SYSTEMATIC REVIEW

Dose optimization by altering the operating potential and tube current exposure time product in dental cone beam CT: a systematic review

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Objectives: Current guidelines highlight the need to optimize exposure parameters on CBCT equipment to levels that are as low as diagnostically acceptable. This systematic review aimed to answer the question “Can altering operating potential (kV) and tube current exposure time product (mAs) on CBCT machines reduce radiation dose to patients undergoing dental and/or maxillofacial scans without a detrimental impact on image quality/diagnostic accuracy?”

Methods: Studies were selected and results reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. For each individual study, two authors (RG and JD or KH) independently extracted data using a specifically designed collection form, and an overall quality value was assigned using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system. Any disagreements in the overall quality value of a study were resolved by discussion between the current authors.

Results: Nearly 75% of studies were considered to be of low or very low methodological quality using the GRADE system, and more studies stated that their results applied only in the specific situations they had investigated. However, most studies demonstrated that patient dose reduction is possible without a clinically relevant reduction in image quality.

Conclusions: For many CBCT machines, it should be possible to optimize one, or more, of the investigated exposure parameters and therefore reduce patient radiation dose, while maintaining diagnostic image quality for some diagnostic tasks. However, more rigorous research is still required. *Dentomaxillofacial Radiology* (2016) **45**, 20150254. doi: [10.1259/dmfr.20150254](https://doi.org/10.1259/dmfr.20150254)

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Introduction

Dose optimization is a fundamental principle of radiation protection of individuals as part of healthcare. This has been defined as keeping doses “as low as reasonably achievable (ALARA principle), economic and societal factors being taken into account” and involves both the design and construction of equipment and day-to-day working procedures.¹

Dental CBCT is still a relatively new imaging technology, but the volume of research related to this imaging technology has grown steadily over the past decade.^{2,3} Guideline documents, recently reviewed by Horner et al(2015),⁴ have been devised at local, national and supranational levels to assist dentists, radiologists, radiographers/technologists and medical physicists in safe use of CBCT; some of these give general guidance on optimization, although detail is absent. For example, the European guidelines⁵ state, “X-ray tube voltage and

tube current-exposure time product should be adjustable on CBCT equipment and must be optimised during use according to the clinical purpose of the examination..."; however, there is no specific instruction on how optimization is to be achieved in practice. Similar general guidance is seen in other publications, for example in the USA^{6,7} and UK.⁸

Radiation dose and image quality are inextricably linked and, as highlighted in the Image Gently® in Dentistry campaign (<http://www.imagegently.org/>), a better description of optimization efforts should be to reduce exposures to levels as low as diagnostically acceptable (ALADA principle).⁹ The question underlying this review was: "Can altering operating potential [kilovoltage (kV)] and tube current exposure time product [milliampere second (mAs)] on CBCT machines reduce radiation dose to patients undergoing dental and/or maxillofacial scans without a detrimental impact on image quality and therefore diagnostic accuracy?" The aim was thus to answer this question by performing a systematic review of the currently available evidence.

Methods and materials

Eligibility criteria

Prior to any literature search being performed, the inclusion and exclusion criteria for the review were determined. A study would be considered for inclusion in the review if it investigated the impact that different dental CBCT machine exposure parameters had on image quality or diagnostic accuracy/outcome. Exposure parameters were defined as kV, milliampere (mA) or time (altered *via* different voxel settings and/or tube and detector rotation). In addition, CBCT *vs* multislice CT dose and image quality studies would be included only if different image/data sets were produced using more than a single set of exposure parameters on the same CBCT machine because, currently, this is the only way that a comparison of image quality can be made between different CBCT exposure parameters. The following types of study would be excluded:

- (1) Dose studies that did not consider image quality and/or diagnostic accuracy when altering exposure parameters.
- (2) Data relating to different fields of view, as they were not included in the definition of an exposure parameter; articles which discuss field of view may be included if kV, mA or time have also been altered/considered.
- (3) Review/discussion articles that were not systematic reviews of the literature.
- (4) Non-English literature without an English abstract. Publications with abstracts only in English would still be read, considered and discussed. If the abstract appeared to report a study which satisfied the inclusion criteria, a pragmatic decision would be taken about the feasibility of translation.

Information sources

Two electronic databases were searched: PubMed/MEDLINE (1998–25 May 2015) and Ovid/EMBASE (1998–25 May 2015). All databases were searched from mid-1990s, as the first publication on dental CBCT was in the late 1990s.^{10,11} These articles were then put through the first stage of study selection. In addition, the primary author manually searched through the reference lists of all the articles eligible for inclusion in the study to find any further studies that many be eligible but had been missed during the database searches. The other authors were also consulted to assess whether any important citations were missing.

Search

Search terms used for Ovid/EMBASE and PubMed/MEDLINE can be seen in Figure 1.

Study selection

Selection for inclusion was in two stages. During the first "screening" stage, the primary author (RG) read the journal titles and full abstracts of the studies found, to see if they fitted the eligibility criteria; those that met the criteria went through to stage two, where the primary author read the full-text article to ensure the studies continued to meet the pre-defined eligibility criteria. Where the primary author was uncertain about the eligibility of a study, this was resolved by discussion

Ovid/Embase Search

1. (cone beam computed tomography and dental and dose and image quality).af.
2. (cone beam computed tomography and dental and dose and diagnostic accuracy).af.
3. (cone beam computed tomography and dental and dose and exposure parameters).af.

