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DIAGNOSTIC CRITERIA AND DOSE LIMITING APPROACHES FOR IMAGE MODALITIES IN ODONTOLOGY

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The drawings on both the cover and page 57 are made for this specific thesis, from the other side of the Atlantic, by Josefin Benchimol. Thank you!

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Diagnostic criteria and dose limiting approaches for image modalities in odontology

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Till Karin, Tim, Josefin, Siri och Ellinor

Jag är i ljuset

Jag sitter på toppen

Å jag älskar jorden

Blomman är min

Jag älskar min familj

Siri Benchimol

Livet förstås baklänges men levs framlänges

Sören Kierkegaard

In memory of Lova Dahl (2004-2017)

ABSTRACT

Objectives

Technical innovations in radiography enable the development of new approaches to reduce the dose to patients. The aim of this thesis was to explore dose optimization approaches for the most frequently used radiographic modalities in dentistry

Material and Methods

Intraoral radiography

The performance of the Automatic exposure control function (AEC) was tested on dry mandibles with soft tissue equivalent of different thicknesses. Furthermore the image quality was compared between images exposed manually and with AEC function.

Two different generations of direct digital intraoral sensors, based on charged couple device (CCD) and complementary metal oxide semi-conductor (CMOS) were compared in terms of dose response function, minimal perceptible contrast details and minimal perceptible exposure difference.

Panoramic radiography

Effective doses obtained from panoramic examinations with ten different collimation features were assessed using the metal-oxide semiconductor field-effect transistor (MOSFET) method. In addition, the applicability of the collimation function under clinical situations was evaluated.

Cone Beam Computed Tomography

Optimized exposure protocols for temporomandibular joint (TMJ) examinations on a phantom were obtained for CBCT and MSCT through subjective image quality analysis. Effective doses, before and after, optimization were compared for CBCT and MSCT using thermoluminescent dosimeter (TLD) technique.

Results

The exposure times using AEC were adjusted automatically according to the thickness of the objects and the resulting image quality was considered adequate by observers. The CMOS sensor was more sensitive to radiation and presented better image quality on low contrast details perception compared to the CCD sensor.

The calculated effective dose of a full size panoramic radiograph was 17.6 μSv at 8mA and 66kV. In 61% of the studied referrals, a collimation including the dental alveolar region was applicable, providing a dose reduction by 40.3%.

The effective doses for bilateral TMJ examination was 92 μSv for CBCT and 124 μSv for MSCT. The image quality of CBCT was considered better than that of MSCT.

Conclusions

AEC might be a feasible approach for acquiring intraoral digital radiographs with good image quality. ProSensor with CMOS technique was preferred in comparison to Dixi sensor with CCD technique due to lower exposure and better detectability of low contrast details.

Collimating panoramic radiographs was an effective approach to reduce radiation dose to patients when clinical indication allowed.

For TMJ examination CBCT was preferred to MSCT due to better image quality at comparable effective doses.

LIST OF SCIENTIFIC PAPERS

I. **Benchimol D**, Näsström K, Shi XQ. Evaluation of automatic exposure control in a direct digital intraoral system.
Dentomaxillofacial Radiology. 2009;38:407-412

II. Shi XQ, **Benchimol D**, Näsström K. Comparison of psychophysical properties of two intraoral digital sensors on low-contrast perceptibility.
Dentomaxillofacial Radiology. 2013;42:20130249

III. Kadesjö N, **Benchimol D**, Falahat B, Näsström K, Shi XQ. Evaluation of the effective dose of cone beam CT and multislice CT for temporomandibular joint examinations at optimized exposure levels.
Dentomaxillofacial Radiology. 2015;44:20150041

IV. **Benchimol D**, Kadesjö N, Koivisto J, Shi XQ. Effective dose reduction using segmenting function in digital panoramic radiography and possible clinical implications in dentistry. *Submitted.*

Scientific paper related to, but not part of, the thesis

Liljeholm R, Kadesjö N, **Benchimol D**, Hellén-Halme K, Shi X-Q. Cone-Beam Computed Tomography with Ultra-Low Dose Protocols for Pre-Implant Radiographic Assessment: An In-Vitro Study. Eur J Oral Implantol 10 (2017), No. 3 (22.09.2017)

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LIST OF ABBREVIATIONS

AEC	Automatic exposure control
CBCT	Cone-beam computed tomography
CCD	Charged couple device
CMOS	Complementary metal oxide semi-conductor
CTDI	Computed tomography dose index
DAP	Dose area product
DLP	Dose length product
DMFR	Dentomaxillofacial radiology
FOV	Field of view
Gy	Grey
ICRP	International Committee of Radiation Protection
LAR	Lifetime-attributable risk
LNT	Linear no-threshold
MSCT	Multi-slice computed tomography
P	Pitch
PAN	Panoramic radiography
PC	Perceptibility curve
ROI	Region of interest
Sv	Sievert
SD	Standard deviation
TMD	Temporomandibular disorders
TMJ	Temporomandibular joint
ULD	Ultra low dose

1 INTRODUCTION

Accurate diagnosis is essential to ensure the most effective treatment of patients in dentistry. Among all diagnostic tools, the radiographic examination is one of the most effective methods for diagnosing hard tissue changes and is often used in dental clinics. However a disadvantage associated with radiographic examinations is the unavoidable radiation dose to the patients. The contemporary view is that ionizing radiation is always considered harmful with no safety threshold, termed the so-called linear no-threshold model (LNT) (1). The sum of low dose exposures have potentially the same effect as one larger exposure, which highlights the importance of risk assessment of ionizing radiation for diagnostic purposes.

According to the International Committee of Radiation Protection (ICRP), radiation examination of patients should be performed according to the principle “As Low As Reasonably Achievable” (ALARA), meaning that the radiation dose should be minimized as well as give adequate diagnostic information (2). The strategy of applying ionizing radiation issued by Swedish Radiation Safety Authority is in accordance with ICPR (3). The extent of the examination and the radiation dose level to a patient should be adapted in such way that the required diagnostic information is obtained at expense of minimally achievable radiation dose.

Minimizing the risks associated with the use of ionizing radiation for diagnostic imaging is an important public health issue since ionizing radiation has enough energy to potentially damage DNA and may therefore cause radiation-induced cancer later in life. This is especially important in children, who are more radiosensitive, and have a longer expected lifetime compared with adults.

Available cohort studies on possible associations between dental radiographic examinations and radiation-induced cancer later in life are rare due to low reliability of registration of exposed dental radiographs. In addition, many other confounding factors, such as life style, stress level, different radiation level in natural background, make it difficult to prove a connection.

A debated article by Claus et al (2012) found an association between intraoral bite-wing radiographs and panoramic X-rays and meningioma, although no association was found between full mouth dental radiographs and meningioma (4). The study was designed as a self-reported data registration from four different age periods, although questions were raised regarding the inconsistency of the results (5). Therefore, the appropriate theory might be that dental radiographic examinations alone cannot be proved to induce meningioma but perhaps together with other external exposures of radiation contribute to the risk of stochastic effects. All in accordance with the linear no-threshold (LNT) model.

Few studies have assessed the cancer risk from computed tomography (CT) made on dental indications. Wu et al (2015) estimated the association between dental implant CT examinations and the lifetime-attributable risk (LAR) of cancer incidence, and reported that in a 30 years-old age group, the LAR for cancer was 2.5 times higher in women compared with men (6). The evaluated factors included sex, scan position and age to the cancer risk. Using a 64-slice CT, the study reported a typical delivery of more than 5-fold radiation dose compared to CBCT. For all ages, the top four cancer risks of organs are thyroid cancer, other cancers, leukemia, and lung cancer contributing to 99% of the attributable risk from CT scans.

Thus, dose optimization is important since ionizing radiation at any dose level can potentially be harmful. In the field of medical and odontological imaging there are continuous developments of techniques and of the corresponding clinical examination protocols. These mainly aim at reducing radiation to the patient and to provide better image quality. The physical properties and effective dose levels of these new innovations or approaches should ideally be primarily tested *in vitro*. The resulting image quality and possible clinical applications need to be further confirmed by clinical studies before widely applied on the market. The obtained information from research will directly influence the choice of examinations and eventually effect treatment plan and the outcome for patients.

In diagnostic imaging, radiation dose level is closely related to the choice of image modalities and diagnostic task-related image quality. Thus in the following sections the most applied image modalities in dentistry, relating to common approach of effective dose measurements and diagnostic image quality will be addressed.

1.1 Image modalities

In this doctoral thesis, the following image modalities will be tested: digital intraoral radiography, digital panoramic radiography, Cone-beam computed tomography (CBCT) and multi-slice computed tomography (MSCT).

1.1.1 Intraoral radiography

The most common radiographic image modality in dentistry is intraoral radiography. In Sweden, analogue film has almost been completely replaced by digital techniques. A study by Svensson et al (2017) reported that 98% were using digital intraoral radiographic technique in a group of 1244 Swedish dentists (7).

