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ORIGINAL ARTICLE

Quality assurance in digital dental imaging: a systematic review

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Abstract

Objectives. Doses induced by individual dental examinations are low. However, dental radiography accounts for nearly one third of the total number of radiological examinations in the European Union. Therefore, special attention is needed with regard to radiation protection. In order to lower patient doses, the staff performing dental examinations must have competence in imaging as well as in radiation protection issues. This paper presents a systematic review about the core competencies needed by the healthcare staff in performing digital dental radiological imaging quality assurance. ***Materials and methods.*** The following databases were searched: Pubmed, Cinahl, Pro Quest and IEEXplore digital library. Also volumes of some dental imaging journals and doctoral theses of the Finnish universities educating dentists were searched. The search was performed using both MeSH terms and keywords using the option 'search all text'. The original keywords were: dental imaging, digital, x-ray, panoramic, quality, assurance, competence, competency, skills, knowledge, radiographer, radiologist technician, dentist, oral hygienist, radiation protection and their Finnish synonyms. ***Results.*** Core competencies needed by the healthcare staff performing digital dental radiological imaging quality assurance described in the selected studies were: management of dental imaging equipment, competence in image quality and factors associated with it, dose optimization and quality assurance. ***Conclusions.*** In the future there will be higher doses in dental imaging due to increasing use of CBCT and digital imaging. The staff performing dental imaging must have competence in dental imaging quality assurance issues found in this review. They also have to practice ethical radiation safety culture in clinical practice.

Key Words: *competence, dental imaging, education, quality assurance*

Introduction

Special attention is needed with regard to quality assurance education in dental imaging because doses incurred during dental examinations are in general relatively low, but dental radiography still accounts for nearly one third of the total number of radiological examinations in the European Union [1]. Digital imaging gives opportunities to get the doses lower with the same image quality, but there is also the possibility for dose increase because it is easy and quick to take many x-rays [1]. Article 7 of the 'Medical Exposures Directive' states that dental practitioners must have adequate theoretical and practical training for the purpose of radiological practices, as well as relevant competence in radiation protection [2]. European guidelines about the issue also require continuing education and training after qualification [2–5]. National radiation protection authorities have Regulatory Guides which dental clinics and other healthcare facilities practicing dental radiography have to obey. In Finland these include the regulatory guide about the Use and regulatory control of dental x-ray installations [6], Radiation protection training in healthcare [7] and Qualifications of persons working in radiation user's organization and radiation protection training required for competence [8] by the Radiation and Nuclear Safety Authority (STUK). However, specific competences to be taught in quality assurance of dental digital imaging education have been poorly defined both at the European and national levels.

There is now widespread acceptance in healthcare that, as in all healthcare clinical practice, also dental and radiographic practices should be as evidence-based (EB) as possible. The European commission

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has developed EB guidelines that have proved effective in the past to arrive at recommendations that will contribute to optimization of the use of ionizing radiation in dentistry [4,5]. This stems directly from the high quality assurance demands of European healthcare to which also apply the demands of clinical audit. According to Article 6 the clinical audits must be done according to national guidelines which are updated from time to time [2].

In order to implement all the new research knowledge and European and national guidelines to dental radiography practices, we need a systematic education for those pursuing their professional studies as well as for adult education. It is necessary to develop new kinds of learning methods to teach students and healthcare professionals to learn in an evidence-based way. This helps them in their lifelong learning to keep up to date during their working career. In order to work evidence-based, a systematic review was made at the first phase of the project about the state of research knowledge about the topic.

The purpose of this review is to contribute to knowledge for developing dental digital imaging quality assurance education for healthcare staff. The aim of this paper is to present a systematic review of the core competencies needed by the healthcare staff: radiographers, dental nurses, oral hygienists and dentists performing quality assurance related to digital dental radiological imaging.