PubMed/MEDLINE Searches

1. (((("cone-beam computed tomography"[MeSH Terms] OR ("cone-beam"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "cone-beam computed tomography"[All Fields] OR ("cone"[All Fields] AND "beam"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "cone beam computed tomography"[All Fields]) AND ("dental clinics"[MeSH Terms] OR ("dental"[All Fields] AND "clinics"[All Fields]) OR "dental clinics"[All Fields] OR "dental"[All Fields])) AND dose[All Fields]) AND (("Image (IN)"[Journal] OR "image"[All Fields]) AND quality[All Fields])
2. (((("cone-beam computed tomography"[MeSH Terms] OR ("cone-beam"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "cone-beam computed tomography"[All Fields] OR ("cone"[All Fields] AND "beam"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "cone beam computed tomography"[All Fields]) AND ("dental clinics"[MeSH Terms] OR ("dental"[All Fields] AND "clinics"[All Fields]) OR "dental clinics"[All Fields] OR "dental"[All Fields])) AND dose[All Fields]) AND (("diagnosis"[MeSH Terms] OR "diagnosis"[All Fields] OR "diagnostic"[All Fields]) AND accuracy[All Fields])
3. (((("cone-beam computed tomography"[MeSH Terms] OR ("cone-beam"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "cone-beam computed tomography"[All Fields] OR ("cone"[All Fields] AND "beam"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "cone beam computed tomography"[All Fields]) AND ("dental clinics"[MeSH Terms] OR ("dental"[All Fields] AND "clinics"[All Fields]) OR "dental clinics"[All Fields] OR "dental"[All Fields])) AND dose[All Fields]) AND (exposure[All Fields] AND ("Parameters"[Journal] OR "parameters"[All Fields]))

Figure 1 Ovid/EMBASE and PubMed/MEDLINE searches.

with the other authors. This occurred on three occasions, and on all three occasions, it was decided that the study being considered did not meet the eligibility criteria; so, these studies were excluded from the review.

Data collection process and data items

The unique nature of most of the studies reviewed meant that well-established extraction tools, such as those produced by the Critical Appraisal Skills Programme (Oxford, UK),¹² were not appropriate to answer the question being asked by this review. As a result, having considered the objectives of the present study and the methodologies used by other systematic literature reviews investigating aspects of dental radiology,^{5,13,14} the primary author developed an extraction form specifically for this systematic review (Figure 2). To ensure the extraction tool resulted in the important information being collected, the process was reviewed in relation to the study objectives after the first five studies had been appraised. At this point, it was noted that some important data had been excluded, and

as a result, an additional field was added to the form in which the CBCT machine(s) used was recorded.

Two of the authors reviewed every eligible publication. The primary author, who has no conflict of interest to declare, reviewed all the studies. The second and third authors (JD and KH, respectively) each reviewed approximately 50% of the studies. However, the second author had been an author on two of the studies reviewed, while the third author had been an author on one study eligible for review and had supervised the work of another. As the second and third authors had not co-authored any of the literature being reviewed, where these authors had involvement in a particular study, then the alternate author was assigned to review it, thus avoiding any potential conflict of interest and reducing bias. All studies where no author had a conflict of interest were randomly allocated between these two authors. Any disagreements in the overall quality value of a study following this data extraction were resolved by discussion between these three authors.

Study					
Year of Publication	Author	Size of study	CBCT Machine Used		
Item		Yes, No, N/A, Comments			
1. Does the study consider the impact of dose and CBCT image quality on a certain treatment (e.g. implant planning) or does/could the study look at dose and image quality for a range of CBCT examinations and treatment uses?					
2. Does the study consider the impact of altering exposure parameters on: a. Primary reconstructions b. Secondary reconstructions c. Three-dimensional reconstructions					
3. Is the study <i>in vitro</i> ? If yes, could the results be easily transferred to a clinical setting with live patients? If no, how were the patients/images selected for inclusion in the study and were withdrawals explained?					
4. What method(s) was/were used to measure image quality (subjective, quantitative, or both)? Is a reliable reference standard used?					
5. Which exposure parameters are altered?					
6. Is effective dose measured? If so, how?					
7. Are statistical tests used? If yes, which tests and do they demonstrate what they were intended to do?					
8. If image reviewers are used, how many are used, what experience did they have and did they all agree (consider margins of difference in sensitivity and specificity values)?					
9. What are the limitations of the study? Are these recognized/acknowledged by the authors?					
10. What conclusions are drawn?					
11. Have new/further areas where research is necessary been identified?					
12. Have the researchers discussed whether or how the findings can be transferred to other populations or considered other ways the research may be used?					
13. Are there any potential conflicts of interest? Have these been acknowledged in the article?					
14. Any other comments					
15. Overall quality using GRADE		High	Moderate	Low	Very Low

Figure 2 Extraction form specifically designed for this systematic review.

Risk of bias in individual studies

The overall quality of each study was assessed according to the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system described by Guyatt *et al.*¹⁵ This system was chosen as the best method to assess the quality of the studies reviewed because, unlike other quality-rating tools such as SIGN50,¹⁶ GRADE takes into account major factors that have an impact on clinical use, not just the type of study and its outcome.¹⁵ The Scottish Intercollegiate Guidelines Network has replaced SIGN50 with an adapted version of GRADE for its own recommendations.¹⁶ The GRADE system was also successfully used by Petersson *et al.*¹⁴ in their systematic review of radiological diagnosis of periapical bone tissue lesions in endodontics.

Risk of bias across studies

The strategies of cross-referencing with systematic reviews included in the present study and discussion between all three authors about studies for inclusion were designed to decrease the probability of any whole studies being missed. To reduce the risk of data from individual studies being excluded, before commencing the study-selection process, it was suggested that if data appeared to be missing, authors of the individual studies should be contacted for clarification. This strategy was, however, not necessary.