Digital intraoral imaging technique can be either indirect, such as storage phosphor plate or direct, which comprises charged coupled device (CCD) and complementary metal oxide semiconductor (CMOS). With the CCD technique, a new feature was developed to facilitate an optimal exposure time regardless of patient size with automatic adjustment of exposure.

1.1.1.1 Automatic exposure control (AEC)

AEC function was developed to automatically adjust the exposure of radiographs according to the composition of the anatomy, and the thickness of the patient, thus reducing the number of retakes due to suboptimal image quality. However, before the technique was applied to intraoral radiology, AEC was established in more advanced radiographic modalities like CT and panoramic radiography. Since the exposure time in panoramic radiography was determined by the speed and path of the sensor, the tube head exposure rate could be adjusted by changes to kilovolt (kV) and milliampere (mA). Earlier research has shown consistently that better image quality was retrieved by using AEC compared to operator selected parameters in panoramic radiography (8). From one manufacturer, a default setting of the parameters were used initially followed by measurement of the mandibular ramus bone density. Depending on whether the measured dose differed from the expected dose the mA could be adjusted followed by the kV. To date, only one article has been published assessing AEC function in intraoral radiography (study I). The AEC method can be described as follows: an initial test exposure of approximately 4 milliseconds (ms) is performed; an algorithm analyses the test exposure and calculates the final exposure time accordingly. The purpose is to obtain a predetermined ideal radiation dose at the sensor. These steps are performed in approximately 0.5 s through an intercommunication between the X-ray device, the computer and the sensor.

1.1.1.2 Charged couple device (CCD) and Complementary metal oxide semi-conductor (CMOS)

The CCD technique was the first digital image receptor technique used in intraoral imaging. Since detectors are more sensitive to light than X-rays, a layer of scintillating material was commonly used to convert X-rays to light. In CCD detectors, the charge from each raw image are read and thus the location of each image element (pixel) can be identified within the image matrix by row and column coordinate. The charge is transmitted through a readout amplifier to an analog–to-digital converter. The sampled voltage from each pixel are given numeric values, designated as the grey level. The number of bits represents the depth of contrast resolution that a sensor can capture. Eight-bits (2^8) gives 256 gray shades, where 0 is black and 255 is white.

Conversion of X-ray photons into digital signals takes place in both CCD-based and CMOS-based sensors. CCD and CMOS differ in the transfer of electronic signal from each pixel. Most often the CCD sensor has only one output node for all charged pixels. When the sensor is exposed, signals are converted into voltage from the output node, buffered and sent as an analogue signal. In comparison, with CMOS, every charged pixel is converted to voltage individually, before going off-chip as digital bits, the voltage can then be amplified separately.

Inside the plastic casing of a CMOS sensor the components are as follows: first there is a scintillator that converts the X-ray beam into visible light, underneath a layer of fiber optics transmits the light to the surface of the CMOS sensor, providing high signal-to-noise ratio, the light is then converted to an electrical signal through the CMOS, where each CMOS element are read separately and finally, an electronic layer that transmits the electrical signal to the computer. In some instances, lying underneath the electronic layer is a protective shield that prevents back scattering.

1.1.2 Panoramic radiography

Panoramic imaging is a common extraoral radiographic method in dentistry, first commercially manufactured in 1961. The method has gained popularity as it enables an overview of the dentomaxillofacial region to be obtained in a single extraoral radiograph. The clinical indications for panoramic radiography are numerous, a possible indication can be assessing the mineralization of teeth in the developing dentition in order to apply a dental maturity method (9).

However, the method has limitations for the detection of the most common indications such as apical periodontitis (10-12), caries (11) and periodontal bone loss (13). Therefore, indications for additional intraoral radiographs are common, and if a full mouth radiographic examination is performed the necessity for a panoramic radiograph might be questionable.

In general practice, routine dental panoramic radiographic screening of new patients lacks indication (14). According to international recommendations prescription of dental radiographic examination needs to be made on an individual basis, have justification as well as be optimized (15).

After the ICRP revised the organ weighting factors in 2007, attention towards effective doses for oral and maxillofacial radiographic examinations increased. Evaluation of two different panoramic radiographic devices with the CCD sensor technique, revealed changes in effective dose ranged between 231-241% due to variations of tissue weighting factors between ICRP 1990 and ICRP 2007 (16). Recently, the increase in absorbed organ dose and effective dose from digital panoramic radiography when applying the ICRP 103 instead of the ICRP 60 recommendations was emphasized in a study demonstrating the importance of the clinician’s awareness of the dose (17). However, this was under the proviso that the diagnostic outcome was the same when trying to evaluate and apply the dose reduction of panoramic radiography.

Minimizing the field of view (FOV) is a simple and effective dose reducing approach, which should be considered in all radiographic examinations. The application of a panoramic collimation feature, makes it possible to minimize the unnecessary doses to patients in available devices. Collimation of panoramic images is available in several modern digital panoramic X-ray units. Reduction of FOV are possible both in vertical and horizontal directions by closely relating the FOV to specific diagnostic tasks, thus avoiding exposure to areas where diagnostic information is not of interest. A recent study reported patient dose reduction by applying collimated panoramic radiography in the vertical direction, and the effect of two different collimator slit heights, 110mm and 140mm, on effective dose were compared in a panoramic system. Considering the differences in exposure time and collimator height for children and adults the effective doses were 7.7µSv and 11.4µSv respectively (18).

1.1.3 Cone-Beam CT and Multi-slice CT

CBCT was introduced into the field of dentistry around the end of the first millennium, making it a relatively new technique. Since the introduction CBCT has become a popular modality. Reasons for the increasing popularity are the enabling of volumetric jaw bone imaging at reasonable costs combined with low radiation doses and affordable in-house equipment (19).

The two techniques, CBCT and MSCT, have technical differences. Modern CBCT uses flat panel detectors that have smaller detector elements compared to a MSCT detector array that results in higher spatial resolution in the CBCT images. However, a drawback to flat-panel detectors are reduced low-contrast resolution. Defining the FOV also differs between CBCT and MSCT, where CBCT has predefined FOV of various size depending on model. With MSCT, the diameter of a volume is predetermined while the length in the superior-inferior direction can be chosen freely. In MSCT the term slice pitch is used describing the distance that the patient table travels during one 360° gantry rotation divided by total thickness of all simultaneously acquired slices.

1.2 Effective dose assessments

The concept of effective dose was proposed by Jacobi in 1975 (20). Effective dose is calculated by multiplying tissue-weighted equivalent dose with the weighting factors for each organ derived from the ICRP. Effective dose measures the sum of the tissue-weighted equivalent dose of low levels of ionizing radiation in the specified tissues and organs representing stochastic health risk, such as cancer induction and genetic effects. Effective dose is the central quantity for dose limitation in the international system of radiological protection of ICRP (15). Sievert (Sv) is the SI unit and for diagnostic imaging in dentistry is commonly expressed in microsieverts (μSv) (21).

The absorbed organ dose can be assessed by several different methods. The most commonly used method is thermoluminescent dosimeter (TLD) technique (22-25). Digital dosimeters applying metal-oxide-semiconductor-field-effect-transistor (MOSFET) technique enables real-time dose monitoring (26-29). Other methods of assessing the effective dose are the Monte Carlo simulation and GafChromic film. Monte Carlo (MC) dosimetry is an alternative approach to TLD dosimetry, involving the simulation of particles and their interaction with matter (30-33). With GafChromic film, darkening of the film is dependent on the received radiation exposure (34-36).

1.2.1 TLD method

TLD are placed inside a Rando phantom in the regions of radiosensitive organs. When ionizing radiation hits the TLD during exposure, positive charged atoms appear when electrons are freed and moved inside the material. After the exposures, which are often repeated in order to increase the reliability, the dosimeters are removed from the phantom and read out by heating the TLDs. Electrons return and energy are released in the form of light. The light intensity is then measured and related to the amount of energy that was initially absorbed through exposure. The method is time consuming and requires manual labor since the phantom has to be dismantled, TLDs removed and positioned in the device for reading out the dose. A recent study by Kadesjö et al (2018) using TLD addresses the dose contribution when accessing the position of impacted maxillary canines between two different CBCT, panoramic radiography and intraoral radiography (35). The study concluded that the effective dose from CBCT examination was between 15 and 30 times higher, for two different devices, for the bilateral examination of maxillary canines than using three periapical radiographs and one panoramic radiograph.

1.2.2 MOSFET method

MOSFET is similar to TLD in that the dosimeters are positioned in radiosensitive organs in a phantom. However, instead of removing MOSFET dosimeters prior to reading, cables connecting the dosimeters to the reading device allows measurements to be obtained almost in real-time at exposure. The technique within the dosimeters is based on electron-hole pairs generated within a layer of silicon dioxide by incident radiation. Electrons trapped in long term sites, result in negative threshold voltage shifts, which can persist for a long time. Measurements of the differences in voltage shift prior to and after exposure is proportional to dose enabling dose measurements. MOSFET has been compared with TLD regarding low-dose measurements and when averaging multiple exposures the two methods are in agreement for dosimetry using anthropomorphic phantom.

