatomic or pathologic boundaries within the RAR limiting implant placement.* Numerous internal anatomic features of the jaws (eg, nasopalatine fossa and canal, nasal fossa, mental foramen, submandibular gland fossa, inferior alveolar [or mandibular] canal) compromise and limit implant fixture placement or risk involvement of adjacent structures. Anatomic anomalies and local pathologies (eg, retained root tips, sinus disease, or adjacent inflammatory processes) may also prevent or restrict implant placement.

For many years, the information required to satisfy these goals has been obtained from clinical examination and, most commonly, two-dimensional (2D) imaging such as intraoral periapical, lateral cephalometric, and panoramic radiography. Using these imaging modalities, implants have been used predictably and with high success rates in clinical practice for more than 30 years. Because of the additional financial cost and higher patient radiation dose, the decision to use cross-sectional imaging such as tomography, multidetector computed tomography (MDCT), or, most recently, maxillofacial cone beam computed tomography (CBCT) should be based on clear clinical benefits. Since its first description in 1998 by Mozzo and coworkers,[3] CBCT has already become an established diagnostic tool for various dental indications, such as endodontics,[4–6] orthodontics,[7] dental traumatology,[8] apical surgery,[9–12] challenging periodontal bone defects,[13,14] preoperative planning of periodontal surgery,[15,16] forensic odontology,[17,18] and dental implant surgery including bone quality assessment.[1,2,19–22] Even for visualization of the paranasal sinuses, for which conventional computed tomography (CT) is considered to be the diagnostic method of choice,[23] CBCT imaging is becoming increasingly popular.[24,25]

While the selection of an imaging protocol is principally based on the assessment of the surgical and restorative difficulty of the clinical situation and the individual practitioners' preferred pattern of practice, choice should also be influenced by an understanding of the evidence supported by additional clinical benefits and recommendations of representative organizations. It is highly desirable to identify situations where cross-sectional imaging may provide crucial treatment planning information that may not be readily appreciated by clinical examination, dental study model analysis, and conventional imaging alone. This includes the potential need for site preparation and the appropriate selection of implant type and size.

The aim of the present paper is to identify, review, analyze, and summarize available evidence on the use of cross-sectional imaging, specifically CBCT imaging, in pre- and postoperative dental implant therapy in regards to *(1)* currently available use guidelines, *(2)* specific indications and contraindications for use, and *(3)* the associated relative radiation dose risk.

MATERIALS AND METHODS

Overall Search Strategy

A systematic literature review was performed using a PICO (Patient or Population, Intervention, Control or Comparison, Outcome and study types) search strategy[26,27] using the MeSH keywords specific to each focus question (Tables 1 to 3) of English-language publications indexed in the MEDLINE database retrospectively from October 31, 2012. This strategy was further augmented by reference to the bibliographies (or citation lists) of all reports identified by the databases (reference harvesting), hand-searching of journals, as well as publications identified after consultation with the Working Group. In addition, grey literature was identified by group consensus and included for consideration. Grey literature is written material (such as reports, technical reports, working papers, or white papers) from government agencies, professional, business and university bodies, and scientific research groups that is difficult to find via conventional online methods such as PubMed because it is not published commercially or is not generally accessible.

Focus Question 1 and Study Parameters

Do guidelines currently exist for the use of cross-sectional radiography, particularly CBCT imaging, in the pre- and/or postoperative assessment of potential dental implant sites?

Guidelines proposed by recognized international associations, government agencies, professional, business and university bodies, and scientific research groups in the field of implant dentistry were selected as the primary study parameter.

Table 1 Systematic Search Strategy for Focus Question 1

Focus question: Do guidelines currently exist for the use of cross-sectional radiography, particularly CBCT imaging for the pre- and/or postoperative assessment of potential dental implant sites?	
Search strategy	
Population	#1 (position paper[Text Word]) AND (radiology[Text Word]) AND (maxillofacial[Text Word]) OR (oral[Text Word]) AND (implant dent*[Text Word]) #2 (guideline) OR (consensus statement) AND (implant dent*[Text Word]) AND (diagnostic imaging[Text Word])
Intervention or exposure	#3 (cone beam computed tomography) AND (position paper) #4 (patient care planning) AND ("Cone-Beam Computed Tomography/methods"[MeSH]) AND ("Dental Implantation/methods"[MeSH])
Comparison	#5 (position paper) AND (radiology[Text Word]) AND (maxillofacial[Text Word]) AND ("Radiography, Dental/methods"[MeSH]) OR "(Radiography, Dental/utilization"[MeSH]) #6 (position paper) AND (radiology[Text Word]) AND (maxillofacial[Text Word]) AND ("Radiography, Dental/methods"[MeSH]) OR ("Radiography, Dental/utilization"[MeSH])
Outcome	#7 (cone beam computed tomography) AND ("Dental Implantation/methods"[MeSH]) AND (patient care planning)
Search combination	(#1) OR (#2) OR (#3) OR (#4) OR (#5) OR (#6) OR (#7) (position paper[Text Word]) AND (radiology[Text Word]) AND (maxillofacial[Text Word]) OR (oral[Text Word]) AND (implant dent*[Text Word]) OR (guideline) OR (consensus statement) AND (implant dent*[Text Word]) AND (diagnostic imaging[Text Word]) OR (cone beam computed tomography) AND (position paper) OR (patient care planning) AND ("Cone-Beam Computed Tomography/methods"[MeSH]) AND ("Dental Implantation/methods"[MeSH]) OR (position paper) AND (radiology[Text Word]) AND (maxillofacial[Text Word]) AND ("Radiography, Dental/methods"[MeSH]) OR ("Radiography, Dental/utilization"[MeSH]) OR (position paper) AND (radiology[Text Word]) AND (maxillofacial[Text Word]) AND ("Radiography, Dental/methods"[MeSH]) OR ("Radiography, Dental/utilization"[MeSH]) OR (cone beam computed tomography) AND ("Dental Implantation/methods"[MeSH]) AND (patient care planning)
Database search	
Electronic	MEDLINE, Organizational websites (http://ec.europa.eu/index_en.htm, http://www.eadmfr.eu/, http://www.sedentexct.eu/content/national-guidance-cbct, http://www.dgzmk.de/, http://www.health.belgium.be/eportal/index.htm)
Journals	*Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology; Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics; Clinical Oral Implants Research; Implant Dentistry; The International Journal of Oral & Maxillofacial Implants; Clinical Implant Dentistry and Related Research; Journal of Oral Implantology; European Journal of Oral Implantology*
Selection criteria	
Inclusion criteria	Manuscripts published by government agencies, professional, business and university bodies, and scientific research groups only Consensus development conference Guideline Practice guideline Clinical conference
Exclusion criteria	Reviews Engineering, medical (eg, otolaryngologic), dental clinical applications Clinical trials Case reports

Search Strategy

Table 1 provides details of the PICO search strategy, inclusional and exclusional selection criteria, and final electronic and journal database from which the articles were identified. This search strategy was designed for high recall rather than high precision in the first instance. There were no language restrictions.

Study Selection and Quality Assessment Procedures

Since the included publications were all non-interventional (neither randomized or non-randomized controlled trials nor controlled clinical trials) and comprised statements from government agencies or professional organizations, subjective quality assessment according to PRISMA[28] was not performed.

Data Extraction Strategy

Clinical practice guidelines have been defined as "statements that include recommendations intended to optimize patient care that are informed by a systematic review of evidence and an assessment of the benefits and harms of alternative care options" (http://www.iom.edu/Reports/2011/Clinical-Practice-Guidelines-We-Can-Trust.aspx).[29] Guidelines help clinicians translate best evidence into best practice. The hallmark of a clinical practice guideline is methodological rigor. Currently accepted guideline statement standards[29–34] present the following key components[35]:

Background and development: This should include specific descriptions on the scope, overall purpose, and specific objectives, the population to whom the guidelines apply, and features of the development group including potential for bias.

Evidence synthesis and analysis methodology: This includes a description of the methodology used to identify and report the best available research evidence through systematic review, the rigor of the literature review including when applicable the search strategy, grading the quality and strength of the synthesized evidence, and external review.

Key specific action statements: These should be supported with a specific action statement profile clearly summarizing the decision-making process, specific clinical scenario use recommendations, modifications due to patient presentation, risk-benefit assessment, reasons for intentional vagueness, and the role of patient preference.

Applicability: Statements should be included on implementation issues such as when, how, and by whom the recommendations can be put into practice, identifying barriers to implementation including resource and financial constraints, update mechanisms, as well as disclosure of the potential for conflict of interest.