Additional analyses and synthesis of results

The question of the feasibility of performing quantitative statistical analysis/meta-analysis was left open until completion of data collection and critical appraisal. If the quantity and quality of studies were judged to be insufficient for this, synthesis of results would be made by qualitative methods only.

Reporting results

To ensure the results of this study were reported to a high standard, the guidance of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method, as described by Liberati *et al.*,¹⁷ was followed.

Results

A PRISMA flow diagram¹⁸ demonstrating how studies were selected for inclusion in this systematic review can be seen in [Figure 3](#).

Two previous systematic reviews on CBCT imaging were eligible for inclusion in this review.^{3,5} No randomized controlled trials were found during the literature search. Of the 22 other full-text articles included in the review, 10 studies looked at the effect of altering the current,^{19–28} 6 studies at altering kilovoltage^{19,20,23,24,26,27} and 18 studies at altering exposure time factors^{19,21,22,24–27,29–39} (some studies looked at more than one exposure parameter, so this total

equals >20 studies). One study⁴⁰ investigated the combined effect of current and exposure times on image quality by altering mAs values.

Only four studies undertook any form of dose measurement,^{21,24,29,31} and just two studies performed a power calculation to identify a suitable study size.^{33,34} A single study²⁶ was performed *in vivo*; all the remaining studies were *in vitro*. 5 different types of reference standard were described across the 11 studies which measured diagnostic accuracy.^{20,25,27,29,30,32–34,36–38}

In addition, of these 22 studies, 17 studies reviewed how altering exposure parameters affected the image quality of scans produced for specific diagnostic tasks ([Table 1](#)), while 5 studies looked at a range of CBCT exposure protocols which could have been used for several diagnostic tasks.^{19,23,29,31,40}

Across the total 22 studies reviewed, 23 different names were given for CBCT machines used in the research. At least 19 different CBCT models were used, produced by 10 different companies, and the details provided by 3 studies were inadequate for exact machine model identification.^{25,32,33} It is worth mentioning at this point that the use of different names for the CBCT is likely to cause confusion and make optimization more difficult for all operators.

Each of the full-text studies reviewed were evaluated and assigned an overall GRADE value ([Table 2](#)). One study, by Sun *et al.*,⁴¹ had to be excluded as it could be evaluated only by its English abstract. This study was written in Chinese, and it did not prove to be feasible to translate the complete text. The abstract stated that the study looked at the impact of altering exposure time on image quality. There was not enough information in the abstract of the study to be able to enable its fair evaluation and therefore assign a GRADE value.

The results of the two systematic reviews included had different outcomes. De Vos *et al.*³ stated that there was no evidence-based research at all in the area of radiation dose and image quality, while the European Commission SEDENTEXCT project⁵ reported that there was evidence that certain exposure parameters have an impact. However, both reviews agreed that more evidenced-based research is needed and that conventions on machine specifications and how methods are described in articles need to be established.

In nine studies, altering the exposure parameters on the CBCT scanner(s) being used had no impact on the diagnostic accuracy of, and/or pathology detection in, the resultant images for the diagnostic task being investigated.^{23,25,30,32–35,37,38,40} This conclusion was also supported by the English abstract of the study performed by Sun *et al.*⁴¹ Neves *et al.*³⁶ went so far as to specify the scanning protocol they believe gives the lowest radiation exposure while maintaining diagnostic quality; however, they also suggested that the position of a particular pathology, in their study root resorption, may have an impact on its detection at lower exposure parameters.

Figure 3 PRISMA flow chart for this study. Adapted from Moher D *et al*¹⁸ with permission.

The results of Lofthag-Hansen²⁴ were mixed. Reducing scan times by using 180° rotation produced images of diagnostic quality for maxillary implant planning but not for mandibular implant planning or periapical diagnosis.

When reviewing the impact of different exposure parameters on implant planning scans, Dawood *et al*²⁶ cautioned that while altering exposure parameters had no impact on two-dimensional images using the Morita F170 Accutomo CBCT machine (J. Morita Mfg. Corp., Kyoto, Japan), they may affect the image quality of reconstructed three-dimensional models which are sometimes needed for this diagnostic task. However, the outcome of the study by Vandenberghe *et al*²⁷ demonstrated that this might not necessarily always be the case.

Ludlow and Walker²¹ were the only authors to produce tables of their radiation dose and image quality data for each diagnostic task and scanning protocol they considered. They suggested that clinicians and operators make their own decision on which scanning protocol to use, based on clinical factors including the diagnostic question to be answered and the size and age of the patient. Bechara *et al*³⁹ also encouraged case-by-case decision-making on exposure factors, as they found that when imaging endodontically treated root fractures using a 360° as opposed to 180° rotation did not improve sensitivity but did improve specificity by reducing artefact, which could potentially reduce the number of patients having to undergo unnecessary treatment.

Table 1 Number of studies that looked at specific diagnostic tasks

Diagnostic task	Number of studies
Implant planning	7 ^{22,24–27,32,37}
Simulated root resorption	2 ^{34,36}
Orthodontic treatment planning	2 ^{21,30}
Periapical bone loss	1 ³⁵
Periapical diagnosis	2 ^{24,33}
Post-operative implant assessment	1 ²⁰
Impacted third molars	1 ²⁸
Temporomandibular disorders	1 ³⁸
Simulated root fracture	1 ³⁹

One study²⁴ investigated the impact on periapical diagnosis and implant planning; so, the table total equals 18 studies not 17 studies.

The four articles which recorded radiation dose measurements each did so in a different way and acknowledged that it was difficult to do this accurately and/or in a cost- and time-effective manner owing to various methodological limitations.^{21,24,29,31}

A summary table giving more details about the methods used in, and findings of, each reviewed publication can be found in Table 3.