Materials and methods

When formulating systematic review questions, the PICO or PICo model is often used. In the PICO model, P = patient or population, I = intervention, C = comparator and O = outcome. It is used when the review focuses on quantitative and especially interventional studies. If the question is descriptive and also qualitative studies are included, the PICo model is preferred. Here also P indicates patient, but in this model I refers to the phenomena of interest and Co to context. These models help to focus the review question and to define the inclusion and exclusion criteria, which are essential for identifying relevant literature [9]. Here the PICo question was used because of descriptive questions and because both qualitative and quantitative studies were included.

The PICo of this systematic review was: *P*opulation = radiographer, dental nurse, oral hygienist and dentist, phenomena of *I*nterest = core competence and *Co*ntext = dental digital imaging.

The following databases were searched: Pubmed, Cinahl, Pro Quest and IEEXplore digital library. Also doctoral theses of the Finnish universities educating dentists were searched.

Included were peer-reviewed research articles and reports describing radiographers', dental nurses', oral hygienists' or dentists' competence including knowledge, skills and attitudes in clinical practice intra-oral, panoramic tomography and cone beam computed tomography. Inclusion criterion was also that the studies were made between 2000–2011.

Excluded were studies that were not about digital dental radiological imaging or about dental imaging not produced by x-rays. Also studies concentrating on detecting certain oral conditions were excluded. Excluded were also articles published before 2000, studies reporting about specific examination protocols and studies about the efficacy or economic evaluations.

The search was performed using both MeSH-terms and keywords by the option 'search all text'. The original keywords were: dental imaging, digital, x-ray, radiography, cone beam, panoramic, intra-oral, quality, assurance, competence, competency, skills, knowledge, radiographer, radiologist technician, dentist, oral hygienist, radiation protection and their Finnish synonyms. In the keyword search the following combinations were used: dental imaging AND quality AND assurance; dental imaging AND radiation protection; dental imaging AND quality AND radiographer OR radiologist technician OR dentist OR oral hygienist; dental imaging AND quality AND competence OR competency OR skills OR knowledge; radiography AND cone beam AND digital AND quality; radiography AND intra-oral AND digital AND quality; x-ray AND panoramic AND digital AND quality; radiography AND dental AND quality AND digital; dental AND imaging AND quality. The MeSH terms used were: radiography, dental, digital, quality control, radiation dosage.

The authors performed the searches from the databases during autumn 2011. Then the researchers looked independently through all the titles and selected relevant titles for abstract-level review. Abstracts were also inspected independently. Out of the relevant abstracts, relevant full-text articles were chosen after a consensus discussion in December 2011. The authors evaluated the quality of the articles independently with respect to the 10 criteria referred to in Table I. After individual evaluation, the results were compared. If there was a difference in the scoring, a compromise was made on the basis of discussion. Two of the authors made the analysis together side-by-side and negotiated about it between the different phases. The result was a compromise of the negotiation. 'Results' chapters of the selected studies were analysed by using simple inductive content analysis. Condensed meanings were first formed out of the text in the results parts of the studies. After that they were coded, first level sub-categories were formed. Since the material was the 'Result chapters' of the selected studies, just main categories were formed after first level sub-categories.

Table I. Quality assessment of the selected articles.