Figure 1. MOSFET in panoramic radiography dosimetry

1.3 Diagnostic image quality

Radiographic imaging is the final product of image acquiring processing that passes through many steps before viewing. The generation of images of diagnostically acceptable quality at low patient dose is a key objective of diagnostic radiography. Image quality refers to the fidelity of the examined anatomic structures on the radiograph. Characteristic of image quality are signal-to-noise ratio (SNR), contrast resolution, spatial resolution and artefacts.

The term SNR is used in radiology to measure true signal, providing true information, in relation to noise. A higher SNR generally results in high image quality with low grainy appearance. When reducing the number of photons, like decreasing the tube current and/or exposure time to reduce the absorbed dose, radiographs normally become noisier. Increasing the tube potential reduces the absorption of photons but also reduces the SNR. In CT and CBCT decreased slice thickness generally reduces SNR.

Contrast resolution, as well as, spatial resolution are important aspects of image quality. Contrast resolution is the ability to distinguish between different light intensity levels in a radiographic image. Good contrast resolution in an imaging modality is of importance in dentistry, for example in detection of initial caries. Spatial resolution describes the capability of an imaging system to resolve fine details of a studied object, which has been traditionally assessed in line-pairs per millimeter. In order to achieve fine structures, high-spatial resolution protocols in imaging systems requires small pixel/voxel size that also demands increased dose. Patient motion has a negative effect causing a blur in the image (37). Since CBCT requires a relatively long exposure time the risk of motion artefacts are real. Today several manufacturers offer features limiting the artefacts caused by motion.

The physical properties of a given image system in terms of contrast resolution and spatial resolution are usually provided by the manufacturer. However when it comes to clinical application, the subjective image quality needs to be evaluated by the clinician due to the involvement of visual perception, clinical experience and individual preference. Most importantly, acceptable image quality varies depending on the diagnostic tasks.

1.4 Radiographical examination of temporomandibular joints

Radiographic examination is of importance for detecting changes in the osseous tissue components of the temporomandibular joint (TMJ). Compared with other available radiographic techniques, tomography is considered as the most accurate method for diagnosing structural changes of the TMJ (38).

A review article by Larheim et al (2015) described the usability of CBCT in examinations of the temporomandibular joint (TMJ) when evaluating different conditions involving the morphology of the osseous joint components, subcortical osseous abnormalities and cortical bone integrity. CBCT was superior in the assessment of osseous TMJ abnormalities compared to conventional radiographic methods, as well as being a cost- effective alternative to MSCT. A common modality for examining pathology involving the TMJ is MSCT that has been reported to be an alternative in primary bone lesions and trauma (39).

2 AIMS

2.1 GENERAL AIM

In this doctoral thesis, several approaches designed to reduce radiation dose to patients were studied in the most frequently used digital radiographic modalities in dentistry. Since the purpose of exposing the patient to ionizing radiation is to obtain adequate diagnostic information, the reduction of radiation was always analyzed in relation to maintaining adequate requested image information.

2.2 SPECIFIC AIMS OF STUDIES

2.2.1 Study I

Performance evaluation of AEC function in an intraoral direct digital system, regarding ability to determine adequate exposure time and image quality adjusted to object thickness.

2.2.2 Study II

Comparison of the psychophysical properties of two direct digital intraoral sensors based on CMOS and CCD, in terms of dose response function and perceptibility curve (PC) test.

2.2.3 Study III

Effective dose of a CBCT device in comparison to a MSCT device using current clinical protocols for TMJ examinations. In order to optimize exposure levels, the image quality for sequential exposures were assessed for both MSCT and CBCT.

2.2.4 Study IV

Estimation of the effective dose from full size panoramic radiography and nine different collimation protocols using an adult phantom. Retrospective assessment was performed on possible clinical applications of the collimation function by using records of radiographic examinations at a specialist clinic.

3 MATERIAL AND METHODS

3.1 Study setting

All the dose assessments in this thesis were performed under *in vitro* settings.

3.2 AEC function

For test objects seven dry human half mandibles with teeth were used.

AEC function was integrated in the FocusLink^{TM} system consisting of Focus^{TM} X-ray unit, SIGMA^{TM} direct digital sensor and ClinicView^{TM} dental diagnostic software (GE Healthcare, Tuusula, Finland). The exposure parameters were fixed at 70 kV and 7 mA, whilst the exposure time was automatically set by the system. The focus to object distance was 37.5 cm and Plexiglas was used to simulate soft tissue.

All the acquired radiographs were exposed in a standardized setting using a laboratory stand holding the Plexiglas and clay to fix the sensor and mandible halves. Parallel technique was employed throughout image acquisition.

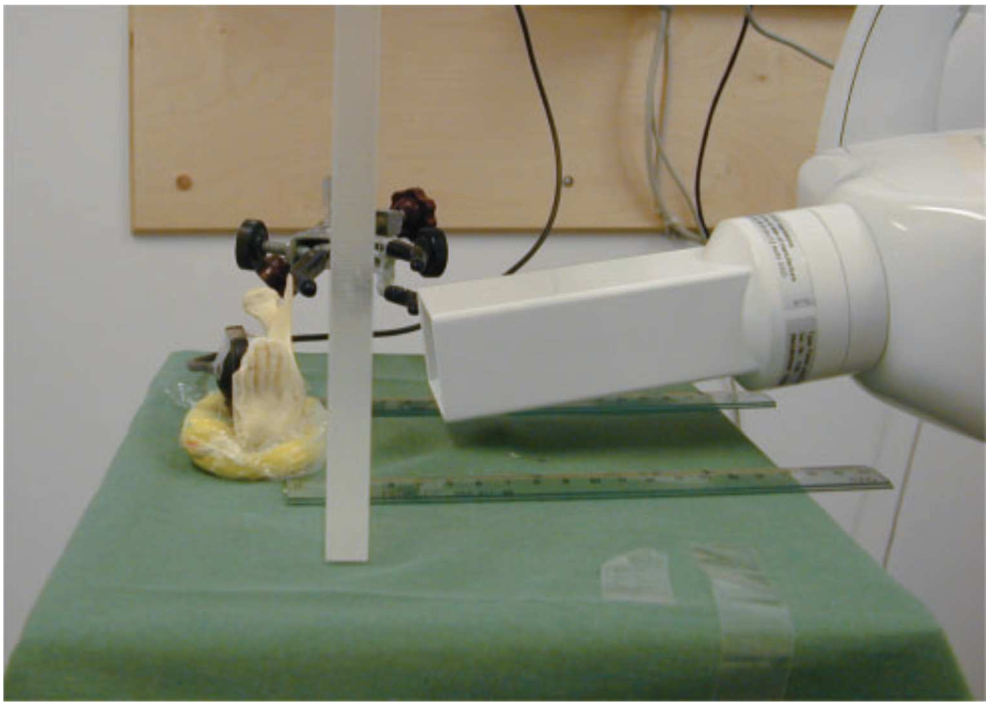

Figure 2. Experimental setup.

The efficiency of AEC function was evaluated by two different approaches, subjectively by six observers and objectively by analyzing the exposure time in relation to the thickness of soft tissue equivalent.

The objective evaluation was performed as follows. Three images were captured in the molar and premolar region, for each mandible half, with the AEC function activated. To simulate patients of different size the following parameters were employed; 1 layer equaled normal sized patient (AEC 1), 2 layers represented a larger sized patient (AEC 2) and without Plexiglas a small sized patient (AEC 0).

In total 21 (3 x 7) raw images, without any image processing, were exported as 8 bits data to the dental imaging software Dimaxis™, (Planmeca™, Finland). Subtraction was performed between image pairs to compare light intensity between exposures with different soft tissue equivalents. Among the subtracted images there were three possible pairs, AEC 0 - AEC 1, AEC 1 – AEC 2 and AEC 0 – AEC 2. The gray levels of corresponding pixels were subtracted by superimposition of the two radiographs (Figure 3). The value of 127 was added to each pixel on the subtracted image to allow the best perception for human vision (Figure 4).

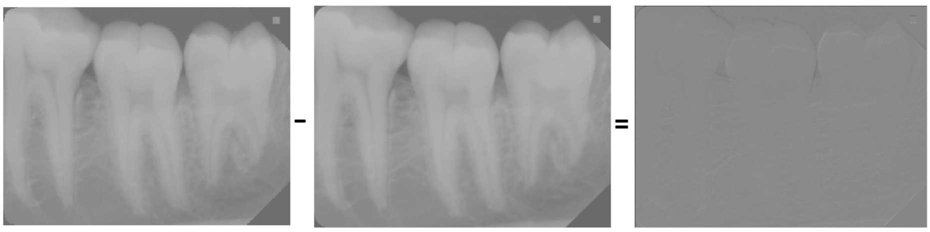

Figure 3. Subtracted image as a result from two intraoral radiographs

Four reference points were manually positioned for each pair of images, for each mandible half. Histogram distribution analysis of the subtracted images were performed. Differences in light intensity between the pairs of images were made by mean value of gray levels and its standard deviation (SD).