In four of the studies,^{19,20,29,31} investigating the effect of different exposure parameters on CBCT image quality was not the main aim of the study. Some basic information relating to these effects could be obtained, however, from the patterns of data in tables and graphs. These studies contradicted each other, with two studies demonstrating that image quality always declined when exposure parameters were reduced,^{20,31} and the remaining two studies demonstrating that it did not.^{19,29} The only other study outcome which suggested that reducing exposure parameters consistently affected image quality was by Parsa *et al*.²²

Every study had used different methods and materials to produce its results; this made comparison and analysis difficult. Nevertheless, many authors suggest patient dose reduction is possible without reducing image quality. However, many authors also suggested that their results can be used only for the specific diagnostic task(s) on the specific model of the machine which they investigated, and that further research is needed.^{21,22,24–27,29,30,32–35,40} In addition, the studies reviewed here have found it difficult to measure radiation dose from CBCT scans accurately.

Discussion

It is important to note from the outset of this discussion that factors other than the ones investigated in this literature review, such as the size and position of field of view and the patient being scanned, have a significant impact on CBCT dose optimization. However, the aim of this literature review was to look specifically at the impact of altering kV and mAs on CBCT dose optimization. Therefore, when considering kV and mAs, within the limitations of the studies reviewed, the answer to the research question asked at the beginning of

this review is “yes”. It is possible to reduce radiation dose to patients undergoing dental and/or maxillofacial scans without causing a detrimental impact on image quality, and therefore diagnostic accuracy, by altering exposure parameters on CBCT machines. However, the results could not be generalized beyond models of machines and/or diagnostic task(s) investigated in each study, and there were several serious limitations to methods which increased the potential bias of the studies reviewed. These limitations are described in the following paragraphs.

Most of the articles reviewed were *in vitro* studies, meaning that the evidence available to operators is low in the hierarchy of evidence;⁴² Lofthag-Hansen²⁴ also found this during her literature search. A higher standard of evidence in this area could potentially be produced by an international radiation dose and visual-grading study,²⁴ led by an organization such as SEDENTEXCT, in which images of real patients are randomly selected and a range of different exposure parameters, CBCT machines and diagnostic tasks are investigated. However, such a study would take a huge amount of time and resources in many dental-imaging institutions; so, a more realistic prospect to improve the evidence available would be to try to reduce the amount of bias in current study methods.

Where diagnostic accuracy was measured, reference standards were not consistent or reliable across studies, and investigation methods were wide ranging and varied, both increasing potential bias and making it impossible to compare accurately the performance of different CBCT systems. However, this problem is not new. De Vos *et al*³ designed a list of CBCT scanner parameters which should be recorded if it is used in a scientific study and the European Commission⁵ stated, “it would also be useful if a valuable standard battery of tests using a standard commercially available phantom were prospectively adopted so that comparisons could be made between the dimensional accuracy of different models”.

As none of the articles reviewed have recorded all the parameters De Vos *et al*³ suggested, or stated they were using a method and phantom prospectively agreed and adopted by CBCT specialists, it would appear that these suggestions have not yet been adopted. It is the opinion of the authors of this article that the quality of evidence produced would increase if standard methods were always used and all CBCT scanner parameters recorded in the literature.

Table 2 Methodological quality of the studies included in this systematic review according to overall Grading of Recommendations Assessment, Development and Evaluation (GRADE) value

Overall GRADE value	Number of studies
High	1 ⁵
Moderate	6 ^{19,21,24,31,34,40}
Low	12 ^{3,20,22,23,25–28,32,35,38,39}
Very low	5 ^{29,30,33,36,37}

Table 3 Summary table of systematic review results

<i>Study</i>	<i>Aims</i>	<i>Study size and population</i>	<i>Exposure factors altered</i>	<i>Equipment used</i>	<i>Reference standard</i>	<i>Outcomes</i>	<i>Overall assessment of study quality</i>
Kwong et al ²³	Subjectively measure the impact that altering mA and kV has on the 2D image quality of three different CBCT examinations using a 16-point ranking scale and a diagnostic quality questionnaire	32 cadaver heads (including soft tissues) and 16 dry skulls—48 resultant images each viewed by 30 observers (total of 90 observers used for the whole study); 30 judges then re-observed images 1 month later; so, intraobserver reliability could be measured	mA and kV	Hitachi CB MercuRay ^a	None	Generally, images taken at lower kV and mAs settings were considered to maintain their diagnostic accuracy and be comparable with those taken at higher exposure parameters. However, there was low interobserver reliability, and researchers stated they had found it difficult to define and quantify clinical image quality. It was also concluded that soft tissues may have an impact on image quality at different exposure parameters, but further research into this was needed.	Low
Loubele et al ²⁹	Quantitatively measure the image quality and radiation dose of CBCT at a range of protocols compared with MSCT maxillofacial protocols	Two different QA phantoms surrounded by water (to emulate soft tissues) and a dry skull; four different CBCT scanning protocols tested	Exposure time	i-CAT ^b	Measurements made with a laser scanner	The tables of data in the article suggest that increasing the exposure time increases the dose while not always improving the image quality, but, no discussion about how changing the exposure time affected image quality and dose of CBCT scans compared with each other, only compared with MSCT scans	Moderate
Loubele et al ¹⁹	Quantitatively measure the image quality of CBCT scans at a range of protocols compared with MSCT maxillofacial protocols	Two different QA phantoms surrounded by water scanned; three NewTom 3G, three Accutomo 3D and seven i-CAT protocols tested	Exposure time, mA and kV	i-CAT ^b , NewTom 3G ^c and Accutomo 3D ^d	None	No discussion about how changing exposure time affected image quality and dose of CBCT scans compared with each other, only compared with MSCT scans. Graphs included in the results section show similar results for different protocols on the same machine, but, results for CNR in air and threshold calculations for aluminium do differ widely between protocols on some machines suggesting that further research is needed (although this is not stated in the article)	Very low

