Imaging Techniques in Dental Radiology

Acquisition, Anatomic Analysis and Interpretation of Radiographic Images

Ingrid Rozylo-Kalinowska

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To my family for their support every day of my life and their enormous patience.

Foreword

Radiographic modalities in DMFR produces two- and three-dimensional information on the facial skeleton and teeth and is increasingly being used in many of the dental specialties, including periodontics, endodontics, orthodontics, orthognathic surgery, trauma and implantology. Being familiar with anatomy and pathology especially in periodontology and periapical lesions as well as endodontics/trauma patients would help professions to discover occult diseases and maxillofacial pathology cases especially that has refereed pain earlier. Treatment planning for maxillofacial pathologies involves gathering as much information as possible. Key tools to successful treatment planning are the appropriate radiographic techniques, allowing visualisation of a site in all three-dimensional aspect with less ionising radiation as possible. Moreover, aware of the systemic diseases and their appearances of the maxillofacial complex is crucial for appropriate diagnose and treatment.

Throughout this book, aspects of radiographic modalities in DMFR including technical details and applications in various disciplines are being discussed. This book offers a comprehensive, detailed, up-to-date review of our current knowledge in the DMFR imaging. The eminently readable text is complemented by numerous and superb illustrations.

As a result, this book offers a comprehensive review of imaging modalities in DMFR. I would like to congratulate the author for her superb efforts which have resulted in this excellent book.

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2020

Preface

Tempora mutantur et nos mutamur in illis—this Latin adage is the sign of the time which changes and people change with it. Since the dawn of radiography and radiology in the end of the nineteenth century, the face of dentomaxillofacial radiography has considerably changed. After the first presentation of the results of experiments carried out by Wilhelm Konrad Roentgen in November 1895, it was not long until the first dental exposure was registered by a German dentist by the name of Otto Walkhoff, and it was already done in January 1896. Radiographic imaging quickly become foundation of diagnostics in dentistry and maxillofacial surgery. During more than 120 years of history of radiography and radiology development has been immense. Although the basics of imaging techniques have remained unchanged for decades, and in case of bisecting angle intraoral technique for more than 110 years (Cieszyński's rule of isometry published in 1907), advances in registration of radiographic image quickly followed. The development concerns both image receptors—now mostly digital—and radiographic equipment fitted with more advanced software, mechanics as well as devices aiding in positioning. Cone-beam computed tomography (CBCT) has first been described in 1990s, but in the recent decade number of installations of these diagnostic X-ray units in dental offices have peaked. Nowadays it is difficult to imagine dental imaging diagnostics without CBCT in almost all, if not all, disciplines of dentistry. However, CBCT is demanding due to necessity of analysis of numerous slices and transformation of perception from two-dimensional to three-dimensional. However, owing to that radiodiagnostics became more precise as teeth and tooth-bearing structures are three-dimensional objects thus traditional two-dimensional radiography is not sufficient to demonstrate all anatomic variations and pathological lesions. Nowadays the question keeps coming back whether Artificial Intelligence (AI), or rather Machine Learning, is only a hype or the future of radiology, does it pose a danger or provide advantage to the profession of radiologist? More time is needed to verify which of these approaches is correct, but it is likely that AI will not replace radiologists, including dentomaxillofacial ones, but will become one of the diagnostic tools in their box relieving them from more tedious tasks providing more time for in-depth evaluation of more complicated cases. However, until that stage of development of AI is reached, dentists and radiologist still have to rely mostly on their skills and abilities in reading dental radiographs. It is obvious that analysis of radiographic images is subjective and depends on knowledge and experience, but is also influenced by external factors such as fatigue, hectic schedules, increasing workloads and patient bias. It is not possible to fully avoid diagnostic errors as humans are not machines, but in order to minimise mistakes, one must constantly learn and practice. So this is the aim of the present textbook—to provide concise information on dental radiography and basics of radiological interpretation which will serve as foundation for further professional development. The book is based on my textbook in Polish called "ABC of dental radiography and radiology" which had the same aim—to provide foundation for all beginners in this extraordinary field of dentistry and radiology.

Photograph of piece of art of Swedish artist Bertia Vallien from the cycle called "Thoughts", which symbolises idiosyncrasy of radiology—technique, knowledge and skills, allows seeing what is inside human body without breach in integument

Lublin, Poland Ingrid Rozylo-Kalinowska

About the Author

Prof. Ingrid Rozylo-Kalinowska, MD, PhD, DSc., graduated from the Faculty of Medicine of the Medical University of Lublin, Poland, in 1997. In the same year she started postgraduate studies in radiology. In the years 1998–2007 she worked in the 2nd Department of Medical Radiology of the Medical University of Lublin. In 1999 she was awarded Ph.D. degree with merits in the Medical University of Lublin and in 2004 the D.Sc. degree by the Medical University of Warsaw, Poland. In 2010 she was granted the Full Professor title by the President of Poland. In the years 2007–2011 she was working as an Assistant Professor in the Department of Dental and Maxillofacial Radiology of the Medical University of Lublin, in 2012 she became the head of the Independent Unit of Propedeutics of Dental and Maxillofacial Radiology of the Medical University of Lublin and in 2018 the Head of the Department of Dentomaxillofacial Radiology of this University. She is specialist in radiology and diagnostic imaging.