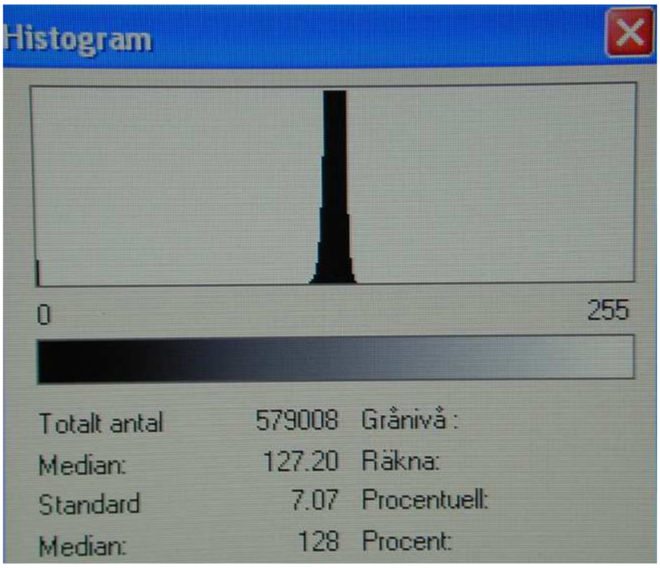

Figure 4. Histogram of subtracted image

For the subjective evaluation of the AEC function, six observers evaluated 35 (5 x 7) images, all with different exposure times for each mandible half. Exposure time ranged from two manually set steps below to two manually set steps above the exposure time determined by the activated AEC function. All images were exposed with one layer of Plexiglas. The observers evaluated the images in a random order regarding the exposure time.

3.3 Evaluation of digital intraoral sensors

Dose response functions for both detectors, ProSensor (CMOS) and Dixi (CCD), were determined by means of exposure to a homogeneous X-ray field. A Planmeca X-ray unit was used at 66 kVp and 8mA. The focus-to-object distance was 25 cm. In order to cover the whole exposure latitude of both types of detectors a number of exposures were obtained. With a calibrated ionization chamber (Model 1035-6; Radcal Corporation, Monrovia, CA) exposures were measured and expressed in microcoulomb per kilogram (μCkg^{-1}).

For each exposure time, five exposures were made and the mean values calculated. The test images were saved as raw 12 bits data without applying any processing algorithm. Within the active area of the two detectors the mean gray levels were measured for each exposure time using the Romexis™ (Planmeca Oy) software.

For constructing perceptibility curves (PCs) an aluminum test object was used. The test object size was a 25 x 25 x 10 mm, covering the total active area of the tested direct digital intraoral sensors (Figure 5). Series of cylindrical wells of different depths were randomly arranged as had been used in an earlier study (40). The depth of the holes ranged from 0.03 to 0.3 mm in steps of 0.03 mm with a standard deviation of 0.01mm. From a total of 16 possible positions, 10 contrast details were randomly chosen.

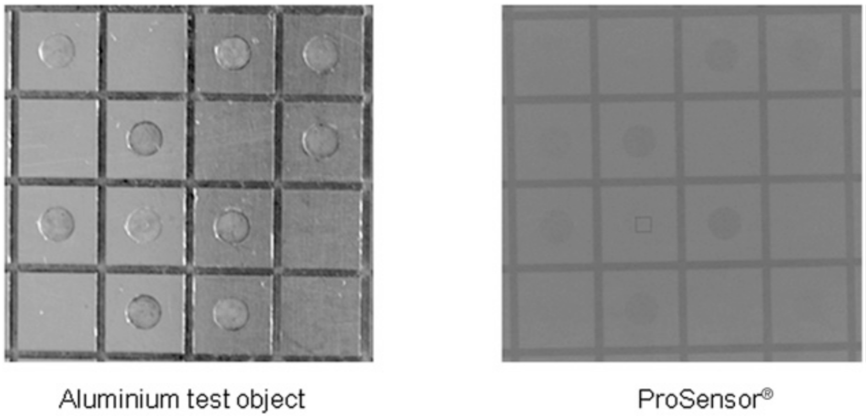

Figure 5. Aluminum test object and test radiograph.

Fourteen exposures were made in total, on the test object, with exposure time ranging from 0.012 to 0.32 s for each sensor from marked underexposure to full saturation. All the test radiographs were exposed with the same setting as the dose response test. The test object was randomly rotated and positioned in one of four possible rotations (0°, 90°, 180° and 270°) before the radiographs were exposed. The reason for this was to prevent observers from recognizing the pattern of the cylindrical wells with different depths to the test object.

A total number of 28 images exposed using both ProSensor and Dixi were randomly arranged in one sequence. Radiographs were displayed in the center of the monitor with a background of dark gray. Twelve observers were instructed to view each radiograph for at least 15 s and then register the number of perceptible object details without adjusting the brightness or contrast of the computer screen during viewing. The registered observations were used to construct a PC, where the reciprocal of the minimum perceptible exposure difference was plotted as a function of exposure.

3.4 Evaluation of effective dose

The quantity effective dose (E) can be used to compare patient dose when using different examination techniques. It is defined by a weighted sum of tissue equivalent doses as:

$$E = \sum_{T} w_T H_T$$

wT is the tissue weighting factor for tissue T and ∑ wT = 1. The sum is performed over all organs and tissues of the human body considered to be sensitive to the induction of stochastic effects. These wT values are chosen to represent the contributions of individual organs and tissues to overall radiation detriment from stochastic effects. HT is the equivalent dose in tissue T. The unit of effective dose is Sievert (Sv).

3.4.1 Study III

The modalities compared were:
- Promax® 3D (Planmeca, Helsinki, Finland) CBCT with 8.0-mm aluminium half-value layer and 210° scan angle.
- GE LightSpeed VCT (GE Healthcare, Little Chalfont, UK) 64-slice MSCT unit and medium bowtie filter (6.4-mm aluminium half-value layer) was used.

Measurements of organ doses were performed on an Alderson Rando® (Alderson Research Laboratories, New York, NY) adult male anthropomorphic phantom with TLD-100, placed at 61 sites within the head and neck region with two detectors at each site. TLDs were read with a Harshaw 5500 (Thermo Scientific™, Waltham, MA) reader. The effective doses were calculated by multiplication of the mean organ doses, from the pair of detectors at each site, with the weighting factors from the ICRP publication calculated 103. Interclass correlation was used to evaluate consistency between detector readings. The clinically used exposure protocol for MSCT was the same used by the Karolinska University Hospital, whilst the CBCT settings were recommended by the manufacturer. In the dose measurements for the CBCT two scout images, frontal and lateral were included whereas for the MSCT, a lateral scout image was included.

The exposure parameters used for ProMax 3D was 90 kV tube voltage, 12 mA tube current and 12 s exposure time with a 4 x 5 cm cylindrical FOV, resulting in a dose area product of 606 mGy cm^{-2}. For LightSpeed

VCT, the following parameters were used: a helical scan with 120 kV tube voltage, 73 mA tube current, 0.5 s rotation time, 0.969 pitch with a scan length of 3 cm, resulting in a dose length product (DLP) of 38.26 $mGycm^{-1}$ and a volume CT dose index (CTDI) of 7.42 mGy.

3.4.2 Study IV

Dose measurements were made on an Alderson Rando anthropomorphic adult phantom similar to the phantom used in study III. The phantom was fixed at the same position during all exposures, ten for each collimation. For all dose measurements, a mobile TN-RD-70-W20 MOSFET device was used. The device comprised high-sensitivity TN-1002RD-H detectors, a TN-RD-16 reader module, a TN-RD-38 wireless blue tooth transceiver and TN-RD-75M software (Best Medical Canada; Ottawa, ON, Canada). Prior to dose measurements, the MOSFET device was positioned and calibrated.

Twenty MOSFET dosimeters were placed into the phantom head layers similar to the protocol described by Ludlow et al (2006) (41). A Planmeca ProMax® (Planmeca Oy, Helsinki, Finland) was used for image acquisition with exposure parameters at 66kV and 16mA. The tube currency was set at 16mA to maximize exposure level to reduce the SD and subsequently improved the reliability of the measurements. The effective dose was then halved in order to get values for the default setting, 8mA, recommended by the manufacturer. In order to increase the accuracy of dose measurements for each segment of interest, ten sequential exposures were made. The mean and standard deviation of effective doses for each panoramic protocol was calculated and compared.

Dose area product was measured using a KermaX-plus IDP 120-131 HS meter (IBA Dosimetry; Schwartzenbrück; Germany) attached on the C-arm tube head cover on the panoramic radiography device. Two exposures were made for all the collimations, and mean dose area product (DAP) values were calculated.