Table 3. Continued

<i>Study</i>	<i>Aims</i>	<i>Study size and population</i>	<i>Exposure factors altered</i>	<i>Equipment used</i>	<i>Reference standard</i>	<i>Outcomes</i>	<i>Overall assessment of study quality</i>
Brown et al ³⁰	Quantitatively measure the effect that altering exposure time has on 3D CBCT image quality by taking measurements between pre-set landmarks as required for orthodontic treatments, off each scan taken	16 linear dimensions between 24 anatomic points on 19 dry dentate human skulls measured; three different protocols tested; two observers used to measure reference standard and one observer for measurements from CBCT images	Exposure time	i-CAT Classic ^b	Measurements taken directly from dry skull	Reducing the number of projections taken (and therefore exposure time) does not reduce the accuracy of 3D measurements taken using CBCT images	Very low
De Vos et al ³	Systematic review of all literature relating to dental and maxillofacial CBCT including image quality and radiation dose	PubMed searched, 380 studies found; 177 studies found to be clinically relevant were analysed in detail	N/A	N/A	N/A	In all CBCT studies, there is inconsistency in how acquisition protocols, and which exposure parameters, are reported. There are also no conventions on how CBCT dosimetry should be measured, resulting in uncontrolled and non-evidence-based radiation dose values being reported. Concluded that there needs to be evidenced-based research carried out on radiation dose in CBCT, which in turn will impact image quality and exposure parameter-setting research	Low
Suomalainen et al ³¹	Quantitatively measure the image quality and radiation dose of different CBCT protocols compared with MSCT maxillofacial protocols	Tissue doses measured using scans of a RANDO [®] (Radiation Analogue Dosimetry System; Nuclear Associates, Hicksville, NY) head phantom. Image quality (evaluated using CNR and MTF) and absorbed dose measured using an RSVPT [™] (Radiosurgery Verification Phantom; The Phantom Laboratory, Salem, NY) head phantom	Exposure time (scans taken at different resolution settings)	Scanora [®] 3D scanner ^c	None	Little discussion about how changing exposure time affected image quality and dose of CBCT scans compared with each other. But, large variations in patient dose and image quality when using different protocols demonstrate a need to optimize imaging parameters. CNR and MTF are reported as being higher, and graphical data demonstrate higher central axis doses, when higher resolution protocols are used	Moderate

Table 3. Continued

<i>Study</i>	<i>Aims</i>	<i>Study size and population</i>	<i>Exposure factors altered</i>	<i>Equipment used</i>	<i>Reference standard</i>	<i>Outcomes</i>	<i>Overall assessment of study quality</i>
Lofthag-Hansen ²⁴	Subjectively measure the impact that altering mAs, kV and exposure has on the 2D image quality of CBCT examinations for pre-operative implant planning and periapical diagnosis using a six-point ranking scale of certainty of diagnostic quality and measuring radiation dose impact using DAP	300 scans taken on one dry skull imbedded in an acrylic material to simulate soft tissues. 27 scans rejected owing to low signal to the detector; so, 273 scans actually included in the study. seven observers with 4–6 years' experience in oral radiology or dentistry. Intra-observer agreement considered via 60 randomly selected duplicate scans	mAs, kV and exposure time (180° and 360° rotational scans taken)	3D Accuitomo ^d and 3D Accuitomo FPD ^d	None	Exposure parameters need to be adjusted for the specific diagnostic task being carried out. Higher exposure parameters are needed for mandible implant planning and periapical diagnosis. 180° rotation provided image quality sufficient for maxillary implant planning and substantially reduces dose. The skull used was that of a large male; so, lower doses for children and females should be possible without reducing image quality, but further research is needed. Further studies also needed to develop effective dose-conversion factors as investigation proved that DAP results were not accurate—too high. Patient outcome level studies need to be devised to ascertain whether techniques are being properly used and provide more substantial evidence for the conclusions made in this study	Moderate
Sur et al ²⁵	Subjectively measure the impact that altering mAs and exposure time has on the 2D image quality of CBCT examinations for pre-operative implant planning using a four-point ranking scale	Six human cadavers without brain tissues scanned. Five independent, certified oral radiologists used as observers, but no intraobserver testing was carried out. All scans were taken at 80 kVp	mAs and exposure time (180° and 360° rotational scans taken)	3D Accuitomo with amorphous silicon flat-panel detector ^d	Scan taken at 80 kVp, 8 mAs and 360° rotation	Scans taken at 4 mAs and 360°, 2 mAs and 360° and 4 mAs and 180° all provided adequate image quality for implant planning. But, for denser and larger volume structures in the posterior part of the mouth, the images were visibly more degraded as exposure parameters were reduced	Low
Durack et al ³⁴	Subjectively measure the impact that altering exposure time has on the image quality of CBCT examinations for the detection of simulated external inflammatory root resorption using a five-point ranking scale and by direct identification with annotation on the scan image itself	Previous studies used for power calculations. three human mandibles used and 10 human incisor teeth; acrylic sheet put over X-ray beam output to replicate soft tissues. 30 sets of images taken, eight observers specializing in endodontics used. All were pre-calibrated and completed; intraobserver sessions at least 1 week later	Exposure time (180° and 360° rotational scans taken)	3D Accuitomo 80 ^d	Scan taken at 90 kVp, 3 mAs and 17.5s (360° rotation)	If exposure time is changed via amount of rotation, this has no difference in the detection of small simulated external inflammatory root resorption at small fields of view. But, further research is needed into irregularly shaped simulated external inflammatory root resorption and to compare sensitivity between different devices at detecting this type of pathology	Moderate
European Commission ⁵	Systematic review of all CBCT dental and	Nine databases searched and national guidelines included	N/A	N/A	N/A	There is evidence that tube voltage, exposure time, mAs and voxel size	High