To address focus question 1 in this context, each publication was characterized in regard to type of sponsoring body, type of organization, constituents represented, modalities considered, and method of identification for inclusion. A thorough review and assessment of each paper was performed by the working group members and the structure of each publication analyzed and characterized non-empirically and qualitatively according to compliance to the key elements of accepted guideline statement standards identified above. In addition, three broad categories were identified with respect to level of compliance with these standards and categorized each publication accordingly:

Clinical practice guideline: These publications provide specific evidence-based action statements developed from a rigorous systematic review and grading of the available literature, producing clinically specific action statements.

Clinical guidance statements: These publications provide recommendations that are consensus-based or derived from a limited methodological approach with partial retrieval and/or analysis of the literature.

Clinical practice advice statements: These publications provide relatively ill-defined, generalized, or non-case-specific statements using an ill-defined methodological approach to literature retrieval and/or analysis representing considered professional and/or expert opinion.

Focus Question 2 and Study

Are there specific indications or contraindications for the use of cross-sectional radiography, specifically CBCT imaging for the pre- and/or postoperative assessment of potential dental implant sites?

Clearly specified selection criteria for the use of CBCT imaging in the field of dental implantology were selected as the study parameter, and further grouped into diagnostic indications and contraindications for planning of dental implant insertion and postoperative assessment.

Search Strategy

Table 2 provides details of the PICO search strategy, inclusional and exclusional selection criteria, and final electronic and journal databases from which the articles were identified. In addition, all the relevant clinical guideline publications from the search strategy related to focus question 1 were included for consideration.

Study Selection and Quality Assessment Procedures

All publications identified in focus question 1 were also included. Since these publications were all non-interventional (neither randomized or nonrandomized controlled trails nor controlled clinical trials) and comprised statements from government agencies or professional organizations, subjective quality assessment according to PRISMA[28] was not performed.

Data Extraction Strategy

The specific indications and contraindications of cross-sectional imaging for implant dentistry from the previously identified guideline documents identified in focus question 1 were reviewed and analyzed. In addition, publications identified from the specific search strategy addressing focus question 2 providing direct or indirect support of the statements were extensively reviewed.

Focus Question 3 and Study Parameters

What additional radiation dose risks are associated with the use of cross-sectional radiography, specifically CBCT imaging, for the pre- and/or postoperative assessment of potential dental implant sites compared to other radiographic modalities?

Table 2 Systematic Search Strategy for Focus Question 2	
Focus question: Are there specific indications or contraindications for the use of cross-sectional radiography, specifically CBCT imaging for the pre- and/or postoperative assessment of potential dental implant sites?	
Search strategy	
Population	#1 ("Dental Implantation, Endosseous"[MeSH]) OR ("Dental Implantation"[MeSH]) OR ("Dental Implantation"[MeSH]) OR ("Dental Implantation, Endosseous"[MeSH]) OR ("dental implants"[MeSH Terms]) OR ("dental"[All Fields] AND "implants"[All Fields]) OR ("dental implants"[All Fields])
Intervention or exposure	#2 ("radiography, dental"[MeSH Terms]) OR ("radiography"[All Fields]) AND ("dental"[All Fields]) OR ("dental radiography"[All Fields]) OR ("dental"[All Fields]) AND ("radiography"[All Fields]) OR ("Radiography, Dental, Digital"[MeSH]) OR (cone beam computed tomography[Text Word]) OR (cone beam computed tomography[Text Word]) OR ("Radiography, Dental, Digital"[MeSH]) OR ("radiography, dental"[MeSH Terms]) OR ("radiography"[All Fields] #3 "dental"[All Fields]) OR ("dental radiography"[All Fields] OR ("dental"[All Fields]) AND ("radiography" [All Fields]) OR ("Tomography, X-Ray Computed"[MeSH])
Comparison	#4 "Patient Care Planning"[MeSH]
Outcome	#5 (pre-surgical[All Fields]) OR (post-surgical[All Fields]) OR (post-surgical[Title/Abstract]) OR (post-surgical [All Fields]) OR (pre-surgical[All Fields]) OR ("postoperative period"[MeSH Terms] OR ("postoperative"[All Fields] AND "period"[All Fields]) OR ("postoperative period"[All Fields]) OR ("post"[All Fields]) AND ("operative" [All Fields]) OR ("post operative"[All Fields]) OR (pre-operative[All Fields])
Search combination	#1 AND (#2 OR #3) AND #4 AND #5 ("Dental Implantation, Endosseous"[MeSH]) OR ("Dental Implantation"[MeSH]) AND ("radiography, dental"[MeSH Terms]) OR ("radiography"[All Fields]) AND ("dental"[All Fields]) OR ("dental radiography" [All Fields]) OR ("dental"[All Fields]) AND ("radiography"[All Fields]) OR ("Radiography, Dental, Digital"[MeSH]) OR (cone beam computed tomography[Text Word]) AND ("Patient Care Planning"[MeSH]) OR ("Dental Implantation"[MeSH]) OR ("Dental Implantation, Endosseous"[MeSH]) OR ("dental implants"[MeSH Terms]) OR ("dental"[All Fields] AND "implants"[All Fields]) OR ("dental implants"[All Fields]) AND (cone beam computed tomography[Text Word]) OR ("Radiography, Dental, Digital"[MeSH]) OR ("radiography, dental"[MeSH Terms]) OR ("radiography"[All Fields]) AND ("dental"[All Fields]) OR ("dental radiography"[All Fields]) OR ("dental" [All Fields]) AND ("radiography"[All Fields]) OR ("Tomography, X-Ray Computed"[MeSH]) AND (pre-surgical [All Fields] OR post-surgical[All Fields]) OR (post-surgical[Title/Abstract]) OR (post-surgical[All Fields]) OR (pre-surgical[All Fields]) OR ("postoperative period"[MeSH Terms]) OR ("postoperative"[All Fields]) AND ("period"[All Fields]) OR ("postoperative period"[All Fields]) OR ("post"[All Fields] AND "operative"[All Fields]) OR ("post operative"[All Fields]) OR pre-operative[All Fields]) AND ("Patient Care Planning"[MeSH])
Database search	
Electronic	MEDLINE, Hand search of publication references
Journals	*Dentomaxillofacial Radiology; Journal of Periodontal & Implant Science; The International Journal of Oral & Maxillofacial Implants; Clinical Implant Dentistry and Related Research; Implant Dentistry; European Journal of Oral Implantology; British Dental Journal; Journal of Orofacial Pain; Clinical Oral Implants Research; Implant Dentistry; Indian Journal of Dental Research; International Journal of Prosthodontics; Journal of Periodontology; Journal of Oral Implantology; Journal of Oral and Maxillofacial Surgery; Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology; Journal of Prosthetic Dentistry; Swedish Dental Journal; Fortschritte auf dem Gebiet der Röntgenstrahlen und der bildgebenden Verfahren*
Selection criteria	
Inclusion criteria	Manuscripts included for focus question 1 Studies related to implant dentistry Clinical trials including case series
Exclusion criteria	Studies describing non-implant associated (eg, third molar) use of CBCT Reviews (other than included in focus question 1) Case reports

The specific radiation dose risks associated with the use of cross-sectional imaging, specifically CBCT, as compared to the radiation dose risks of conventional radiographic methods in the field of dental implantology, were selected as the study parameter.

Search Strategy

Table 3 provides details of the PICO search strategy, inclusional and exclusional selection criteria, and final electronic and journal database searches from which the articles were identified.