Reference	1	2	3	4	5	6	7	8	9	10
Bedard et al. [10]	**	**	**	**	*	**	**	**	**	**
Bhaskaran et al. [11]	**	**	**	**	*	**	*	**	*	**
Mah et al. [12]	**	**	*	*	*	*	*	**	*	**
Okamura et al. [13]	**	**	**	*	*	**	*	*	**	**
Baksi [14]	*	**	**	**	*	**	*	**	*	**
Chiu et al. [15]	**	**	**	**	**	**	**	**	**	**
Zhang et al. [16]	*	*	*	*	*	*	*	*	*	*
Ergun et al. [17]	*	**	**	**	**	**	**	**	**	**
Vandenberghe et al. [18]	*	**	**	*	*	**	**	*	**	**
Grassl and Schulze [19]	*	**	**	**	**	**	*	**	**	*
Vandenberghe et al. [20]	**	**	**	**	*	**	**	**	**	**
Vandenberghe et al. [21]	*	**	**	**	**	**	**	*	**	*
Heo et al. [22]	*	**	**	**	**	**	*	**	**	**
Sakurai et al. [23]	**	**	**	**	**	**	**	**	**	**
Ramesh et al. [24]	**	*	**	**	**	*	*	*	**	**
Lopes et al. [25]	**	**	**	**	**	*	**	*	**	**
Sogur et al. [26]	**	**	**	**	**	*	*	**	**	**
Ang et al. [27]	*	**	**	**	*	**	**	**	**	**
Matsuda et al. [28]	**	**	*	**	*	**	**	**	**	*
Akdeniz et al. [29]	**	**	**	**	**	**	**	**	*	**
Martins et al. [30]	*	*	**	*	**	**	**	**	*	**
Martins et al. [31]	**	**	**	**	*	**	*	*	*	**
Kalathingal et al. [32]	**	**	**	**	**	**	**	**	**	*
FOgli et al. [33]	**	*	**	*	*	*	*	**	**	**
Hellen-Halme et al. [34]	**	**	**	**	**	**	**	**	**	**
Baksi et al. [35]	**	**	*	**	**	**	**	**	*	**
Hellen-Halme et al. [36]	**	*	**	**	**	**	**	*	**	**
Suomal ai nen [37]	**	**	**	**	**	**	**	**	**	*
Vassileva and Stoyanov [38]	**	**	**	**	**	**	**	**	**	**
Lofthag-Hansen et al. [39]	**	*	**	**	**	**	**	*	**	*
Wenzel et al. [40]	**	**	**	**	**	**	**	*	**	**
Lofthag-Hansen [41]	**	**	**	**	**	**	**	**	**	**
Kljunen [42]	**	*	*	*	**	**	**	**	*	**
Sur et al. [43]	**	**	**	**	*	**	**	**	*	**
Rtter et al. [44]	**	**	**	**	**	**	**	**	**	**
Sezgin et al. [45]	**	**	**	**	*	*	**	**	*	**
Gavala et al. [46]	**	**	**	**	**	**	**	**	**	**
Hayakawa et al. [47]	**	**	**	**	**	**	*	**	**	**
Dannewitz et al. [48]	*	**	**	**	*	**	*	**	**	**
Gjbels et al. [49]	*	**	**	**	*	**	**	**	**	**
Alkurt et al. [50]	**	**	**	*	*	*	**	**	**	**
Peker et al. [51]	**	*	**	**	**	**	**	**	**	**
Helmrot and Thilander-Wang [52]	**	**	**	**	**	**	**	**	**	**

1. Study background and theoretical framework are clearly defined.
2. The purpose, aim and research questions are clearly defined.
3. The design is clearly stated.
4. The setting is clearly described.
5. Independendent, dependent, confounders.
6. Data sources and analysis methods are clearly described.
7. Describes any efforts to address potential sources of bias.
8. Answers the research questions logically.
9. Discusses the study's limitations and generilizability.
10. Relevace to the topic.
**Satisfies assessment criteria.
*Partly satisfies assessment criteria.

Results

Medline gave 355 hits, Cinahl 41, Pro Quest 507 and IEEXplore digital library 212. Also doctoral theses of the Finnish universities educating dentists were searched manually and four applicable titles were found. A total of 1119 titles about the topic were found with the keywords and Mesh-terms used. After this the titles were examined from the viewpoint of relevance and most of the titles (n = 1022) were found to be irrelevant. Abstracts of studies with the relevant looking-titles were reviewed (n = 97). After that 57 papers were read in full and the final selection was made mostly on the basis of methodological quality. This resulted in 43 papers (Figure 1).

Overview of the selected studies

A total of 43 articles were included in this review according to the criteria. The aim of the study, materials and methods and analysis of data was well described in most studies. Most deficiencies were in describing sources of bias and in the description of variables, especially confounding ones (Table I).