Table 3. Continued

Study	Aims	Study size and population	Exposure factors altered	Equipment used	Reference standard	Outcomes	Overall assessment of study quality
	maxillofacial literature, including articles on radiation dose and image quality, to produce Europe-wide guidelines for the safe and appropriate use of CBCT in the dental and maxillofacial region	from around Europe. Resultant literature was independently assessed and coded into seven pre-decided categories by a range of dental professionals and medical physicists who specialize in CBCT. Articles were then further assessed using a generic <i>pro forma</i> (or SIGN and QUADAS checklist if suitable) to identify weaknesses in study design. Delphi technique used to check final consensus of professionals on grading of articles using an adapted SIGN50 system				all have an impact on image quality and radiation dose, but further research is needed for individual machine types and diagnostic tasks. More research needs to be performed to assess the effect of the number of projections (and therefore exposure time) on image quality and radiation dose. It would also be useful if a valuable standard battery of tests using a standard commercially available phantom were prospectively adopted, so that comparisons could be made between the dimensional accuracy of different models of machines	
Lennon <i>et al</i> ³⁵	Does altering exposure time affect the image quality of CBCT scans when detecting periapical bone loss (small, artificial lesions)?	Five human mandibles on a stand surrounded by plastic in the scanner to simulate soft tissues. 10 observers looked at images twice, 2 weeks apart	Exposure time (180° and 360° rotational scans taken)	Accutomo 3D FPD ^d	None	No significant difference in the diagnostic accuracy between 180° and 360° rotational scans, but some of the more experienced observers complained that it was difficult to decide if a lesion was present in more subtle cases; interobserver agreement was poor	Low
Luckow <i>et al</i> ²⁰	Does altering the jaw position of the patient help improve resultant CBCT image quality when imaging patients following implant surgery? Exposure parameters also altered	Pig's head complete with soft tissues and vertebral body scanned. Quantitative measures used to evaluate image quality	mA and kV	3D Accutomo 60 ^d	Micro-CT and synchrotron radiation-based micro-CT scans	No discussion about how changing exposure time affected image quality and dose of CBCT scans. However, graphs, statistics and results section demonstrate that image quality improves as kV and mA are increased	Low
Neves <i>et al</i> ³⁶	Subjective observer study into whether altering the number of projections taken affected the image quality of CBCT scans and therefore the ability of clinicians to diagnose simulated external root resorption	20 pre-molar teeth scanned, covered in utility wax and placed into a mixture of plaster and ground rice to simulate soft tissue	Exposure time (scans taken at different resolution settings)	Classici-CAT ^b	Actual teeth and skull	A protocol that used a 0.3-mm voxel size and then reconstructed at 0.25-mm voxel size was considered the best to use, as it produced images that were of diagnostic quality but gave the patient a lower radiation dose. The position of the external root resorption can affect diagnosis using CBCT.	Very low

Table 3. Continued

Study	Aims	Study size and population	Exposure factors altered	Equipment used	Reference standard	Outcomes	Overall assessment of study quality
Al-Ektrish ³²	Investigate the accuracy and reliability of measurements for implant planning taken from CBCT scans performed at three different exposure times	Five human mandibles used; measurements taken at 55 sites by two observers	Exposure time	"a CBCT device (Iluma, Imtek Imaging, 3M Co., St Paul, MN) with a large FOV and a flat-panel detector"—possibly Illuma LFOV ^g	Measurements taken directly from dry skull	Reliability and dimensional accuracy of measurement not affected by a reduction in exposure time. However, observers did express in the discussion that it was more difficult to identify bony margins at the lowest exposure time and that lowering exposure times did increase the amount of streaking artefacts on the images	Low
Dawood et al ²⁶	A subjective observer pilot study, using a five-point scale of certainty of diagnostic quality, to investigate if exposure parameters affect the CBCT image quality when scanning for pre-surgical implant planning	Patients selected by clinical criteria as they normally would be	mA, kV and exposure time (scans taken at different resolution settings and at 180° and 360° rotations)	Morita F170 Accutomo ^d	None	There is potential to reduce patient dose for these examinations, but using a low dose protocol may affect the quality of 3D models needed for planning computer-guided implant surgery, so, further research in this area is needed	Low
Vandenberghe et al ²⁷	Subjective observer study to investigate how altering exposure parameters affects the 3D computer model accuracy of jaws reconstructed from CBCT scans for implant planning	One human edentulous cadaver, including most soft tissues; six CBCT machines used, resulting in 47 exposure protocols being used and 94 CBCT scans being taken	mA, kV and exposure time	3D Accutomo 170 ^d KaVo 3D Exam ^e Promax 3D ^h Picasso Trio ⁱ Scanora 3D ^e Iluma Elite ^j	Micro-CT high resolution protocol scan	Exposure protocols only influenced model accuracy to a minor extent (scan time was a more important variable than kV or mA), but high-resolution protocols do not necessarily yield better models. Only slight deviations were found between upper and lower jaw model accuracy	Low
Bechara et al ³⁹	Subjective observer study to investigate whether altering the exposure time (and therefore number of images) has an effect on detecting simulated root fractures in endodontically treated teeth	66 endodontically treated roots were imaged twice (once on each rotation setting); 33 roots had been fractured. All roots were mounted in a bovine rib covered with wax to simulate jaw bone and soft tissues. Five observers used a five-point scale to classify the presence of a root fracture; observers looked at images twice 2 weeks apart	Exposure time (180° and 360° rotational scans taken)	3D Accutomo ^d	None	Using a 180° rotation does not affect the average sensitivity but can lead to lower specificity for this diagnostic task, as the amount of artefact caused by high-density structures was reduced on the 360° rotational images	Low
Hashem et al ³³	Investigate whether altering exposure time has an effect on accuracy of measurements of root anatomy used to detect simulated external inflammatory root resorption	12 porcine hemimandibles split into small sections; no soft tissue; 120 CBCT scans taken; 80% power calculation	Exposure time (180° and 360° rotational scans taken)	Morita Accutomo ^d	Measurements taken directly from porcine dry hemimandible sections	With all other exposure factors, the same 180° and 360° rotational scans produced equally accurate measurements; therefore, adequate diagnostic images can be obtained while reducing patient radiation dose	Very low