Table 3 Systematic Search Strategy for Focus Question 3

Focus question:	**What additional radiation dose risks are associated with the use of cross-sectional radiography, specifically CBCT imaging, for the pre-and/or postoperative assessment of potential dental implant sites compared to other radiographic modalities?**
Search strategy	
Population	#1 (Dental Implants[Text Word]) OR ("Dental Implantation, Endosseous"[MeSH]) #2 (dent*)
Intervention or exposure	#3 (Imaging, Three-Dimensional/methods"[MeSH]) OR (cone beam computed tomography[Text Word]) OR ("Cone-Beam Computed Tomography/standards"[MeSH]) OR ("Cone-Beam Computed Tomography/methods"[MeSH]) #4 (CBCT[Title/Abstract]) OR (cone beam computed tomography[Title/Abstract])
Comparison	
Outcome	#5 (radiation dosage) OR ("Radiation Dosage"[MeSH]) #6 (dosimetry[Title/Abstract]) OR (dose[Title/Abstract])
Search combination	(#1 AND #3 AND [#5 Or #6]) OR (#2 AND #4) ("Imaging, Three-Dimensional/methods"[MeSH]) OR (cone beam computed tomography[Text Word]) OR ("Cone-Beam Computed Tomography/standards"[MeSH]) OR ("Cone-Beam Computed Tomography/methods"[MeSH]) AND (Dental Implants[Text Word]) OR ("Dental Implantation, Endosseous"[MeSH]) AND ("Radiation Dosage/standards"[MeSH]) OR (radiation dosage) OR ("Radiation Dosage"[MeSH]) OR (dosimetry[Title/Abstract]) OR (dose[Title/Abstract]) AND (CBCT[Title/Abstract]) OR (cone beam computed tomography[Title/Abstract]) AND (dent*)
Database search	
Electronic	PubMed
Journals	*Dentomaxillofacial Radiology; Journal of Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology; American Journal of Orthodontics and Dentofacial Orthopedics; British Journal of Radiology; European Journal of Radiology; La Radiologia medica; Journal of Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology;Imaging Science in Dentistry*
Selection criteria	
Inclusion criteria	Maxillofacial Effective dose reported ($ICRP_{2007}$)
Exclusion criteria	Reviews Case reports

Study Selection and Quality Assessment Procedures

The Working Group considered only studies that reported effective dose (E), using the most recent published organ weighting factors, referred to as $ICRP_{2007}$, or mean absorbed dose for specific head and neck organs.[36] In $ICRP_{2007}$, the estimated risk weighting factors for specific tissues have been revised, and a number of additional tissues found in the head and neck region are 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 as compared to pre-2007 publications ranging from 32% to 422%[37,38] and therefore the inclusion criteria included only dose literature specifying $ICRP_{2007}$ calculations.

Data Extraction Strategy

Publications reporting $ICRP_{2007}$ effective doses were reviewed, analyzed and specific results summarized in tables.

RESULTS AND DISCUSSION

Focus Question 1

The initial PICO search strategy resulted in identifying 266 published articles dating back to 1967. By applying the inclusional and exclusional criteria, six publications were initially identified. A hand search of relevant references within the bibliographies of the publications identified one additional publication, not revealed by the PICO search. Based on discussions between the working group members, websites of professional dental organizations (specialty, general dental, or multidisciplinary) and government organizations, both national and international, were also searched and a further five "grey literature" publications were found. Thus, twelve publications were identified, providing guidelines for the use of cross-sectional radiography, particularly CBCT imaging, for the pre- and/or postoperative assessment of potential dental implant sites (Table 4).[1,2,39–48]

Table 4 Analysis of Publications Reporting Guidelines for the Use of Cross-Sectional Radiography for the Assessment of Potential Dental Implant Sites

Study	Organization	Representing	Type	Modalities considered CBCT	CST	IO/EO	Source	Comment
Tyndall et al[48]	AAOMR	OMFR, US	PO (S)	+	+	+	PICO	Update of White et al[40]
Harris et al[2]	EAO	Europe	PO (MD)	+	+	+	PICO	Update of Harris et al[1]
DGZMK[47]	DGZMK	German Dent. Association/ German Assoc. for Implantology	PO (MD)	+	+	–	GL	In German
Benavides et al[46]	ICOI	International	PO (MD)	+	+	+	PICO	
SHC[45]	SHC	Belgium Govt.	GA (N)	+	–	–	GL	
EC[44]	EC	EU	GA (I)	+	–	–	GL	SEDENTEXCT guidelines[43] adopted by the EC
SEDENTEXCT[43]	SEDENTEXCT	EADMFR / EU	PO (MD)	+	–	–	GL	Collaboration in response to EU Directives
AO[42]	AO	International	PO (MD)	+	–	–	PICO	Adopted Harris et al[1]
ARö[41]	DGZMK	German Dental Association	PO (G)	+	–	–	GL	In German
Harris et al[1]	EAO	Europe	PO (MD)	–	+	+	PICO	
White et al[40]	AAOMR	OMFR, US	PO (S)	–	+	+	HS	
Tyndall and Brooks[39]	AAOMR	OMFR, US	PO (S)	–	+	+	PICO	

SHC: Superior Health Council; EC: European Commission; SEDENTEXCT: Safety and Efficacy of a New and Emerging Dental X-ray Modality Computer Tomography; AO: Academy of Osseointegration; ARö: Association for Radiology; AAOMR: American Association of Oral and Maxillofacial Radiology; EAO: European Academy of Osseointegration; ICOI: International Congress of Oral Implantologists; DGZMK: German Society of Dental Sciences; OMFR: Oral and Maxillofacial Radiology; EADMFR: European Academy of Dentomaxillofacial Radiology; PO (S): dental professional organization, specialty; PO (G): dental professional organization, general; PO (MD): dental professional organization, multi discipline; GA (I): government agency, international; GA (N): government agency, national; CBCT: maxillofacial cone beam computed tomography; CST: cross-sectional tomography including tomography and multi-detector computed tomography; IO/EO: includes intraoral (eg, periapical, occlusal) and extraoral (eg, panoramic, lateral cephalometric) radiographic techniques; +: included in publication; -: excluded in publication; PICO: PICO search result; HS: hand search; GL: grey literature search result.

Publication dates ranged from 2000 to 2012, with most (9) being published within the last 3 years. The most recent publications presented updates to initial statements made by respective organizations specifically addressing CBCT use for implant dentistry.[2,48] One publication developed by a professional organization[43] was adopted almost in toto by an international government agency.[44] Most reports were from professional organizations (10) with only two publications from government agencies, both of which were European—one being national and the other representing the European Union. Only three publications, all published in 2012, provide CBCT use guidelines in the context of all dental imaging modalities (eg, cross-sectional tomography including tomography and multidetector computed tomography, intraoral [periapical, occlusal], and extraoral [panoramic, lateral cephalometric] radiography).

The authors analyzed each of the identified publications according to the key elements of clinical practice guideline development described above (Table 5). Only three publications satisfy the requirements for the highest level of compliance with currently accepted guideline statement criteria, as clinical practice guidelines. Two of these publications[42,44] adopt the same evidence synthesis methodology and provide the same action statements as the parent publication by the SEDENTEXCT Project.[43] Evidence synthesis in all other publications is poor. However, there appears to be a trend towards reporting more specific action statements in the most recent publications from discipline specific (ie, American Academy of Oral and Maxillofacial Radiology [AAOMR])[48] and multi-discipline (ie, Academy of Osseointegration[42] and European Academy of Osseointegration[2]) dental professional organizations.

Considering the results of the analysis of focus question 1, the authors report that there are currently twelve publications which provide guidelines for the use of cross-sectional radiography, particularly CBCT imaging, in the pre- and/or postoperative assessment of potential dental implant sites. However, in the context of validity, only one publication, the guidelines of the SEDENTEXCT project reprinted by two other

Table 5 Comparison, Analysis, and Classification of Strength of Publications Reporting the Use of Cross-Sectional Radiography

Guideline component		Reference				
Component	Specific element	Tyndall et al[48]	Harris et al[2]	Benavides et al[46]	SHC[45]	EC[44]
Background/ development	Purpose	+++	+++	++	++	Same as reference 43
	Population	+++	+++	++	++	Same as reference 43
	Group features	++	++	+	++	Same as reference 43
Evidence synthesis	Rigor of literature review	+	–	+	Same as reference 43	Same as reference 43
	Methodology	–	–	+	Same as reference 43	Same as reference 43
	Evidence grading	–	–	+	Same as reference 43	Same as reference 43
Action statements	Prescription	+++	++	++	+	Same as reference 43
	Modification	+++	++	++	+	Same as reference 43
	Risk/benefit	++	++	++	Same as reference 43	Same as reference 43
Applicability	Implementation	+	–	–	–	Same as reference 43
	COI	–	–	–	Same as reference 43	Same as reference 43
Publication Classification		CGS	CPA	CGS	CPA	CPG

CPG: clinical practice guideline; CGS: clinical guidance statement; CPA: clinical practice advice
–: the element is not reported, +, ++, and +++: weak, moderate, or strong scientific rigor, with +++ being the highest score.

organizations, complies with standards for evidence synthesis.[43] However, the publication which provides the strongest action statements is the publication by the AAOMR.[48] There is a clear need for guidelines that provide strong action statements based on a rigorous methodologic review of the evidence.

Focus Question 2

The initial PICO search strategy identified 694 published articles dating back to 1969. By applying the inclusion and exclusion criteria, the authors initially identified 43 publications.[49–92] A hand search of relevant references within the bibliographies of the publications identified 12 additional publications, not revealed by the PICO search.[93–104] One additional "grey literature" publication was found.[105]

Publications identified by the PICO strategy (43), hand (12), and "grey literature" searches (1) were either cohort or case-controlled studies. Table 6 provides a summary of recommended imaging modalities with emphasis on cross-sectional and CBCT imaging according to stage of implant therapy and clinical situation.