The studies were made in 19 different countries in Asia, Europe and America, with some studies having international research groups. The studies were mostly descriptive, experimental case studies made in laboratory conditions by exposing phantoms. The data was collected of exposures from phantoms made from aluminum including steps from human cadavers including the mandible and/or teeth [11–14,18–28,34,35,39,40,42,43,47]. Retrospective image analysis was performed in four studies [15,36,37,44] and patients were exposed in six studies [37,41,48–51]. Head phantoms were used in order to optimize programmes and collect doses [42,47] or to measure organ doses with Thermo luminescence Dosimeters (TLDs) [45,46]. Patients' doses in dental imaging were collected from clinical practice [52]. The data was analysed either by Mean Grey Values or evaluating image quality by several observers. Multiple regression analysis and other mathematical methods were used (Table II).

Studies according to dental imaging modalities

Articles about intra-oral dental imaging [10–32] considered image quality, fading of Storage Phosphor Plates (SPP) and quality assurance in intra-oral imaging and there was also one article about contamination of SPPs in clinical use [16]. One article was also committed to positioning from the point of view of image quality [15]. In articles about fading, we found both signal fading and loss in image quality after some minutes [24,26,29–31]. On the other hand, some articles showed no or small signal fading without loss of information [19,20]. Also the re-use of SPPs varied in the studies. According to one study, SPPs can be used more than hundreds of times without significant loss of image quality [17] and, according to another one, 95% of our plates were rendered non-diagnostic after only 50 uses [10]. Image quality or image quality with different doses from different points of view was researched in the studies found. There were studies about comparing between conventional and digital systems and about comparison between different digital systems [11,14,19–21]. Other aims of the selected studies were the effect of scanning resolution to image quality [23], the effect of luminance and bit depth to image quality [22], generator's effect [18] and artifacts in intra-oral images [15]. The effect of partial erasing was also studied [25]. Two methods for quality assurance in intra-oral imaging were developed [12,13] and quality assurance methods for both intra-oral and extra-oral equipment was researched in one article [33].

Panoramic dental imaging issues were focused on image quality and dose optimization and on comparing between different film-screen systems and/or digital systems [48–51]. Four of them were patient studies. Effective dose was compared with conventional and digital systems [46] and the effect of paediatric settings in panoramic imaging was studied by effective dose in phantom study [47]. Methods for dose calculation in dental imaging overall was also studied [52].

Cone Beam Computed Tomography (CBCT) is quite a new method in dental imaging [1]. The use of CBCT in clinical practice was studied extensively in one article [37]. Dose and image quality were studied [39,40,42] and image quality between intra-oral images and CBCT was compared [40] as well as doses between CBCT, computed tomography and panoramic imaging [45]. Doses to children were studied in a phantom study [42] and different methods for dose calculation were tested [38]. In a retrospective study, picture analysis was performed of CBCT pictures [44]. Quality and differences of *displays* in dental imaging and lightning was also studied [34–36].

Core competencies in digital dental radiological imaging quality assurance

Core competencies needed by the healthcare staff, radiographers, dental nurses, oral hygienists and dentists in performing digital dental radiological imaging quality assurance described in the selected studies were:

(1) *Competence in management of dental imaging equipment: x-ray generator, image receptors, scanners and displays*. The healthcare professional needs to be able to manage the equipment and to know how to use the programmes and features of the

Table II. Selected studies by dental imaging modality.

Main categories according to modalities	Total number of articles and reference number	Country	Type of research
Cone beam	9 (37–45)		
Image quality (4) Dose (5)		Japan (2), Finland (2), Germany, Sweden (2), Denmark and Brazil, Bulgaria	3 *in vivo*, others *in vitro*, 1 retrospective study of image quality
Panorama	6 (46–51)		
Image quality (4) Dose (2)		Greece, Japan, Bulgaria, Germany, Turkey and India	4 *in vivo*, 2 *in vitro*
Intra-oral	23 (10–32)		
Image quality (13) Fading (8) QA (1) Contamination (1)		USA (5), Taiwan, Brazil (3), Turkey and Sweden, Japan (3), Turkey (4), Korea, The Netherlands (3) Germany, UK	*in vitro* (aluminium phantoms or human bone/teeth), samples from SPPs
Displays	3 (34–36)	Sweden	image analysis
Dose all modalities	1 (52)	Sweden	*in vivo*
QA	1 (33)	Italy	*in vitro*
Total number of articles	43		

equipment. They also need to know the effect of each choice to image quality and patient dose. The type of image receptor, its features and scanning, storing and handling must be familiar to the staff [17–21,23,26,28,31–36,38,39,42,49].