Table 3. Continued

Study	Aims	Study size and population	Exposure factors altered	Equipment used	Reference standard	Outcomes	Overall assessment of study quality
Ludlow and Walker ²¹	Investigate whether altering exposure parameters has an impact on quantitative measures of image quality (CNR and MTF) and effective doses for both adults and children undergoing a range of CBCT scans related to orthodontic treatment	Two human-equivalent head phantoms used—one child and one adult. Effective dose measured using optically stimulated luminescent dosimeters and thermoluminescent dosimeters	Exposure time (scans taken at different resolution settings) and mA (Quickscan + protocols only)	i-CAT FLX ^b	None	Effective doses for the child phantom were an average of 36% higher than effective doses for the adult phantom. Results for effective doses (total and certain organs) and image quality measurements were listed in tables in relation to different protocols. Authors then stated that clinicians needed to choose the best protocol for the region and pathology being investigated on a case-by-case basis	Moderate
Parsa et al ²²	Investigate whether altering exposure time has an impact on the grey values (quantitative measure) at proposed implant sites on resultant CBCT images	One partially edentulous human mandible cadaver fixed in formaldehyde, imaged 36 times on the Accutomo 170 ^d and 24 times on the NewTom 5G ^c	Exposure time (scans taken at different resolution settings and at 180° and 360° rotations) and mA (some NewTom 5G protocols only)	Accutomo 170 ^d and NewTom 5G ^c	None	Resolution/voxel size (and therefore exposure time) had a significant impact on the grey values of images produced on both machines. Altering the number of projections taken (and therefore further changes in exposure time) also had an effect on the grey values of images produced on the Accutomo 170 ^d , but this could not be tested on the NewTom 5G ^c	Low
Waltrick et al ³⁷	Investigate whether altering exposure time has an impact on taking linear measurements (quantitative) and visibility of the mandibular canal (subjective) on the resultant CBCT images when imaging for implant planning	12 edentulous and uniform hemimandibles; three different CBCT protocols used, generating 108 transverse images; two observers each measured 36 sites	Exposure time (scans taken at different resolution settings)	i-CAT ^b	Measurements taken directly from dry skull	All protocols produce images that are adequate for linear measurements in the posterior mandible and provide high visualization of the mandibular canal	Very low
Neves et al ²⁸	Subjective observer study into whether altering the mA settings affected the image quality of CBCT scans and therefore the ability of clinicians to identify the position of impacted mandibular third molars	12 dry mandibles (total of 20 impacted mandibular third molars scanned) at seven different mA settings. Total of 140 examinations reviewed by two observers who assessed overall image quality using a four-point scale. Observers looked at 70 examinations again 30 days later for reliability	mA	Kodak 9000 unit ^k	None	As mA was decreased, image noise increased and therefore image quality decreased. The protocol that used 10 mA was considered the best to use, as it produced images that were not any worse than scans taken at a higher mA and therefore resulted in images of diagnostic quality but a lower radiation dose for the patient	Low

Table 3. Continued

Study	Aims	Study size and population	Exposure factors altered	Equipment used	Reference standard	Outcomes	Overall assessment of study quality
Yadav et al ³⁸	Investigate whether altering exposure time has an effect on detecting arthritic changes in temporomandibular joints	17 dry skulls used with water-filled latex gloves and wax around joints to simulate brain and soft tissue had 102 simulated lesions created in them at randomly selected sites. One orthodontist and one oral maxillofacial radiologist reviewed all the images	Exposure time (180° and 360° rotational scans taken)	3D Accuitomo ^d	The original documents of the known lesion positions	With all other exposure factors, the same 180° and 360° rotational scans produced equally accurate results; therefore, adequate diagnostic images can be obtained while reducing patient radiation dose	Low
Pauwels et al ⁴⁰	Investigate the impact altering mAs has on CNR (quantitative measurement) and image quality (subjective, qualitative measurement)	40 scans taken using a PMMA phantom and a RANDO [®] (The Phantom Laboratory, Salem, NY) anthropomorphic skull phantom. CNR of air measured using scans of the PMMA phantom. Six radiologists then assessed each scan for overall image quality and diagnostic confidence for three clinical applications using a four-point scale	mAs	3D Accuitomo, 170 ^d CRANEX, 3D ^e SCANORA 3D ^e Galileos Comfort ^f	None	Although CNR increased at lower mAs values, observers felt that most images were still clinically acceptable. However, it is not currently possible to determine diagnostic reference levels for multiple CBCT models	Moderate

2D, two dimensional; 3D, three dimensional; CNR, contrast-to-noise ratio; DAP, dose-area product; FOV, field of view; kV, kilovoltage; mA, milliampere; mAs, milliampere second; MSCT, multislice CT; MTF, modulation transfer function; QA, quality assurance; QUADAS, quality assessment of diagnostic accuracy studies; PMMA, poly(methyl methacrylate); SIGN, Scottish Intercollegiate Guidelines Network; SIGN50, SIGN 50th guideline.