Before the advent of CBCT use for implant dentistry, the AAOMR was the first professional dental organization to provide specific recommendations for cross-sectional imaging in implant dentistry.[39] Simply stated, they indicated that "…any potential implant site includes cross-sectional imaging orthogonal to the site of interest." Choice of imaging modality was determined by the potential number of implant sites, if bone grafts were considered, or if complex trauma was present. Tomography was recommended for patients presenting with less than eight sites, whereas multidetector computed tomography (MDCT) was recommended for patients with greater than eight to ten sites. However, they acknowledged that, "…currently there is no published evidence to support the position that some form of cross-sectional imaging should be a part of implant site assessment..."

A second report from the AAOMR by White and coworkers addressed imaging for a variety of clinical situations including implant placement.[40] The authors reaffirmed the position of the AAOMR proposing cross-sectional imaging for all potential implant sites by indicating that "cross-sectional information con-

Reference						
SEDENTEXCT[43]	AO[42]	ARö[41]	Harris et al[1]	White et al[40]	Tyndall and Brooks[39]	DGZMK[47]
+++	Same as reference 43	+	++	++	++	++
+++	Same as reference 43	+	++	+	–	++
+++	Same as reference 43	++	++	+	+	++
+++	Same as reference 43	–	–	–	+	++
+++	Same as reference 43	+	–	+	–	++
+++	Same as reference 43	–	–	–	–	–
++	Same as reference 43	–	+	+	+	++
++	Same as reference 43	–	++	+	++	+
++	Same as reference 43	–	++	+	++	+
++	Same as reference 43	–	+	+	+	+
–	Same as reference 43	–	–	–	–	—
CPG	CPG	CPA	CGS	CPA	CPA	

cerning a qualitative and quantitative assessment of preoperative implant site bone is now readily achievable and needed. Such information is essential for optimum implant selection…" Furthermore, they stated "panoramic imaging alone is not sufficient to provide all of the necessary information described earlier for optimum implant selection and should be augmented with tomography." In addition, they provided specific indications for MDCT.

The European Association for Osseointegration (EAO) held a consensus workshop to provide recommendations for imaging in various clinical situations published in 2002.[1] They presented their findings as answers to a series of focus questions. While the EAO made no specific mention of CBCT, they made a number of key points in relation to the use of cross-sectional imaging (at that time, spiral tomography and MDCT): *(1)* Clinicians should decide if a patient requires cross-sectional imaging on the basis of the clinical examination, the treatment requirements, and information obtained from standard imaging modalities (ie, combinations of conventional dental images); *(2)* the technique chosen should provide the required diagnostic information with the least radiation exposure to the patient; and *(3)* cross-sectional imaging be used in situations where more information is required after appropriate clinical examination and standard radiographic techniques. The specific clinical situations that could potentially benefit from cross-sectional imaging were subjective in nature. Essentially, they were defined as when there was a possibility of implant intrusion on anatomic structures (eg, incisive canal, maxillary sinus, mandibular canal) or doubt (based on clinical or interpretation of standard radiographic procedures) in the amount of adequate bone volume or shape of alveolar ridge. In addition, the authors of this publication were the first to suggest that cross-sectional imaging not be part of a "routine protocol" for postoperative examinations "unless there is a need for assessments in situations where some kind of complications have occurred, such as nerve damage or postoperative infections in relation to nasal and/or sinus cavities close to implants".

The Working Group for Radiology of Germany (ARö) convened an expert group to provide the dental profession in Germany with general guidelines for the use

Table 6 Analysis of Publications Reporting Guidelines and Specific Indications and/or Contraindications for the Use of Cross-Sectional Radiography for the Assessment of Potential Dental Implant Sites

Clinical situation	Specific indication(s)
Initial examination	
Preoperative	
All sites	
Clinical doubt of alveolar bone height, width and/or shape	
Bone density evaluation	
Specific anatomic sites	Anterior maxilla (nasal floor, naso-palatine canal, anterior superior alveolar canal) Posterior maxilla (maxillary sinus and related structures, posterior superior alveolar canal, maxillary tuberosity, pterygoid plates Anterior mandible (lingual foramen, incisive canal, genial tubercles) Posterior mandible (inferior alveolar nerve canal, mental foramina, anterior loop, retromolar foramen, sublingual fossa [lingual undercut], mylohyoid undercut, lingula of ascending ramus) Zygomatic region (orbital floor, infraorbital foramen, zygomatic bone)
Anterior aesthetic zone	
Site development	Sinus augmentation Block or particulate bone grafting Ramus or symphysis grafting Pathology/impacted teeth in field of interest Prior traumatic injury
Computer-assisted treatment planning, treatment options, optimal implant position	
Postoperative	
Integration	Marginal peri-implant bone height Bone-implant interface Postaugmentation assessment (eg, sinus, particulate/block)
Postoperative complications	Altered sensation Infection/postoperative integration failure Implant mobility Rhino-sinusitis

Pa: intraoral periapical radiograph; Pan: panoramic radiography.
*Papers included from Focus Question 1.
**Papers included from Pico strategy, hand search, and grey literature search (Focus Question 2).

of CBCT in various clinical situations.[41] In a small section on implant dentistry, the authors provided only two recommendations: *(1)* that "a computer-aided planning on the basis of three-dimensional radiograph procedure should be performed with the help of CBCT," and *(2)* "that because of beam hardening artifacts, the assessment of bone in the immediate peri-implant region as well as the region between adjacent implants is limited." As a follow-up publication, the proceedings of different dental associations of Germany from a consensus meeting in 2010 were published by the Deutsche Gesellschaft für Zahn-, Mund- und Kieferheikunde (DGZMK)[47] focusing on indications for three-dimensional diagnosis and treatment planning for dental implants and guided surgery. The group based their recommendations on a systematic literature search, although the selected papers were not presented or discussed.

The Academy of Osseointegration (AO) provided an update on general clinical guidelines on the provision of dental implants[42] initially published in 2008[106] based on a 2006 consensus conference.[107] For implant dentistry, the AO adopted the indications for the use of CT imaging proposed by the EAO[1] and recommended that for CBCT use members review the provisional specific guidelines promulgated by the SEDENTEXCT

Modality Recommendations According to Reference*			
Pa	Pan	Cross-sectional (inc. MDCT)	CBCT
1*, 2*, 39*, 40*, 47*, 48*	1*, 2*, 39*, 40*, 47*, 48*		
		39*, 40*, 48*	39*, 45*, 48*
		1*, 2*, 47*, 50**, 52**	2*, 41*, 42*, 43*, 44*, 46*, 47*
1*	1*		42*, 43*, 44*, 46*, 77**
		1*, 2*	2*, 42*, 43*, 44*, 46*, 61**, 79**, 87**, 95**, 96**, 100**, 103**
		1*, 2*, 47*	2*, 42*, 43*, 44*, 46*, 47*, 97**, 101**, 105**
		1*, 2*	2*, 42*, 43*, 44*, 46*, 84**, 93**, 94**, 98**
	49**, 67**, 104**	1*, 2*, 47*, 55**, 56**, 57**, 62**,64**	2*, 42*, 43*, 44*, 46*, 47*, 68**, 70**, 71**, 74**, 81**, 82**, 89**, 92**, 94**, 98**, 99**, 102**
		1*, 2*, 76**	2*, 46*
		1*	46*, 90**
		1*, 2*, 47*, 48*	1*, 41*, 46*, 47*, 48*, 82**
		1*, 2*, 39*, 40*, 48*	2*, 41*, 46*, 48*
		1*, 2*, 48*	2*, 48*
		47*	46*, 47*, 48*
		39*, 40*	46*, 48*
		47*, 51**, 53**, 54**, 58**, 59**, 60**, 63**, 65**	2*, 36, 41*, 42*, 43*, 44*, 46*, 47*, 48*, 69**, 72**, 73**, 80**, 88**, 90**
48*			
48*			
			46*, 48*, 82**, 83**
		1*, 2*, 47*, 48*, 66**	2*, 46*, 47*, 48*, 75**, 78**, 86**, 91**
		1*, 2*, 48*	2*, 46*, 48*
			48*
		1*	46*

group at that time—a document that has been revised and accepted[43] and subsequently adopted by the European Commission (EC).[44] In addition, they indicated that large field of view images should not be routinely used.