(2) *Competence in image quality and factors associated to it*. Optimal image quality according to the indication and means how to achieve it are one of the most important abilities in imaging professionals' clinical work. The staff has to know what elements affect image quality and how to follow-up patient doses regularly. In digital dental imaging this is even more important than in conventional because there is no feedback on under- or over-exposure [11,13–16,19,20,22,23,25–27,29,31,37,39,41–44,48–51].

(3) *Competence in dose optimization*. Dose optimization is very closely associated with image quality. The staff has to be aware of the Dose Reference Levels (DRLs) in national and international level and they must be able to compare the doses of their own unit to those. Choice of modality, choice of programmes and sensitivity of image receptor must be under control. Dose optimization is particularly important in imaging children and young adults, as well as pregnant women [11,12,16,18,20,37–43,50,52].

(4) *Quality assurance competence*. Quality control tests of equipment, image receptors, scanners, monitors and lead aprons must be part of imaging professionals' everyday work. The staff must be aware of artifacts in images (what they look like, what causes them and how to correct them) as well as abnormal function of equipment or kVp/mA/s creeping. The viewing conditions and displays must also be included in the QA programme [10,12,16–18,24,25,28–30,44] (Figure 2).

Discussion

Dental radiological imaging has moved from conventional film-screen imaging to digital imaging during the last 15 years. The change has been important, especially in intra-oral imaging, because digital imaging is much quicker and easier for the user and that is probably why, in Finland, for example, the number of intra-oral images has increased substantially in recent years [53]. Intra-oral digital radiography offers still a potential for significant dose reduction; some studies report that, depending on the diagnostic task, a lower exposure may be used when density and contrast is adjusted using the software features. The type of the image receptor may affect image quality and dose needed as well as the loss of information due to delay in scanning [10–14,17–19,54]. Another change is emerging use of the CBCT in dental imaging. It offers a lot of new possibilities but also higher doses [53,54]. It is important that quality