^aHitachi Medical Systems, Tokyo, Japan.

^bImaging Sciences International, Hatfield, PA.

^cQuantitative Radiology, Verona, Italy.

^dJ. Morita Mfg. Corp., Kyoto, Japan.

^eSoredex, Tuusula, Finland.

^fKaVo Dental GmbH, Biberach, Germany.

^gPlanmeca Oy, Helsinki, Finland.

^hVatech, E-WOO Technology Co. Ltd, Gyeonggi-Do, Republic of Korea.

ⁱImtec Plaza, Ardmore, OK.

^jKodak Dental Systems, Carestream Health, Rochester, NY.

^kSirona, Bensheim, Germany.

^lInformation gained from Comparison of CBCT Machines on SENDENTXCT website. Available from: <http://www.sendentext.eu/content/comparison-cbct-machines?sort=asc&order=Model>.

Measuring effective dose with thermoluminescent dosimeters for all the tissues in the head and neck is very time consuming and expensive, and owing to the wide range of different machines, results could not be generalized.^{21,24} Therefore, international research and agreement is also needed to find a cost- and time-effective way of reliably calculating the dose that patients undergoing CBCT receive so that operators can know exactly how altering different exposure factors will impact both patient dose and resultant image quality. Dose-area product (DAP) measurements would seem to be the most practicable means of representing patient dose, as these have been proposed for definition of Diagnostic Reference Levels, are readily measured in clinical situations, relate reasonably well with effective dose^{5,8} and, since the introduction of regulation 60601-2-63 by the International Electrotechnical Commission in 2012, manufacturers have been required to provide a DAP measurement on all CBCT equipment.⁴³ However, Lofthag-Hansen²⁴ found that the central point of the scan is not always at the centre of the clinical region of interest, and so, patient radiation dose measurements could be both overestimated or underestimated depending on the area being imaged using DAP measurements. However, this does not mean that DAP cannot be used to assess dose-reduction strategies and compare the results from different CBCT equipment and/or different diagnostic tasks in dose-optimization studies.

Alternative methods of measuring dose should not be discounted though. Recent research suggests that dose-height product could provide a more accurate alternative to DAP measurements;⁴⁴ however, further research in this area is urgently needed. Some have investigated possible conversion co-efficients that may allow DAP readings to be used to work out an estimation of effective dose.⁴⁵ Programs based on the Monte Carlo simulation, such as the one investigated by Koivisto *et al*,⁴⁶ also need to be considered. These can be of value because they permit easy manipulation of exposure variables without performing time-consuming experiments in the field.

Four studies^{19,21,31,40} used contrast-to-noise ratio (CNR) as a quantitative measure of image quality, to provide objective data to complement subjective image quality assessment. However, the materials used to measure CNR can vary; so, comparison between different studies is difficult if the studies have used different materials. Furthermore, the reliance of CNR data based on a Perspex[®] (Mitsubishi Rayon Group, Southampton, UK)–air interface can be questioned when clinical images rely on the contrast between hard and soft tissues. Alternatives, or additions, to CNR, such as tests of spatial resolution, modulation transfer function or other parameters, may also be important objective measures of image quality. Clearly, further work looking at the relationships between these objective measurements and clinical image quality is needed.

While much research appears to have been carried out into the impact that dose optimization has on image quality for implant-planning CBCT scans, only

two studies,^{28,39} which were of low quality, have been carried out relating to other common CBCT diagnostic tasks, such as identifying the position of impacted teeth or trauma, in which many patients would be younger and so dose optimization of paramount importance.^{3,5} This provides a substantial issue for dental radiographers and other CBCT operators, because for such diagnostic tasks, there is currently minimal evidence of the impact altering different exposure parameters has on resultant scan image quality. Reducing exposure parameters may still result in a diagnostically acceptable image but could also result in an undiagnostic image, meaning that the scan would need to be repeated and the patient would get substantially more radiation dose than if the scan had been taken at the “standard” exposure parameters in the first instance. It would be logical to concentrate on developing optimization strategies for the most common CBCT examinations performed in the most radio-sensitive age group. A recent survey by Hidalgo Rivas *et al*⁴⁷ showed that in a sample of UK Dental Hospitals, the most common CBCT examination in children and young people was for a localized region of interest in the anterior maxilla.

Limitations of this systematic review

There is a possibility of missing studies because CBCT is such a fast-expanding, new modality; however, the primary author requested if any further articles matching the keywords of the PubMed searches were published, the website send an automatic e-mail; however, no alerts were received.

Conclusions

The evidence reviewed in this systematic review suggests that for most CBCT machines, when undertaking the diagnostic tasks investigated in each specific study, it should be possible to alter one, or several, of the investigated exposure parameters (kV, mA or time) and therefore reduce patient radiation dose, while maintaining diagnostic accuracy and/or image quality. The range of diagnostic tasks included in this review mean that any conclusions about efficacy cannot be generalized to all clinical situations and/or CBCT machines. However, although a considerable number of studies looking at the impact of altering exposure parameters on the image quality of CBCT scans have been undertaken since previous systematic reviews were conducted,^{3,5} the later studies are still of low quality in the hierarchy of evidence and have several common limitations which may increase potential bias. To increase the standard of evidence these studies produce, there is a need for international agreement and compliance on: a cost- and time-effective way of accurately measuring patient radiation dose, what constitutes a reliable reference standard of image quality in CBCT imaging and which information should be recorded in each study regarding the CBCT device(s) used.

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