The SEDENTEXCT Project was a funded collaborative European Atomic Energy Community (EURATOM) project of dentists, dento-maxillofacial radiologists, imaging technologists, medical physicists, and equipment manufacturers from within Europe under directives from the European Commission.[43] It is the only funded group that has developed CBCT use guidelines. The report includes all aspects of CBCT use with a specific section on implant dentistry. The analysis of the literature was performed with moderate methodologic rigor; however, as the literature available for formal review was limited in quantity, the Guideline Development Panel (GDP) also reviewed case reports/series and non-systematic reviews. The GDP did not develop new clinically-based use criteria, however, and accepted the EAO guidelines for cross-sectional imaging[1] as equivalent for CBCT imaging. This group made two specific recommendations: "that CBCT could be considered as an alternate to existing cross-sectional techniques when the radiation dose was lower" and that "CBCT provides advantages to MDCT because of adjustable fields of view reduce radiation dose detriment." In addition they were the first to report uncertainty on the validity and reliability of CBCT bone density measurements as an index of bone quality. These findings were corroborated by a recent study that was evaluating the variability of intensity values in CBCT imaging compared with multislice computed tomography (MSCT) HU units in order to assess the reliability of density assessments in jawbone phantoms.[21] The authors concluded that the use of intensity values in CBCT images is not reliable, because these values are influenced by device, imaging parameters, and positioning.

The publication by the Superior Health Authority (SHA) of Belgium is the only national government professional organization to provide specific guidelines and indications for the use of CBCT with a specific reference to implant dentistry.[45] The working group comprised experts in dentistry, oral and maxillofacial surgery, radiology, medical physics, and radiation protection. This group acknowledged basing their guideline on expert consensus as well as the scientific literature identified by the SEDENTEXCT Project.[43] The SHA provide only one statement regarding the use of CBCT for dental implants "... if 2D images do not provide sufficient information, a dental CBCT image can be made of the dental and maxillofacial region by experienced operators for diagnostic purposes and/or preoperative surgical planning in the event of ... preoperative planning for ... and the placing of implants". The working group did apply the caveat that use was predicated on compliance with the principles of radiation protection "... especially by adjusting the size of the field to the indication, selecting the mA(s) settings according to individual cases and potentially adapting other optimization means ..."

Benavides et al[46] reported the consensus findings from a multi-disciplinary international professional organization concerned with dental implantology. They stated that based on their literature review and expert opinion, "... it is virtually impossible to predict which treatment cases would not benefit from having this (CBCT) additional information before obtaining it" and suggested that CBCT should be considered as an imaging alternative: *(1)* "in cases where the projected implant receptor or bone augmentation site(s) are suspect", and *(2)* when "conventional radiography may not be able to assess the true regional three-dimensional anatomical presentation." In regards to situations in which CBCT was considered as superior to conventional radiography, the group cited five specific indications including computer-aided implant planning cases, anterior esthetic zone or regions of suspicious anatomy (eg, concavities, ridge inclination, inadequate bone volume), pre- and post-bone graft evaluation, history of suspected trauma to the jaws, and evaluation of post-implant complications (postoperative neurosensory impairment, osteomyelitis, acute rhino-sinusitis). They indicated that future research was needed in the areas of CBCT-derived bone density measurements (as first identified by the SEDENTEXCT Project),[43] CBCT-aided surgical navigation, and post-implant CBCT artifacts.

Harris and coworkers in 2012 reported on a follow up EAO consensus workshop 10 years after the original workshop in 2002.[2] The workshop was closed and included European experts in both clinical practice and radiology on the basis of their established scientific contributions to the field, specialist knowledge, significant clinical experience, and relevant activities in their academic institutions. The consensus group stated that cross-sectional imaging is not indicated for situations, "if the clinical assessment of implant sites indicates that there is sufficient bone width and the conventional radiographic examination reveals the relevant anatomical boundaries and adequate bone height and space". The group made general and specific recommendations for cross-sectional imaging (including CBCT) for implant site assessment and treatment planning. Generally, cross-sectional imaging was recommended when clinical examination and conventional radiography have failed to adequately demonstrate relevant anatomical boundaries or the location of important anatomical structures. More specifically, imaging was deemed appropriate in cases where extensive bone augmentation is anticipated, for all sinus augmentation and guided surgery cases, in some instances for autogenous bone donor sites and special techniques (eg, zygomatic implants and osteogenic distraction) and possibly in some cases presenting with postoperative complications (eg, nerve damage or infection).

In 2012, the AAOMR produced literature based, consensus-derived, clinical guidance recommendations for overall imaging approaches in implant dentistry with emphasis on CBCT technology[48] as an update to their report twelve years earlier.[39] Eleven specific action statements are provided within each phase of implant therapy including initial assessment (three statements), preoperative site specific imaging (four statements), and postoperative imaging (four statements). Recommendation 4 and 5 together form the basis of the report and state that "... radiographic examination of any potential implant site should include cross-sectional imaging ..." and "CBCT should be considered as the imaging modality of choice for preoperative cross-sectional imaging ..." They also provide specific action statements in that initial imaging should comprise panoramic and intra-oral radiography only (recommendations 1, 2, and 3), CBCT should be considered prior to and after clinical conditions indicating a need for bone augmentation or site development (recommendations 6 and 7), and CBCT postoperative use be restricted to situations where implant retrieval is anticipated or if the patient presents with implant mobility or altered sensation.

The literature results from the PICO, hand, and grey literature searches provide specific evidence in support of many of the recommendations described above: numerous authors have described the importance of various anatomic structures identified on cross-sectional imaging[71] including the inferior alveolar (mandibular) canal,[55,57,68,70,102] anterior loop and mandibular incisive canal,[89,93] mental foramen,[56,64,92,99] lingual canal,[84,98] submandibular gland fossa/lingual undercut,[74,94,100] maxillary incisive/nasopalatine canal,[61,79,87,95] and maxillary sinus,[62,81,82,97,101,105] and highlight the variability of imaging identification and characteristics of these structures in relation to implant placement. In addition, the value of cross-sectional imaging in treatment planning of sinus augmentation procedures has been reported.[85]

Many authors have reported on the improved clinical efficacy of cross-sectional imaging and, more recently CBCT, as compared with standard radiographic techniques to facilitate the evaluation of implant sites,[50,52] in achieving an ideal position of dental implants as compared to conventional techniques[88,90] particularly in the mandible[53,59] or influencing treatment options such as choice and placement of implants in edentulous regions of the jaws[51,54,58,60,63,65,69,72,73,80] as well as the zygomatic arch.[76] However, some authors have demonstrated that clinical examination and panoramic radiography alone may provide sufficient imaging for posterior mandibular implant placement,[49,104] especially when there is a 2-mm margin of safety above the inferior alveolar canal.[67]

Placement of dental implants is an important cause of iatrogenic inferior alveolar nerve injuries.[66,86] Overall, implant cases only account for 3% of all reported postsurgical neurosensory disturbances.[108] But when focusing on permanent neurosensory disturbances, the contribution of implant placement is four-fold (12% of injuries).[108] Overall, the incidence of neuropathic orofacial pain following implant placement varies from 0% to 24% for transient and 0% to 11% for permanent damage, depending on the anatomical area, the presurgical planning, the surgical act, and the postoperative neurosensory evaluation method.[109] Recently some authors have correlated post-implant mandibular nerve neuropathy with preoperative imaging. Renton and coworkers reported that of 30 patients with implant placement related permanent neuropathy of the inferior alveolar nerve (IAN),[91] CBCT preoperative imaging was associated with only 10%, whereas the remaining patients had only intraoral images (30%), panoramic radiography (50%), and long cone periapical radiography (48%). CBCT imaging has been reported to be of value in assessment of IAN risk injury in regard to immediate implant placement at premolar and first molar sites in the posterior mandible[78] and, together with surgical guides, in reducing immediate postoperative complications.[75]

Besides neurosensory disturbances, neurovascular complications due to implant surgery can also result in severe intraoral hemorrhage. Significant hemorrhages are mostly described after anterior mandibular implant placement, and sinus augmentation prior to or with implant placement. For mandibular implant placement, there are 19 case reports related to hemorrhage in the floor of the mouth and potentially life-threatening upper airway obstruction (see Jacobs et al).[109] Significant bleeding may also occur during sinus augmentation procedures. Because of its location in the lateral sinus wall, the intraosseous artery has the potential to cause bleeding complications in lateral window osteotomies.[110] Nevertheless, it has to be stated that it will be difficult to prove a clear benefit of CBCT over conventional two-dimensional imaging such as panoramic radiography with respect to damage of the IAN or other vital neurovascular structures in prospective studies. Recently, a study calculated patient sample sizes ranging from 39,584 to 245,724, or 140,024 to 869,250 of mandibular third molar removals needed, ideally performed by only one or two surgeons, to prove a potential benefit from presurgical CBCT scans, with respect to the most important outcome parameter of reduced damage to the IAN.[111]

There are limited studies suggesting good correlation in the use of CBCT density values to monitor ossification of sinus augmentation material[83] and cancellous bone.[77]

Focus Question 3

The PICO search identified 121 publications. After screening of the abstracts (50) and full text articles (28), and hand searching (2), a total of 22 articles were included.[37,38,112–131] Table 7 provides the results of this literature search, providing a summary of the current evidence on effective dose ($ICRP_{2007}$)[36] or mean absorbed dose for specific organs for cross-sectional and conventional imaging classified as to the dose measurement reported; the purpose of the study, whether general dose information or specifically related to implant dentistry; and the type and number of devices examined. Only two articles specifically reported effective doses for the use of CBCT imaging in oral implantology,[117,118] and one reported dose-area products for two CBCT devices in two diagnostic tasks (periapical diagnosis and implant planning).[124] Most articles reported on measured effective doses in the context of general maxillofacial imaging.