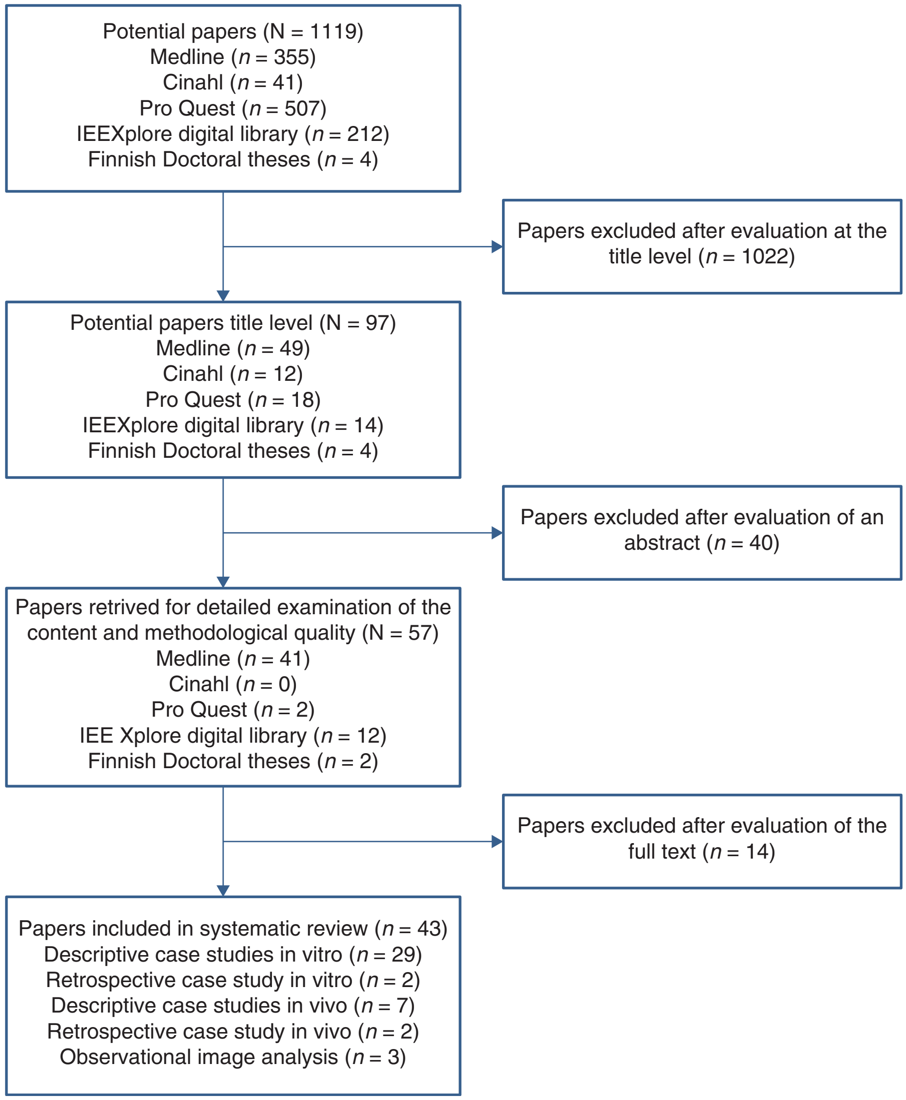

Figure 1. The selection process of the studies and findings by research type.

assurance education associated to intra-oral imaging is very practice-oriented since thereby it serves best also the needs of dental nurses and oral hygienists who take a lot of intra-oral x-rays and have less theoretical quality assurance education in their basic studies than radiographers or dentists. This should be taken into account in planning this kind of education.

Dental imaging staff must be able to perform routine quality control with proper maintenance and they also have to be able to check all the standard dose reduction features. For each imaging modality, there are many actions that can be taken to achieve a significant reduction in dose and still have high image quality [54,55]. The staff must have competence to execute routine tests of the functions of the equipment, measuring image quality parametres regularly, not forgetting the image receptors. They should also check that exposure settings used are the minimum consistent with the type of the imaging system used [55–58] as well as according to patient's size [42,44].

Dental imaging staff need education that will help them to perform optimally indicated, clinically good quality dental x-rays respecting the ALARA—as low as reasonably achievable—principle, taking into account the special needs of different kinds of patient groups. When switching to digital image receptors, the retake rate can increase, mainly due to wrong positioning of the X-ray tube and small image receptor with respect to the region of interest (ROI). Furthermore, repeating the exposure is much easier when using digital receptors and this has been reported to lead to increased reject rates and course artifacts [15–17,55]. The effect of ambient light and monitor brightness and contrast settings may also influence image quality and accuracy of the diagnosis [22,34–36] and measuring the monitors and ambient light are also parts of quality control tests and competence in dental imaging [55]. Scanning resolution and bit depth are