3.5 Evaluation of image quality

When assessing the AEC function 35 radiographs, five from each mandible half with one layer of Plexiglas, were evaluated by six observers. The radiographs were displayed centrally on the monitor, one at the time, with a dimmed light viewing condition. The observers classified the radiographs diagnostic quality regarding using the following three-point scale: 1 = unacceptable; 2 = acceptable; 3 = excellent. Images with the quality score ≥2 were interpreted as satisfactory.

In study III a simple image quality assessment was performed at different exposure levels for CBCT and MSCT respectively. An anthropomorphic phantom was used as test object and the TMJ was evaluated in terms of how well the observers could identify cortical and trabecular bone of the TMJ, the intra-articular joint space, the subjective experience of noise level in the images. All the questions were assessed on a 1-3 scale, with 3 being excellent, 2 acceptable and 1 unacceptable. The overall image quality was considered diagnostically acceptable when all observers rated all four criteria as at least acceptable.

3.6 Evaluation of possible collimation

A retrospective analysis of possible collimation was conducted on all the incomming referrals during the period 2017-01-01 to 2017-03-31 to the Department of Dental Medicine, Karolinska Institutet. Only patients aged ≥18 years that had panoramic examination during the first quarter of 2017 or had a previous panoramic radiograph taken within one year were included. The referrals were categorized into nine groups by a radiologist (DB) depending on the clinical indication for panoramic examination: (1=implants - both pre and post, 2=temporomandibular joint disorders, 3=teeth and jawbone (periapical, periodontal, caries), 4=prior to tooth removal, 5=postsurgical problem/follow up, 6=cyst, tumor and bone disease, 7=infection, 8=orthognathic surgery/orthodontic treatment, 9=trauma). Based on the diagnostic questions written in the referrals a classification was made upon possible collimation in the dose assessment protocol, PAN 1- PAN 10. The assessments of possible collimation and protocol (figure 6) were performed by a radiologist (DB). By summing up assessed collimation for each individual the dose reduction was calculated and presented in percentage compared to constant use of full panoramic images. Furthermore the proportion of each collimation protocol were calculated to give an indication of usability.

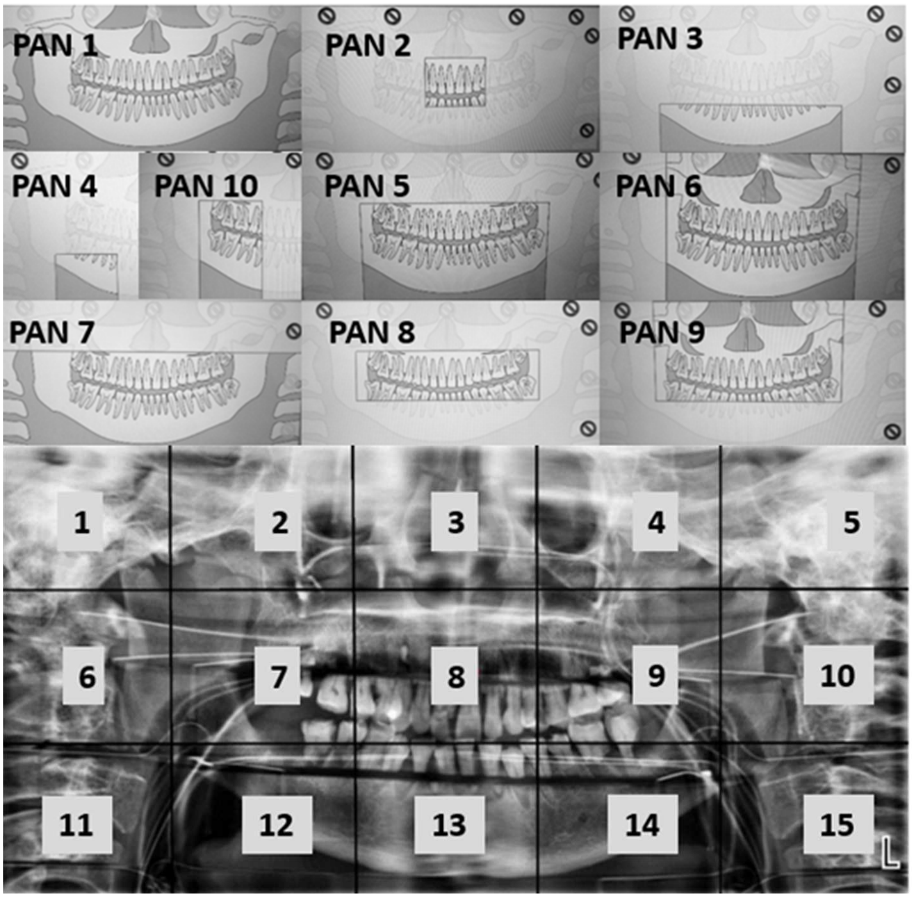

Figure 6. The chosen collimations for panoramic radiographs used to measure effective dose and categorize clinical applicability, PAN 1 - PAN 10. PAN1=full size, PAN 2=Upper front, PAN 3= mandibular teeth, PAN 4=Lower right mandibular molars, PAN 5=All teeth, PAN 6=All teeth and antrum, PAN 7=All teeth and ramus, PAN 8=maxillary teeth, PAN 9=maxillary teeth and maxillary sinus, PAN 10=Lower right mandibular molars and anterior ramus. The different segments numbered 1-15 in the lower part of the figure.

3.7 Statistical analyses

3.7.1 Study I

The mean values of the exposure times determined by AEC function from seven specimens were calculated for the images exposed with and without one or two layers of Plexiglas, respectively. The relationship between exposure times and thickness of the soft tissue equivalence was presented by a box plot.

Paired student T-test was performed to compare the mean gray levels obtained for the three sets of subtracted images from the seven mandibles. This resulted in three possible pair combinations between the three sets of subtracted images.

Regarding the observer´s evaluation on optimal exposures, the median values were calculated for all the 35 images based on data from six observers. The relationship between these 35 median values and the five exposure times, two “underexposed”, two “over exposed” and one exposed with AEC, were analyzed.

3.7.2 Study II

The mean numbers of perceptible object details and their standard deviations were calculated and statistically compared between the two types of detectors using the paired t-test. For the PC test, polynomial fit was used to demonstrate the total perceptible exposure differences over the active exposure range for both sensors. The areas under the PCs were compared between the Dixi and the ProSensor by calculating the integral values.

3.7.3 Study III

In order to determine the organ dose the mean reading of each detector pair was used. Consistency between detector readings was evaluated by interclass correlation.

3.7.4 Study IV

The mean and standard deviation for the effective dose for each collimated panoramic radiograph was calculated. The fraction of each collimation as compared to the effective dose of a full panoramic radiograph was calculated in percentage. For the referrals the sum of each category was counted, and subsequently the total amount of possible reduction of effective dose was calculated

3.8 Ethical considerations

In the first study, analyzing AEC function, the test objects were seven dry human mandible halves with teeth, bought in 1983 (Anatomy~Osteology~Preparator, Woerden, the Netherlands). An ethical application was submitted to the Local Board of the Medical Ethics Committee (2007/1288-31/2). The committee concluded that although human biological materials were being used, no potential conflicting ethical aspects existed, as there is no registration of the origin of the specimens.

Both study II and III were preclinical studies without need of ethical approval.

For the fourth study, with respect to the retrospective assessment of the referrals, an ethical approval was obtained from the ethical committee in Stockholm, Karolinska Institutet with Dnr: 2013//1701-31/3 and an amendment dated 2015-04-15.

4 RESULTS

4.1 Objective evaluation

4.1.1 Study I

The purpose was to evaluate how well the AEC function adjusted the exposure when mimicking patients of different size. The mean exposure times with AEC activated for the seven mandibles, exposed with different soft tissue equivalents, were 0.056 s, 0.071 s and 0.093 s, respectively (Figure 7). A good correlation was seen between the three different exposures and number of Plexiglas using Spearman rank correlation coefficient of 0.85 ($P<0.001$).

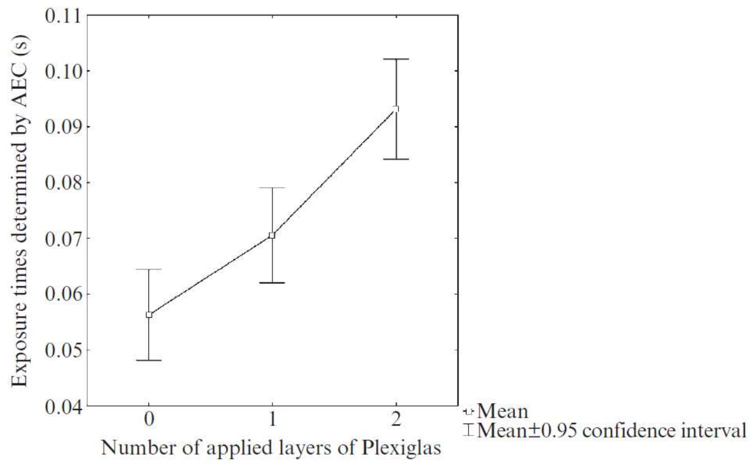

Figure 7. The relationship between the number of Plexiglas® and exposure time required for achieving satisfactory radiographs, determined by the AEC

The mean gray levels and standard deviations of the seven subtraction radiographs are presented in table 1. No statistically significant difference with one-way ANOVA were found between any of the three groups ($P=0.36$).