Table 7 Summary of Current Evidence on Effective Dose ($ICRP_{2007}$) or Organ-Specific Mean Absorbed Dose for CBCT

			Application				Modality examined (No. of devices studied)		
Study	Year	Measurement	Implant	General	Ortho	Other	CBCT	MSCT	Pan
Ludlow et al*[37]	2006	E		+			3		
Ludlow and Ivanovic[38]	2008	E		+			8	1	
Silva et al[112]	2008	E			+		3	1	
Hirsch et al[113]	2008	E		+			2		
Palomo et al[114]	2008	E		+			1		
Lofthag-Hansen et al[115]	2008	E		+			2		
Roberts et al[116]	2009	E		+			1		
Loubele et al[117]	2009	E	+				3	2	
Okano et al[118]	2009	E	+				3	1	
Suomalainen et al[†119]	2009	E		+			3	2	
Qu et al[120]	2010	E		+			1		
Carrafiello et al[121]	2010	E		+			1	1	1
Librizzi et al[‡122]	2011	E				+	1		
Ludlow[123]	2011	E		+			1		
Lofthag-Hansen et al[124]	2011	DAP	+			+	2		
Theodorakou et al[125]	2012	E		+			5		
Davies et al[126]	2012	E		+			1		
Pauwels et al[127]	2012	E		+			12		
Grünheid et al[128]	2012	E			+		1		1
Qu et al[129]	2012	E		+			1		
Koivisto et al[130]	2012	E		+			1		
Jeong et al[131]	2012	E		+			3	1	

CBCT: cone beam computed tomography; Ortho: orthodontics; MDCT: multi-detector computed tomography; Pan: panoramic radiography; E: effective dose using $ICRP_{2007}$ calculations; DAP: dose-area product.
*Individual organs were summed using 1990 and proposed 2005 ICRP tissue-weighting factors.
†One of five studies published and summarized in the academic dissertation: Kiljunen T. Patient dose in CT, dental cone beam CT and projection radiography in Finland, with emphasis on pediatric patients. STUK / Radiation and Nuclear Safety Authority. Helsinki, Finland, 2008.
‡Application of CBCT in this study for imaging of the temporomandibular joint.

Table 8 provides the radiation effective dose (based on $ICRP_{2007}$)[36] measured in µSv for specific CBCT equipment and conventional radiographic techniques. CBCT devices were grouped according to their FOV, resulting in three categories: CBCT devices with small (< 40 cm^2), medium (40 to 100 cm^2), and large (> 100 cm^2) FOVs. Reported dose-area products (DAPs) were converted using specific publications.[132,133] When looking at the reported effective dose ranges for all three groups, there is a wide range of doses ranging from 11 to 252 µSv for small, from 28 to 652 µSv for medium, and from 52 to 1,073 µSv for large. Although Table 8 lists a wide variety of doses for a wide variety of indications with many different CBCT machines, it is obvious that dose values reported in various studies are not always comparable in absolute terms, as thermoluminescent dosimeter (TLD) calibration, TLD positioning, number of TLDs (per organ), organs measured, phantom characteristics, and exposure conditions may easily yield differences in organ doses of greater than 80%.[127]

Table 8 Published Effective Doses (µSv) ($ICRP_{2007}$) for Small, Medium, and Large FOV CBCT in Comparison to MSCT, Panoramic, and Cephalometric Radiography

Study	Publication year	CBCT unit specification	Scanning characteristics (machine dependent)	Adult / adolescent/ child protocol	Effective dose (µSv)
CBCT: Dentoalveolar small (< 40 cm²)					
Lofthag-Hansen et al[115]	2008	3D Accuitomo IID	3 × 4 cm² 3–6.5 mA	Adult	11–27*
Suomalainen et al[119]	2009	3D Accuitomo IID	3 × 4 cm²	Adult	27
Loubele et al[117]	2009	3D Accuitomo IID	3 × 4 cm²	Adult	29
Lofthag-Hansen et al[124]	2011	3D Accuitomo IID	3 × 4 cm² 4–6 mA	Adult	29–48†
Lofthag-Hansen et al[124]	2011	3D Accuitomo IID	3 × 4 cm² IQ sufficient-better for implant planning	Adult	15–81†
Hirsch et al[113]	2008	3D Accuitomo FPD	4 × 4 cm²	Adult	20
Lofthag-Hansen et al[115]	2008	3D Accuitomo FPD	4 × 4 cm² 4–6 mA	Adult	21–31*
Okano et al[118]	2009	3D Accuitomo FPD	4 × 4 cm²	Adult	102
Lofthag-Hansen et al[124]	2011	3D Accuitomo FPD	4 × 4 cm² 4–6 mA	Adult	41–69†
Lofthag-Hansen et al[124]	2011	3D Accuitomo FPD	4 × 4 cm² IQ sufficient-better for implant planning	Adult	21–116†
Hirsch et al[113]	2008	3D Accuitomo FPD	6 × 6 cm²	Adult	43
Lofthag-Hansen et al[115]	2008	3D Accuitomo FPD	6 × 6 cm² 4.5–6 mA	Adult	52–77*
Suomalainen et al[119]	2009	3D Accuitomo FPD	6 × 6 cm²	Adult	166
Okano et al[118]	2009	3D Accuitomo FPD	6 × 6 cm²	Adult	50
Lofthag-Hansen et al[124]	2011	3D Accuitomo FPD	6 × 6 cm² 4–6 mA	Adult	90–151†
Lofthag-Hansen et al[124]	2011	3D Accuitomo FPD	6 × 6 cm² IQ sufficient-better for implant planning	Adult	46–252†
Theodorakou et al[125]	2012	3D Accuitomo 170	4 × 4 cm² lower molars	10 y old	28
Theodorakou et al[125]	2012	3D Accuitomo 170	4 × 4 cm² lower molars	Adolescent	32
Pauwels et al[127]	2012	3D Accuitomo 170	4 × 4 cm²	Adult	43
Hirsch et al[113]	2008	Veraviewepocs 3D	4 × 4 cm² / 4 × 4 cm² + pano	Adult	31/30
Hirsch et al[113]	2008	Veraviewepocs 3D	8 × 4 cm² / 6 × 6 cm²	Adult	40/40
Pauwels et al[127]	2012	Kodak 9000 3D	5 × 3.7 cm² lower molars	Adult	40
Theodorakou et al[125]	2012	Kodak 9000 3D	5 × 3.7 cm² upper front	10 y old	16
Theodorakou et al[125]	2012	Kodak 9000 3D	5 × 3.7 cm² lower molars	Adolescent	24
Pauwels et al[127]	2012	Kodak 9000 3D	5 × 3.7 cm² upper front	Adult	19
Pauwels et al[127]	2012	Kodak 9000 3D	5 × 3.7 cm² lower molars	Adult	40
Pauwels et al[127]	2012	Pax-Uni3D	5 × 5 cm² upper front	Adult	44
Suomalainen et al[119]	2009	Scanora 3D	6 × 6 cm²	Adult	91
Jeong et al[131]	2012	Implagraphy	8 × 5 cm²	Adult	83
CBCT: Dentoalveolar medium (40–100 cm²)					
Jeong et al[131]	2012	3DeXAM	10 × 5 cm² LJ	Adult	111
Pauwels et al[127]	2012	3D Accuitomo 170	10 × 5 cm² UJ	Adult	54
Jeong et al[131]	2012	AZ3000CT	7.9 × 7.1 cm²	Adult	333
Ludlow and Ivanovic[38]	2008	Prexion 3D	8.1 × 7.6 cm² standard/HR	Adult	189/388
Ludlow and Ivanovic[38]	2008	Promax 3D	8 × 8 cm² low/high dose	Adult	488/652