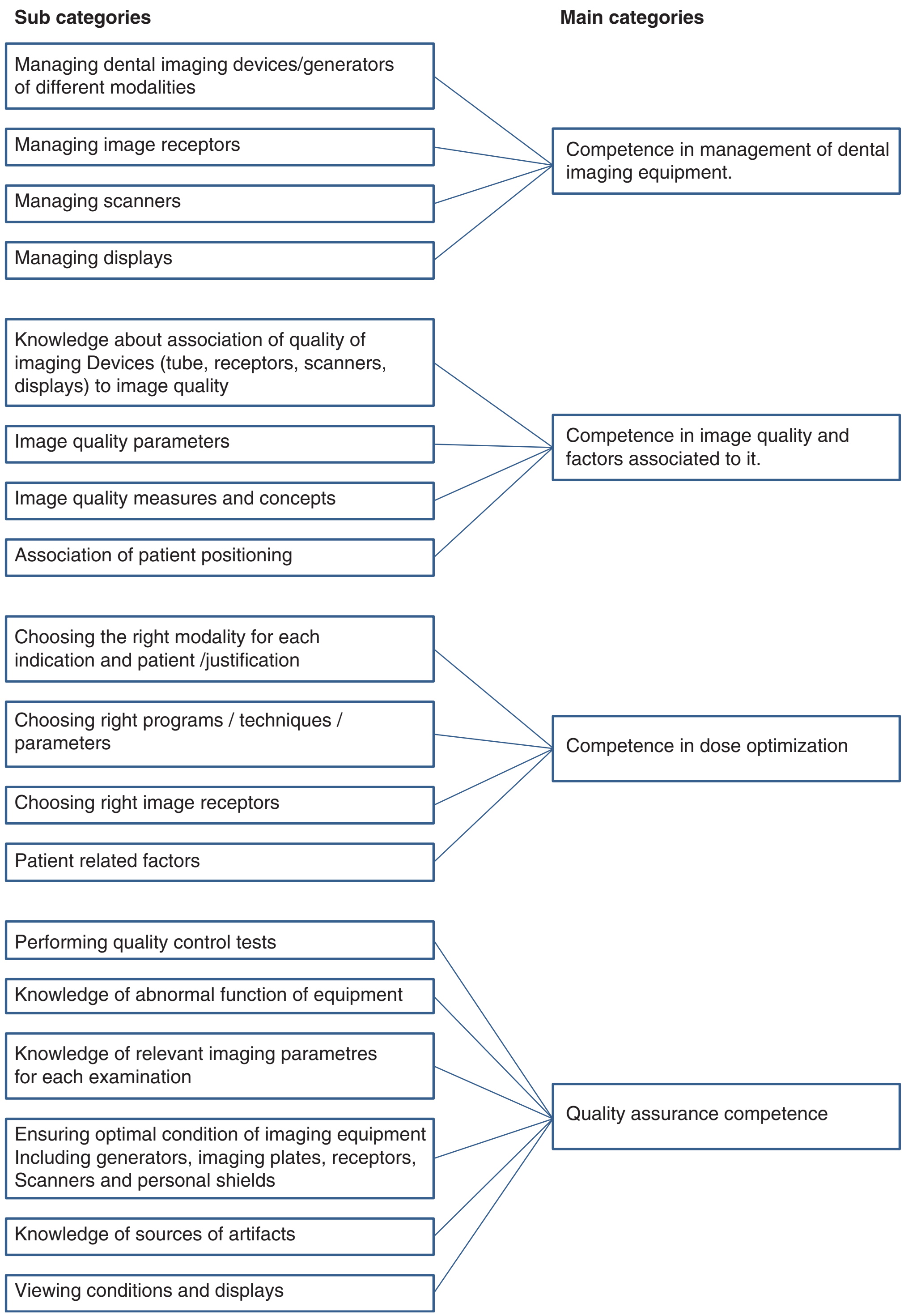

Figure 2. Core competencies in digital dental radiological imaging quality assurance.

also important in digital imaging and effect on image quality [22,23]. Although radiation exposure arising from dental radiology is low, a child may undergo many repeated procedures during childhood and adolescence. Therefore, the accumulated effect of radiation exposure should be taken into consideration. The salivary and the thyroid glands are among the organs at risk in dental radiology. The salivary glands are often within the primary beam, while the thyroid receives a dose mainly due to scattered radiation [42,45,59]. The staff must be aware of dose calculation methods and limits they have [38,42,45,55]. Especially the CBCT may increase doses from dental imaging and the users must be aware of the possibilities to optimize the doses according to the indication [37,39–43].