Table 1. The mean gray level and standard deviation of subtracted radiographs.

Subtracted images	*Mean grey level*	*SD*
AEC 0 – AEC 1	126.6	2.5
AEC 0 – AEC 2	126.5	2.1
AEC 1 – AEC 2	127.9	1.0

AEC, Automatic Exposure Control

4.1.2 Study II

The dose response function for an exposure range between 0 µCkg^{-1} and 10 µCkg^{-1} for both sensors showed, for a 12-bit image, a linear function between exposures and grey levels. With the same exposure difference the dose response function was steeper for ProSensor indicating higher contrast details compared with Dixi (Figure 8).

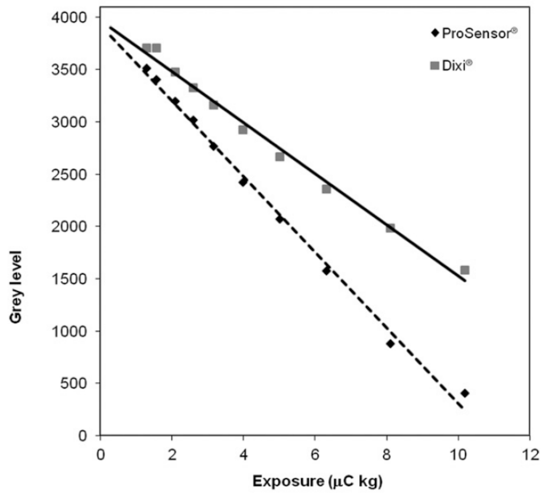

Figure 8. Dose response for ProSensor and Dixi. Linear functions for both sensors for exposures that are lower than 10 µCkg^{-1}.

4.1.3 Study III

Comparison were made for TMJ examinations using either CBCT or MSCT regarding effective dose before and after the optimization of exposure settings. Using the protocols, before optimization, the effective dose was 20% higher for a bilateral TMJ examination with the LightSpeed VCT compared with a unilateral ProMax 3D TMJ examination. Since bilateral TMJ examination is most often indicated in clinic the effective dose for a bilateral Promax 3D examination was 60% higher than from a LightSpeed VCT examination.

With the optimized exposure parameters, the estimated effective dose for a bilateral TMJ examination was 92 µSv and 124 µSv for Promax 3D and Lightspeed VCT respectively. The Lightspeed VCT has an estimated 35% higher effective dose than ProMax 3D after optimization.

4.1.4 Study IV

The reduction of effective dose examined with nine differently collimated panoramic radiographies in comparison with a full size panoramic radiograph, was evaluated. The calculated effective dose for all the evaluated panoramic collimations (Figure 9), presented as mean and standard deviation were: PAN 1 17.6 µSv, PAN 2 2.3 µSv, PAN 3 7.9 µSv, PAN 4 5.0 µSv, PAN 5 10.5 µSv, PAN 6 11.7µSv, PAN 7 16.8 µSv, PAN 8 4.6 µSv, PAN 9 4.5 µSv and PAN 10 59 µSv.

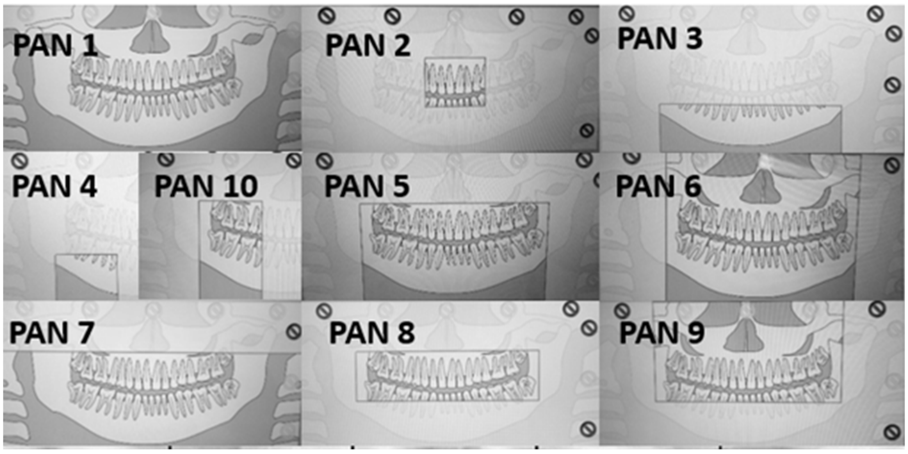

Figure 9. Studied collimations.

The calculated reduction in effective dose using the collimation function in comparison with a full size panoramic image are listed in order of reduction degree: PAN 2 (86.9%), PAN 9 (74.4%), PAN 8 (73.9%), PAN 4 (71.6%), PAN 10 (66.5%), PAN 3 (55.1%), PAN 5 (40.3%), PAN 6 (33.5%) and PAN 7 (4.5%). The highest dose reduction was seen with PAN 2 and the lowest with PAN 7. PAN 5 that includes teeth and supporting bone reduced dose with approximately 40% and if the ROI only includes unilateral lower molars the dose reduction was 66.5%.

4.2 Subjective evaluation

4.2.1 Study I

Observer evaluation of the diagnostic image quality for the five different exposure times are presented as box plots in Figure 10. The subjective diagnostic image quality peaked at the exposure time determined by the AEC function (0.07 s) and were lowest for the exposure times of 0.052 and 0.104. This suggests that AEC function provides a more preferable diagnostic image quality than manually selected exposures. A significant difference were found with Friedman ANOVA between exposure levels with respect to observers' evaluation scores (P = 0.028).

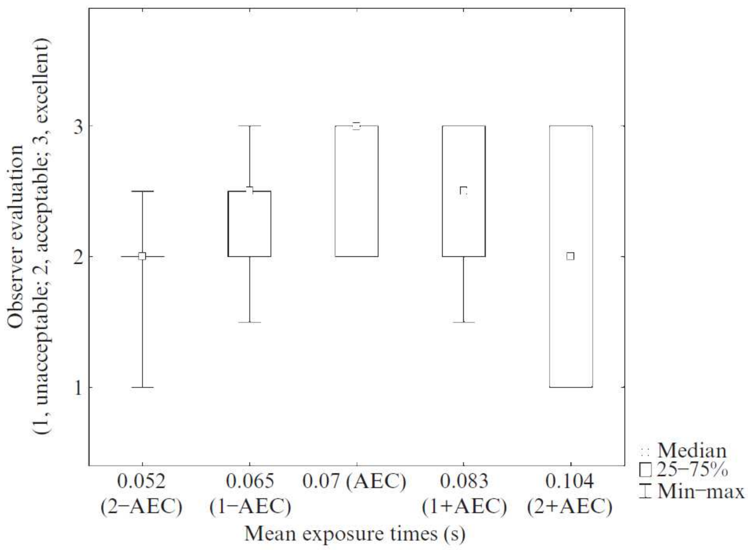

Figure 10. Observer evaluations of the subjective image quality categorized by five different exposure times

4.2.2 Study II

The observer evaluation of perceptible low-contrast details of Dixi and ProSensor showed a significant difference with paired T-test, the latter had a higher number of visible details ($p<0.001$) in the range of 2.1-25.4 μCkg^{-1}. No details were detected for the Dixi sensor when the exposure was below 6.3 μCkg^{-1} and for the ProSensor the lower limit was 1.6 μCkg^{-1}; whereas the upper limit was at the exposure of 31.8 μCkg^{-1} for ProSensor and 40.5 μCkg^{-1} for Dixi sensor (Figure 11).

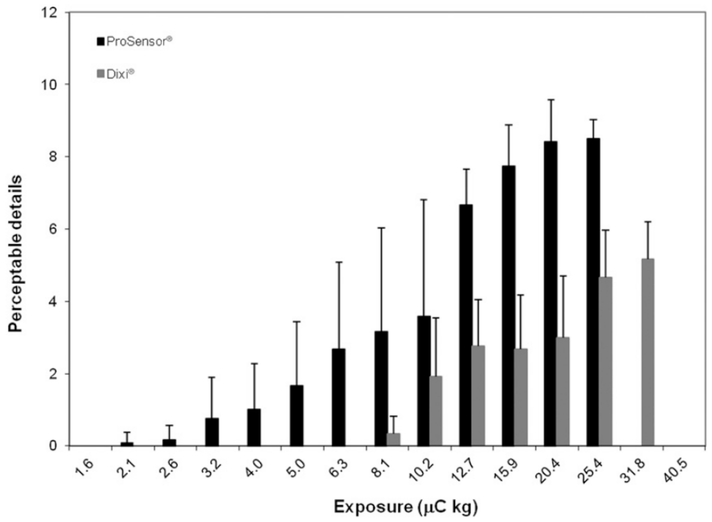

Figure 11. Mean values of perceptible aluminum test object details as a function of exposure for radiographs obtained from the two studied sensors

4.2.3 Study III

In Figure 12, the four observers overall assessments of image quality at different exposure levels for CBCT and MSCT are demonstrated. For MSCT the lowest tube setting with the observer's ratings ≥2 was 80 mA and therefore the chosen optimized exposure level. The optimized exposure level for the CBCT regarding similar observer's rating criteria was 6 mA.