Table 8 *continued* **Published Effective Doses (μSv) ($ICRP_{2007}$) for Small, Medium, and Large FOV CBCT in Comparison to MSCT, Panoramic, and Cephalometric Radiography**

Study	Publication year	CBCT unit specification	Scanning characteristics (machine dependent)	Adult / adolescent/ child protocol	Effective dose (μSv)
Suomalainen et al[119]	2009	Promax 3D	8 × 8 cm²	Adult	674
Qu et al[129]	2012	Promax 3D	8 × 8 cm² low/high dose/standard	Adult	30/306/197
Theodorakou et al[125]	2012	Promax 3D	8 × 8 cm² low dose	10 y old	28
Theodorakou et al[125]	2012	Promax 3D	8 × 8 cm² low dose	Adolescent	18
Koivisto et al[130]	2012	Promax 3D	8 × 8 cm²	Adult	153
Pauwels et al[127]	2012	Promax 3D	8 × 8 cm² low/high dose	Adult	28/122
Pauwels et al[127]	2012	Veraviewepocs 3D	8 × 8 cm²	Adult	73
Theodorakou et al[125]	2012	Scanora 3D	10 × 7.5 cm²	10 y old	67
Theodorakou et al[125]	2012	Scanora 3D	10 × 7.5 cm²	Adolescent	52
Pauwels et al[127]	2012	Scanora 3D	10 × 7.5 cm² UJ/LJ/UJ+LJ	Adult	46/47/45
Ludlow[123]	2011	Kodak 9500	5 × 15 cm² without/with filtration	Adult	93/76
Ludlow[123]	2011	Kodak 9500	9 × 15 cm² without/with filtration	Adult	163/98
Pauwels et al[127]	2012	Kodak 9500	9 × 15 cm²	Adult	92
Pauwels et al[127]	2012	Picasso Trio	12 × 7 cm² low/high dose	Adult	81/123
Pauwels et al[127]	2012	NewTom VGi	12 × 8 cm² high dose	Adult	265
Theodorakou et al[125]	2012	3D Accuitomo 170	14 × 5 cm² UJ	10 y old	214
Theodorakou et al[125]	2012	3D Accuitomo 170	14 × 5 cm² UJ	Adolescent	70
Roberts et al[116]	2009	i-CAT classic	16 × 6 cm² standard/HR	Adult	59/93
Roberts et al[116]	2009	i-CAT classic	16 × 6 cm² standard/HR	Adult	96/189
Theodorakou et al[125]	2012	i-Cat Next Generation	16 × 6 cm² LJ/UJ	10 y old	63/43
Theodorakou et al[125]	2012	i-Cat Next Generation	16 × 6 cm² LJ/UJ	Adolescent	49/33
Ludlow and Ivanovic[38]	2008	i-Cat Next Generation	16 × 6 cm²	Adult	74
Davies et al[126]	2012	i-Cat Next Generation	16 × 6 cm² LJ low/high dose	Adult	58/113
Davies et al[126]	2012	i-Cat Next Generation	16 × 6 cm² UJ low/high dose	Adult	32/60
Pauwels et al[127]	2012	i-Cat Next Generation	16 × 6 cm² LJ low dose	Adult	45
CBCT: Craniofacial (> 100 cm²)					
Ludlow et al[37]	2006	CB Mercuray	10 × 10 cm²	Adult	283
Ludlow and Ivanovic[38]	2008	CB Mercuray	10 × 10 cm²	Adult	407
Palomo et al[114]	2008	CB Mercuray	10 × 10 cm²	Adult	603
Librizzi et al[122]	2011	CB Mercuray	10 × 10 cm² TMJ imaging	Adult	283
Theodorakou et al[125]	2012	3D Accuitomo 170	14 × 10 cm²	10 y old	237
Theodorakou et al[125]	2012	3D Accuitomo 170	14 × 10 cm²	Adolescent	188
Theodorakou et al[125]	2012	Scanora 3D	14.5 × 13.5 cm²	10 y old	85
Theodorakou et al[125]	2012	Scanora 3D	14.5 × 13.5 cm²	Adolescent	74
Pauwels et al[127]	2012	Scanora 3D	14.5 × 13.5 cm²	Adult	68
Theodorakou et al[125]	2012	NewTom VG	15 × 11 cm²	10 y old	114
Theodorakou et al[125]	2012	NewTom VG	15 × 11 cm²	Adolescent	81

Table 8 *continued* **Published Effective Doses (μSv) ($ICRP_{2007}$) for Small, Medium, and Large FOV CBCT in Comparison to MSCT, Panoramic, and Cephalometric Radiography**

Study	Publication year	CBCT unit specification	Scanning characteristics (machine dependent)	Adult / adolescent/ child protocol	Effective dose (μSv)
Pauwels et al[127]	2012	NewTom VG	15 × 11 cm²	Adult	83
Silva et al[112]	2008	NewTom 9000	15 × 15 cm²	Adult	56
Qu et al[129]	2012	NewTom 9000	15 × 15 cm² with/without thyroid shielding	Adult	79/95
Ludlow et al[37]	2006	NewTom 9000	15 × 15 cm²	Adult	52 recalculated
Loubele et al[117]	2009	NewTom 3G	15 × 15 cm²	Adult	57
Pauwels et al[127]	2012	NewTom VGi	15 × 15 cm²	Adult	194
Ludlow and Ivanovic[38]	2008	Galileos	15 × 15 cm² low/high dose	Adult	70/128
Theodorakou et al[125]	2012	Galileos comfort	15 × 15 cm²	10 y old	70
Theodorakou et al[125]	2012	Galileos comfort	15 × 15 cm²	Adolescent	71
Pauwels et al[127]	2012	Galileos comfort	15 × 15 cm²	Adult	84
Ludlow et al[37]	2006	CB Mercuray	15 × 15 cm²	Adult	436
Ludlow and Ivanovic[38]	2008	CB Mercuray	15 × 15 cm²	Adult	569
Palomo et al[114]	2008	CB Mercuray	15 × 15 cm²	Adult	680
Okano et al[118]	2009	CB Mercuray	15 × 15 cm²	Adult	511
Librizzi et al[122]	2011	CB Mercuray	15 × 15 cm² TMJ imaging	Adult	436
Silva et al[112]	2008	i-CAT Classic	16 × 13 cm²	Adult	61
Ludlow et al[37]	2006	i-CAT Classic	16 × 13 cm²	Adult	105
Roberts et al[116]	2009	i-CAT Classic	16 × 13 cm²	Adult	134
Ludlow and Ivanovic[38]	2008	i-CAT Classic	16 × 13 cm²	Adult	69
Ludlow and Ivanovic[38]	2008	i-CAT Next Generation	16 × 13 cm²	Adult	87
Theodorakou et al[125]	2012	i-CAT Next Generation	16 × 13 cm²	10 y old	134
Theodorakou et al[125]	2012	i-CAT Next Generation	16 × 13 cm²	Adolescent	82
Pauwels et al[127]	2012	i-CAT Next Generation	16 × 13 cm²	Adult	83
Davies et al[126]	2012	i-CAT Next Generation	16 × 13 cm²	Adult	77
Theodorakou et al[125]	2012	3D Accuitomo 170	17 × 12 cm²	10 y old	282
Theodorakou et al[125]	2012	3D Accuitomo 170	17 × 12 cm²	Adolescent	216
Theodorakou et al[125]	2012	Skyview 3D	17 × 17 cm²	10 y old	105
Theodorakou et al[125]	2012	Skyview 3D	17 × 17 cm²	Adolescent	90
Pauwels et al[127]	2012	Skyview 3D	17 × 17 cm²	Adult	87
Ludlow et al[37]	2006	i-CAT Classic	16 × 22 cm²	Adult	193
Loubele et al[117]	2009	i-CAT Classic	16 × 22 cm²	Adult	82
Roberts et al[116]	2009	i-CAT Classic	16 × 22 cm²	Adult	206
Carrafiello et al[121]	2010	i-CAT Classic	16 × 22 cm²	Adult	110
Grünheid et al[128]	2012	i-CAT Classic	16 × 22 cm² LR	Adult	65–69
Grünheid et al[128]	2012	i-CAT Classic	16 × 22 cm² HR	Adult	127–131
Ludlow[123]	2011	Kodak 9500	18 × 20 cm² without/ with filtration	Adult	260/166

Table 8 *continued* **Published Effective Doses (μSv) ($ICRP_{2007}$) for Small, Medium, and Large FOV CBCT in Comparison to MSCT, Panoramic, and Cephalometric Radiography**