Evaluating the limitations and bias of the systematic review

The review question was defined according to PICo-model (Patient or population–phenomena of Interest–Context) instead of PICO (Patient or population–Intervention–Comparator–Outcome). PICo is often used when the aim of the systematic review is descriptive and it is anticipated that the review will comprise various types of studies instead of just quantitative ones [9]. In this review this seemed to be a right decision since the review resulted in the kind of studies that using the PICO-type of question setting could have excluded them. For the purposes of this review the databases used seemed relevant and sufficient since each of them produced some articles not present in other ones but also a lot of duplicates which indicate saturation. Use of the IEEXplore digital library may have been unnecessary because using this database did not produce articles that were not present in the other databases. Keywords used were sufficient. Using Mesh terms produces quite little results since the topic is the kind that there are applicable little Mesh terms.

The authors of the article performed searches from the databases instead of having this done by librarians. The librarians were consulted in the search process, especially about the search terms and keywords relevant for different databases. The search was performed by the authors because the phenomenon in question is about a special subject not very well known by librarians. Two of the authors made the analysis together side-by-side and negotiated about it between the different phases. The result was a compromise of the negotiation. The process was quite clear and there were not many discrepancies during the analysis, which indicates the validity of the analysis.

Quality of the selected studies varied. Here the quality of studies was not evaluated according to levels of evidence typically used in systematic reviews having their main aim to show evidence about the effect size of some phenomena. The aim of this review was descriptive and this is why the quality of the studies was assessed according to the researchers' performance in each study type. Most of the studies were good quality, satisfying at least eight of the 10 evaluation criteria [10,11,17,22,23,25–27,29,32,34–38,40,41,43,44,46,47,49,51,52]. Fourteen of the studies fulfilled five-to-seven quality criteria fully and may be evaluated as satisfying level studies [13,14,18,19,21,24,28,30,31,39,42,45,48,50]. There were also three studies of quite low quality [12,16,33], but they were included in the review because they contributed important knowledge about the topic.

Like mentioned previously, most deficiencies were in describing sources of bias and in the description of variables, especially confounding ones.

There were many articles from the 1990s but they were not included in this systematic review. A lot of articles dealt with conventional dental imaging or compared x-ray films sensitivity and image quality to those of digital image receptors. The studies were mostly experimental using phantoms. The results were not tested in clinical practice. That may cause problems in applying them in practice, but on the other hand it is not ethically acceptable to expose people without any benefit to them. Making the literature search and writing this article took almost a year. This may have resulted in a bias in terms of the results. During the time this article will be published there may be some new research from the topic that is not included in this review.

Conclusions

Core competencies needed in clinical work by the healthcare staff (radiographers, oral hygienists dental nurses and dentists) in performing digital dental radiological imaging quality assurance are:

(1) *Competence in management of dental imaging equipment: x-ray generator, image receptors, scanners and displays*. The staff have to know thoroughly the function and features of the equipment in order to find any malfunction, artifacts, etc.
(2) *Competence in image quality and factors associated to it*. Image quality and how to follow-up patient doses regularly. In digital dental imaging this is even more important than in conventional imaging because there is no feedback on under- or over-exposure.
(3) *Competence in dose optimization*. The staff have to be aware of the Dose Reference Levels (DRLs) at national and international levels and compare doses of own unit to those. Choice of modality, choice of programmes and sensitivity of image receptor must be under control. Care must be taken, especially with children and young adults as well as pregnant women.
(4) *Quality assurance competence*. Management of Quality assurance tests of equipment, image receptors, scanners, monitors and lead aprons must be part of everyday work. The staff must be aware of artifacts in images (what they look like, what causes them and how to correct them) as well as abnormal function of equipment or kVp/mA/s creeping. The viewing conditions and displays must also be included in the QA programme.

Studies about dental imaging quality assurance had mostly their focus elsewhere than in the competencies needed. There is a need for focused high quality research about dental imaging quality assurance competence in the field. In the future there will be higher doses in dental imaging due to increasing use of

CBCT and digital imaging. The staff performing x-ray images must be highly educated and have competence in the issues found in this review. They also have to demonstrate an ethical radiation safety culture in clinical practice.

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