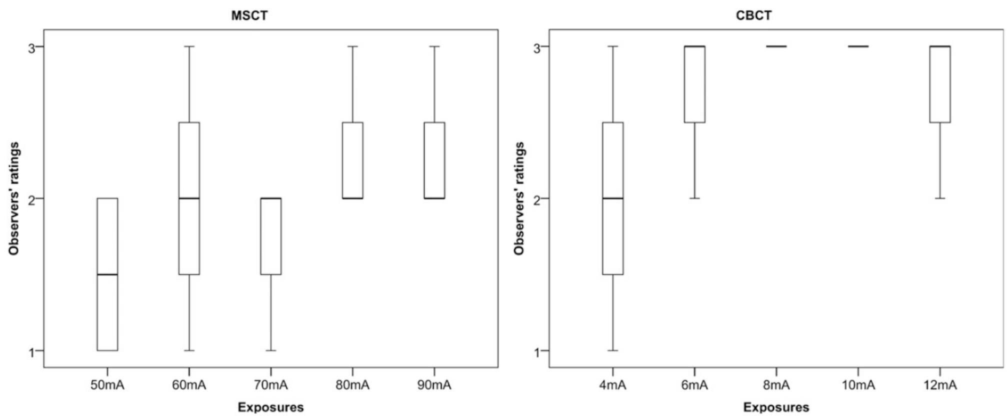

Figure 12. Overall assessment of image quality, based on four observers for MSCT and CBCT.

4.2.4 Study IV

In study 4, 252 patients were included with a mean age of 53 years and an age range between 20-86 years. The gender distribution was 62% females (n=156) and 38% males (n=96). All the referrals were assessed regarding possible collimation, PAN 1 – PAN 10.

In the studied group, 81% of the referrals, were assessed as being suitable for panoramic radiographic examination, using either PAN 1 or PAN 5. Also, the inclusion of PAN 3 and PAN 10, extended this to include 93% of patients in the sample.

Based on the clinical questions in the referrals. Other collimations than PAN 1 were considered as possible in 78% (n=197) of the sample. A full size panoramic image was considered to be necessary in 22% (n=55) of the referrals. The calculated possible total dose reduction for the studied group was 35% compared with if the full size panoramic protocol (PAN 1) was used on all referrals, regardless of indication.

5 DISCUSSION

The dental profession should strive to set radiation doses at the lowest level possible. In dentistry, several approaches allow optimization of image quality whilst keeping individual exposure at the lowest level. Some approaches are evaluated in this thesis (Figure 13).

Ongoing studies by radiological professionals are continuously working to develop methods to limit possible negative health effects induced by radiographic examinations.

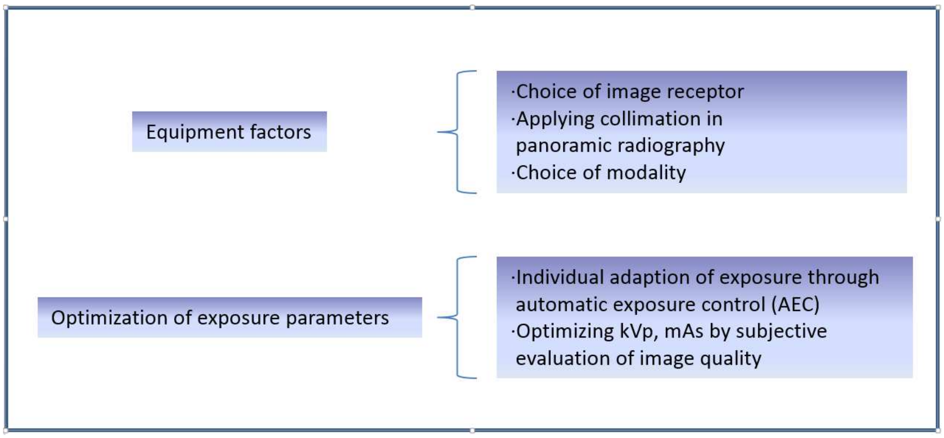

Figure 13. Summary of dose reducing strategies in the dentomaxillofacial area examined in this doctoral thesis.

5.1 Individual adaption of exposure through AEC

AEC is a common feature within medical radiology, with extensive numbers of research studies. Despite earlier research within dentistry evaluating AEC in panoramic radiography however to our knowledge, only one published article has assessed AEC in intraoral radiography (study I).

In medical radiography, AEC has demonstrated the ability to ensure adequate image quality for the required clinical task (42).

The potential advantage of implementing AEC in intraoral examinations in dentistry is that satisfactory diagnostic image quality can be achieved since the exposure level can be consistent regardless of patient size. Unnecessary retakes of radiographs due to inadequate exposures might therefore be eliminated. However with respect to intraoral radiography, the most common error related to image quality was found to be incorrect receptor positioning, according to an earlier study evaluating images sent to the Dental Insurance Office in Sweden for treatment approval (43).

The main development associated to AEC will most likely be that of improved diagnostic performance through the avoidance of underexposed or overexposed radiographs, although, an suboptimal exposed digital radiograph might not be evident due to post image processing. In addition, the clinical work may be more feasible since no manual setting of parameters will be necessary.

Since AEC function requires an initial exposure, according to the manufacturer 0.004 s, to calculate the final exposure time a dose contribution will be added to the final exposure.

The preclinical setting in study I using the subtraction technique was favorable, since the geometrical alignment between the X-ray unit and the object was fixed for all images of each object. The only variable in the set-up was the different thicknesses of added Plexiglas. Achieving similar projection geometry between different images *in vivo* can be difficult (44).

When subtracting the images, if AEC function worked correctly, the resulting mean gray level value should be close to zero. However, in the current study, 127 was added to all images to improve the perception, thus the value should be closer to 127 to increase the visibility. The result from the three different pairs of subtracted images had a mean gray level in the range of 126.5-127.9 with a standard deviation of 1.0-2.5. The AEC performed as expected.

In a study by Schropp et al (2012), the validity of acrylic as a soft-tissue simulation material for use *in vitro* radiographic studies was evaluated (45). According to the results, the average density of a typical human cheek corresponded to acrylic with a thickness of 14.5 mm. Since each layer of acrylic had a thickness of 12 mm in study I, the estimation of the thickness of an average human cheek was slightly underestimated.

The set-up of study I was *in vitro*. Therefore, it should be considered that the evaluation of AEC function in a clinical setting might be difficult to completely assess with study I.

The AEC function was only available together with the CCD based SIGMA™ direct digital sensor that had a cable connection to the computer. When the next generation of sensors from the manufacturer was launched, the technique was CMOS based and lacked a hardwired connection between the computer and sensor, and consequently, AEC function was no longer available. To the best of our knowledge no vendor on the Swedish market offer AEC for intraoral radiographical use.

5.2 Choice of image receptor

The dose response functions constructed for the two sensors, Dixi and ProSensor, showed different slopes when plotted on linear scales. A steeper slope suggested higher sensibility and improved capacity to record small exposure differences. The ProSensor performed better than the Dixi sensor that reached saturation around the gray level of 1500 (12-bit data), indicating a better ability to convert radiation contrast into visual contrast. The results from the *in vitro* set-up may not be directly applicable into the clinical situation since image post processing will enable the use of a wider range of the histogram, and thus the difference between the two types of sensors may be less apparent.

Brüllmann et al (2013) compared six different sensors, 2 CCD-based and 4 CMOS-based, with respect to contrast and resolution properties (46). The results demonstrated that there were considerable contrast differences between the different types of sensors at identical exposure times. At longer exposure times the CMOS-based sensors exhibited higher contrast resolution

Good contrast detail detectability, good spatial resolution and a good dose-response curve over a wide exposure latitude are desirable of an intraoral digital system. Udupa et al (2013) compared sixteen various intraoral digital systems on the market and showed that they varied markedly from one another regarding these properties (47).

The integrals of the area under the PC curves doubled for the ProSensor compared with the Dixi sensor when considering low-contrast differences. Furthermore, the exposure range, where observers could perceive contrast details was clearly narrower for Dixi sensor than for the ProSensor.

The results also implied that the human visual system was relatively insensitive to contrasts in light and very dark regions.

A study using an aluminium test object may not perfectly resemble a clinical situation since diagnosis involves more complicated radiographical interpretations (48). For example, with respect to caries detection, our results suggests that diagnostics will probably improve for clinicians when using ProSensor compared to Dixi sensor.