Study	Publication year	CBCT unit specification	Scanning characteristics (machine dependent)	Adult / adolescent/ child protocol	Effective dose (μSv)
Pauwels et al[127]	2012	Kodak 9500	18 × 20 cm²	Adult	136
Ludlow and Ivanovic[38]	2008	ILUMA	19 × 19 cm² standard/HR	Adult	98/498
Ludlow et al[37]	2006	CB Mercuray	20 × 20 cm² standard/HR	Adult	558/1025
Palomo et al[114]	2008	CB Mercuray	20 × 20 cm²	Adult	761
Ludlow and Ivanovic[38]	2008	CB Mercuray	20 × 20 cm²	Adult	1073
Librizzi et al[122]	2011	CB Mercuray	20 × 20 cm² TMJ imaging	Adult	916
Ludlow et al[37]	2006	New Tom 3G	20 × 20 cm²	Adult	59
Ludlow and Ivanovic[38]	2008	New Tom 3G	20 × 20 cm²	Adult	68
Ludlow and Ivanovic[38]	2008	i-CAT Next Generation	23 × 17 cm²	Adult	74
Davies et al[126]	2012	i-CAT Next Generation	23 × 17 cm²	Adult	78
Pauwels et al[127]	2012	ILUMA Elite	21 × 14 cm²	Adult	368
Carrafiello et al[121]	2010	Aquilion 64	9 × 4 cm² LJ	Adult	990
Okano et al[118]	2009	HiSpeed QX/I	15 × 7.7 cm² UJ/LJ	Adult	769
Loubele et al[117]	2009	Philips M × 8000IDT	LJ/head	Adult	541/1160
Suomalainen et al[119]	2009	GE 4 slice CT	25 × 34.8 cm²	Adult	685
Suomalainen et al[119]	2009	GE 64 slice CT	25 × 41.25 cm²	Adult	1410
Loubele et al[117]	2009	Somatom Volume Zoom 4	LJ/head	Adult	494/1110
Jeong et al[131]	2012	Somatom Emotion 6	LJ low dose	Adult	199
Jeong et al[131]	2012	Somatom Sensation 10	5 cm² LJ	Adult	426
Loubele et al[117]	2009	Somatom Sensation 16	LJ/head	Adult	474/995
Silva et al[112]	2008	Somatom Sensation 64	10 × 12 cm²	Adult	430
Theodorakou et al[125]	2012	Somatom Sensation 64	20 × 11.7 cm²	10 y old	605
Theodorakou et al[125]	2012	Somatom Sensation 64	20 × 12.8 cm²	Adolescent	1047
Extraoral radiography in 2D (panoramic/cephalometric)					
Theodorakou et al[125]	2012	Veraviewepocs 2D	15 × 10 cm² panoramic	Adolescent	6
Silva et al[112]	2008	Orthophos DS	15 × 11 cm² panoramic	Adult	10
Carrafiello et al[121]	2010	Orthophos XG	15 × 23 cm² panoramic	Adult	50
Grünheid et al[128]	2012	OP 100	15 × 30 cm² panoramic	Adult	21.5
Silva et al[112]	2008	Orthophos DS	18 × 15 cm² cephalometric	Adult	10
Grünheid et al[128]	2012	OP/OC 100	18 × 24 cm² cephalometric	Adult	4.5
Theodorakou et al[125]	2012	Veraviewepocs 2D	20 × 20 cm² cephalometric	Adolescent	2

UJ: Upper Jaw; LJ: Lower Jaw; LR: Low Resolution; HR: High Resolution; IID: Image Intensifier Detector; FPD: Flat Panel Detector; IQ: Image Quality. Within each of the five categories (small, medium, large CBCT, MSCT, extraoral radiography), ranking is based on chronologically reported data for machine-specific dose ranges, with an increasing field of view (FOV), while ordering from child to adult.

*Effective dose (E) was converted from dose-area-product (DAP measurements using the general formula E = DAP × EDAP with EDAP = 0.08 μSv per mGy cm² deriving from the conversion factor for panoramic radiography found by Helmrot & Alm Carlsson (2005).[132] This was the conversion factor used in the paper Lofthag-Hansen et al.[115]

†The DAP-data in the paper by Lofthag-Hansen et al[124] has been converted to effective dose using the conversion factor EDAP = 0.15 μSv per mGy cm². Reference is personal communication with Ebba Helmrot, PhD, Department of Dentomaxillofacial Radiology, The Institute for Postgraduate Dental Education, Jönköping, Sweden, and the results presented in a poster at the IAEA conference in Bonn, Germany, 3–7 December 2012.[133]

Patient risk from radiation has been a continuing concern in oral and maxillofacial imaging, due to the frequency of radiographic examinations in dental practice. ALARA is the acronym for *As Low As Reasonably Achievable* and is a fundamental principle for diagnostic radiology.[134,135] In recent years, epidemiologists have suggested a link between genetics, sex, the immune system, and exposure to radiation with an increased risk of meningioma.[136–138] In particular, the association between self-reported dental radiographic exposure may be associated with an increased risk of intracranial meningioma.[138] With the increased use of CBCT imaging in dental practice, clinicians must be made aware that patient radiation doses associated with CBCT imaging are higher than those of conventional radiographic techniques. Therefore, routine replacement of current radiographic techniques must be considered with great care—especially when treating children. To measure the radiation risk for patients from a radiographic device or technique, the effective dose is considered as the most widely accepted figure.[127,139] Effective dose is measured using an anthropomorphic phantom, representing the shape and attenuation of an average human, most commonly an adult male.[140] However while average effective doses to the children and adolescent phantoms have been reported to be similar to adult doses,[125] specific organs in children (eg, salivary glands, thyroid) may receive up to a fourfold increase in dose relative to that of the adolescent. It is therefore imperative that dental CBCT examinations on children should be fully justified over conventional radiographic imaging, and that dose reduction is always achieved by reducing the field of view (FOV) size of the CBCT examinations to the actual region of interest.[127]

The present results indicate that depending on the CBCT equipment type and operator preferences, alteration of various exposure (milliamperage, kilovoltage), image quality (number of basis images, resolution, arc of trajectory), and radiation beam collimation settings (FOV) can markedly affect radiation dose to the patient. In fact, this review confirmed a recent report that CBCT devices on the market demonstrate a 20-fold range of the effective doses.[127] In addition, currently available CBCT units from different manufacturers vary in dose by as much as 10-fold for an equivalent FOV examination. The present literature review suggests that a single average effective dose is not a concept that should be used for the CBCT technique as a whole, when comparing it to alternative radiographic methods. As most devices exhibited effective doses in the 50-200 μSv range, it can be stated that CBCT imaging results in higher patient doses than standard radiographic methods used in dental practice for dental therapy but remain well below those reported for common MDCT protocols. Strategies which optimize exposure, such as FOV reduction to the region of interest, half-trajectory scanning, and reduction in exposure parameters often provide images of sufficient image quality for most diagnostic tasks associated with dental therapy.

To minimize patient radiation dose, the working group suggests that practitioners adopt CBCT equipment specific protocols to incorporate the imaging goal for the patient's specific presenting circumstances. The protocol should include considerations of exposure (mA and kVp), minimum image-quality parameters (eg, number of basis images, resolution), and restriction of the FOV to visualize adequately the region of interest.

CONCLUSIONS

On the basis of the data found in the literature, the following can be concluded:

- Most published national and international guidelines on implant dentistry do not offer evidence-based action statements developed from a rigorous systematic review approach.
- Most publications on guidelines for CBCT use in implant dentistry provide recommendations that are consensus-based or derived from a limited methodological approach with only partial retrieval and/or analysis of the literature or contain even generalized or non-case-specific statements.
- Indications or contraindications reported for CBCT use in implant dentistry are based on nonrandomized clinical trials, either cohort or case-controlled studies.
- The reported indications for CBCT use in implant dentistry vary from preoperative analysis regarding specific anatomic considerations, site development using grafts, and computer-assisted treatment planning to postoperative evaluation focusing on complications due to damage of neurovascular structures.
- It will be difficult to prove a clear and statistically significant benefit of cross-sectional imaging (with special emphasis on CBCT) over conventional two-dimensional imaging such as panoramic radiography with respect to damage of the IAN or other vital neurovascular structures in the arches resulting in dysesthesia or pain in comparative prospective studies due to the high number of cases needed for such an evaluation (power).
- Effective doses for different CBCT devices exhibit a wide range, but for all devices, significant dose reduction can be achieved by reducing the FOV to the actual region of interest.

- Practitioners who prescribe or use CBCT units should design specific CBCT equipment protocols that are task specific and incorporate the imaging goal for the patient's specific presenting circumstances. The protocol should include considerations of exposure (mA and kVp), minimum image-quality parameters (eg, number of basis images, resolution), and restriction of the FOV to visualize adequately the region of interest.

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