5.3 Choice of modality, optimizing exposure parameters by subjective evaluation of image quality

The scant number of available published studies on effective CBCT examination dose on TMJ, reported a large spectrum varying between 20-916 µSv (47, 48). The difference in the FOV, variation in voxel size, choice of CBCT examination protocols, as well as accepted subjective image quality made it difficult to compare between these studies. In our study, we demonstrated that when subjective image quality and the smallest possible FOV were taken into consideration, the effective dose values were relatively comparable between CBCT and CT for TMJ examination. This was contradictory to most previously published studies.

The complexity of temporomandibular disorders (TMD) demands a clear and precise image for evaluating potential osseous changes of TMJ components and provides effective management for the patient (49). CBCT has been established as a powerful diagnostic tool for the diagnosis of osteoarthritis in the TMJ (50). It has been proposed that accuracy between CBCT and MDCT was comparable in the detection of changes in the osseous surface of the TMJ (51). Study III showed that subjective image quality was better for CBCT and that CBCT should be recommended as the choice of image modality for evaluating hard tissue changes in TMJ.

Previous research often comes to the conclusion that examinations with MSCT contributes to a considerably higher dose compared to CBCT (25, 52, 53). The proportion of dose between the two modalities are however multifactorial and as shown in the third study, the dose is not necessarily in favor of CBCT. The clinical indication for every radiographical examination is of importance for deciding appropriate protocols often regarding FOV and exposure parameters (mA, s, kV). The importance of optimization of exposure parameters according to the diagnostic task has been shown earlier (54).

Large potential for dose reduction has been shown in optimization studies for both dentomaxillofacial MSCT and CBCT examinations (52-54). Comparison of exposure parameters recommended by the manufacturer in study III, indicates a potential dose reduction by as much as 50% for TMJ imaging when using optimized exposure protocol for ProMax 3D. Interestingly Planmeca OY has launched a new feature, ultra-low dose, enabling a potential further reduction of dose. Future clinical research is needed to evaluate the clinical suitability of TMJ examination with this new feature.

5.4 Applying collimation in panoramic radiography

In previous studies, the effective dose has been calculated for full size panoramic radiography with the variation between 6.4-75 μSv (17, 34, 55-59). The most common technique used for measuring effective dose was TLD, where various number of dosimeters were placed in allocated phantom head positions (22, 35, 43). The phantom head has to be dismantled prior to the reading and the TLDs placed in a TLD oven. Thus, when performing multiple assessments of different FOVs, positioning of the phantom head is crucial, and small differences in positioning will create changes in the registered absorbed doses (60).

Ludlow et al (2006) introduced a dose detector placement with 24 measurement points, for assessing effective dose within the dental field (41). A study by Pauwels et al in 2012, compared the effective dose, when using 147 and 152 measurement points with 24 measurement points, showed that the latter provided insufficient accuracy (22). This was especially evident in small FOVs.

The MOSFET technique using digital dosimeters was considered a strength in the design of study IV since digital dosimeter measures the dose instantly without the need of dismantling the phantom (61). In a recent study, two techniques for measuring the dose, TLD and MOSFET, were found to be in good agreement (27). To the best of our knowledge assessment of the effective dose using MOSFET for differently collimated panoramic radiographs have not been performed before. However, due to the limited number of dosimeters distributed in the phantom, in the set-up, the effective doses calculated for the smaller FOVs should be considered as indicative. The organs affected most by the collimation, in terms of absorbed dose, are also the organs contributing most to the effective dose.

Indications for collimated panoramic radiographs should base on the anamneses and the clinical examination and then specified region of interest may be defined. Fewer incidental radiographic findings were expected as a consequence of a limited FOV. Incidental findings that can be missed include cystic or tumorous lesions, signs of osteomyelitis, signs of osteoporosis and carotid artery stenosis (62-65). However, incidental findings are relatively rare and the FOV, especially in children, should only include the regions of interest as a dose reducing measure (66). Many panoramic devices on the market provide collimations options of varying degrees. Implementing the collimation function as a clinical routine should be promoted since that would enable dose reduction and thus benefit many patients.

The results of study IV suggests that full size panoramic imaging only is necessary in 20% of the examinations. The field of view including teeth and supporting bone will probably be sufficient in 60% of examinations, reducing the dose by approximately 40% per panoramic image.

Although panoramic examination on children were not included in study IV, the importance of dose optimization through collimation is obvious. Children are at a potentially higher risk compared to adults due to a higher radiosensitivety and longer expected lifetime. The calculated risk for children aged up to 10 are approximately three times higher compared with a 30 years old person (67).

It has been shown that panoramic radiographs, taken on 7- to-12-years old children, are exposed with an X-ray beam that frequently covers an area much larger than the area of interest (68). It was therefore recommended that the design of panoramic devices should include the possibility of different collimation settings that were easily adjusted during radiographical examination. Svanaes et al (1985) suggested a modification of the panoramic examinations on children achieved by altering the width and height of the irradiated film area (69). A study performed by Locht (1983) reported considerable dose reduction by limitation of the irradiated area (70).

There are a great variety of clinical indications for panoramic radiography in dentistry, examples include dental implants, trauma, dental status, infections, orthodontic/orthognathic treatment, cysts, tumors and tooth removal (71-75). The most common protocol on adult patients is presumably a full size image. Dose reduction can be achieved if the FOV is restricted to the area of interest.

6 CONCLUSIONS

- Ongoing technical developments within the field of radiology demand task depended evaluations of the innovations in order to best serve the clinical needs.

6.1 Intraoral radiography

- With AEC function, exposure time can be automatically adjusted according to different object thicknesses while maintaining good image quality. Therefore, AEC has the potential of being a helpful aid in direct digital intraoral radiography for the dental profession.
- ProSensor based on CMOS technique and Dixi sensor based on CCD technique from Planmeca OY, were compared in terms of PC test and it was concluded that the ProSensor may be more beneficial to patients due to increased perception of low-contrast details and reduced radiation dose.

6.2 Panoramic radiography

- Limiting dose by applying collimation function in panoramic radiography is a feasible and straightforward approach, and can be easily implemented in practice.
- A restricted FOV in panoramic radiography is appicable in approximatelly 80% of examinations.
- In 60% of all panoramic examinations the clinical indication justifies collimation that only involves teeth and supporting bone, thus reducing the dose by 40 % compared with a full size image

6.3 CBCT and MSCT

- Exposure protocols recommended by the manufactures and the resultant image quality shall be tested and evaluated before clinical application.
- Without optimization of protocols, the effective dose from CBCT can be 60% higher than MSCT and doubled compared to after optimization of the CBCT protocol (study III).

7 FUTURE RESEARCH

The main purpose of the thesis was to highlight the importance of bridging technology with clinical application. There are continuous innovation in radiology, especially in the field of CBCT technique and its diagnostic values for various diagnostic tasks. I am particularly interested in low dose CBCT technique and, of course, possible clinical indications.

An Ultra Low Dose™ (ULD) function was recently introduced by Planmeca, Oy. According to a recent in vitro study it has the potential to reduce effective dose by >70% (76). As a continuation of my doctoral education, a randomized control study with the aim to evaluate ULD protocol in children with alveolar bone defect in cleft lip and palate was planned and initiated.

CBCT WITH ULTRA-LOW DOSE PROTOCOL IN EXAMINATION OF ALVEOLAR BONE DEFECT IN CLEFT LIP AND PALATE

Cleft lip and palate disorder are among the most common birth defects, with the reported incidence in the Stockholm region of 1.7/1000 live births (77). When the alveolar process is involved CBCT can be indicated to assess the local anatomy before and after bone augmentation.

Minimizing the radiation dosage is especially important for children since the estimated risk for cancer formation or hereditable effects is approximately three times higher than for an adult aged 30 (67).

By applying a more sensitive detector and a sophisticated image processing algorithm, Planmeca Oy claimed that with ULD protocol the effective patient dose may be reduced by up to 76%. Since the accepted diagnostic image quality is highly associated with diagnostic tasks, clinical studies on evaluation of new diagnostic features are important.

The aim of the study was to compare whether Promax 3D Mid CBCT with ULD normal dose protocol will provide adequate information in order to assess necessary clinical questions in the region of the maxillary alveolar cleft compared to normal dose protocol.

The study design will be a randomized controlled trial examining the effect of two different Promax 3D Mid CBCT protocols, i.e. ULD normal dose setting versus normal dose setting, on image quality examining children with cleft involving the alveolar process.

34 children will be included in each group. Both groups will have patients of both gender and all age groups. The majority will be between 8-12 years of age.

Image conditions chosen for the FOV is 80mm in diameter and 50mm in height. Normal clinical procedure using axial, coronal and sagittal reconstructions of 1 mm thick slices will be used for the evaluation. Two dentomaxillofacial radiologists with experience in assessing CBCT images will evaluate all radiographic 3D material.

An ethical approval was obtained from the ethical committee in Stockholm.

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