Scientific work of Ingrid Rozylo-Kalinowska includes over 200 full papers and over 300 conference contributions. She is supervisor of 13 completed Ph.D. theses, 5 ongoing Ph.D. processes as well as of 11 M.Sc. dissertations.

She completed six training periods abroad (France, Jordan, Spain, UK).

Her didactic work includes dental radiography and radiology, maxillofacial radiology, medical radiology and diagnostic imaging for dentists, medical radiologists, radiographers as well as Polish and English Division students of dentistry, radiography and dental hygiene.

She is the Immediate Past president of the European Academy of DentoMaxilloFacial Radiology. She will host the 18th European Congress of Dentomaxillofacial Radiology, in Lublin, Poland, in June 2022. She is the regional director of International Association of Dentomaxillofacial in Europe. She is the vice president of the Polish Dental Association. She is the chairman of the Section of DentoMaxillofacial Radiology of the Polish Medical Radiological Society. She is a member of the European Society of Radiology and Pierre Fauchard Academy, the Polish Section. She is a board member of the local division of the Polish Hygienic Society.

She is the editor-in-chief of the *Journal of Stomatology*, journal of the Polish Dental Association. She belongs to the editorial boards of several scientific journals and serves as a reviewer of numerous manuscripts submitted to international scientific journal.

She is a co-editor and co-author of the book “Temporomandibular Joint Imaging” (Springer, 2018), five dentomaxillofacial radiology textbooks in Polish, chapters on dentomaxillofacial radiology in four Polish textbooks, as well as parts of the “English-Polish and Polish-English Dental Dictionary” (1999) and “Practical Dental Dictionary” (2016). She translated eight medical textbooks (including three on dental as well as head and neck radiology) from English or German to Polish.

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I would like to thank Dr. Anna Michalska for aid in database search for new and interesting radiographs. The book would not be complete without the efforts of Dr. Leszek Szalewski, who apart from being a skilled dentist, is a dedicated photographer and was very helpful in taking photographs that I was unable to take myself, e.g. the one included in the Foreword.

I would like to extend my gratitude and thankfulness to my models—my daughter Ewelina and my PhD student Dr. Katarzyna Portka. They both were extremely patient and dedicated although the task was tiresome and time-consuming.

This book would never come to life without its predecessor published in Polish by the Editorial House "Czelej"—I am grateful to them for granting permission for using the materials as framework of the current book.

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Abbreviations

AAOMR	American Academy of Oral and Maxillofacial Radiology
ARPNSA	Australian Radiation Protection and Nuclear Safety Agency
CBCT	Cone-beam computed tomography
CT	Computed tomography
EADMFR	European Academy of Dentomaxillofacial Radiology
EAO	European Association of Osseointegration
ESE	European Society of Endodontology
FOV	Field of view
ICRP	International Commission on Radiological Protection
MRI	Magnetic resonance imaging
MSCT	Multi-slice computed tomography
PSP	Photostimulable storage phosphor
ROI	Region of interest
SADMFR	Swiss Association of Dentomaxillofacial Radiology
SPP	Storage phosphor plate
TLD	Thermoluminescent dosemeter
TMJ	Temporomandibular joint
US	Ultrasound

Introduction to Dental Radiography and Radiology

1

In contemporary dental practice it is utterly impossible to imagine diagnostic workflow without the benefits of radiology. Radiographs are the foundation of imaging diagnostics in dentistry as the main areas of interest in this field are hard tissues of teeth and tooth-bearing bone. Visualisation methods using ionising radiation are still the most suitable for imaging of dental and alveolar tissues as they are based on attenuation of X-rays by dense objects. Radiographic machines and cone-beam computed tomography (CBCT) are more and more frequently being installed and used in dental offices. In maxillofacial radiology the scope of imaging is wider encompassing also soft tissues, thus other imaging methods, some of which are not based on ionising radiation, are applied. These methods include ultrasonography (US), magnetic resonance imaging (MRI), fluoroscopy and multislice computed tomography (MSCT). However, such machines and facilities are mostly based in hospitals and large medical outpatient clinics, and so far have not been widely applied in dental practice, therefore they will not be discussed within the frames of this book.

Before the onset of panoramic radiography, various X-ray projections have been in use in dentomaxillofacial radiology to demonstrate teeth and maxillofacial skeleton. Many of them have been replaced by panoramic radiography, but several types are still requested. The next change in dentomaxillofacial radiology was introduction of cone-beam computed tomography, and its popularity can be judged by number of brands offering such equipment as well as growing numbers of installations in dental offices, apart from hospitals and diagnostic imaging centres. It is CBCT that makes even more radiographic projections obsolete in dentomaxillofacial radiography, as instead of taking several two-dimensional radiographs one three-dimensional volume may solve diagnostic problem.

Contemporary dental radiography comprises intraoral radiography, extraoral radiography and cone-beam computed tomography. Intraoral radiographs are all those taken with an image detector (called also image sensor or image receptor) placed inside patient's oral cavity. On the contrary, all radiographs registered with image sensor outside patient's cavity are called extraorals. All radiographs can be

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taken using digital sensors or analogue image detectors, i.e. radiographic films; however, recently radiographic films also become redundant following the transition from analogue to digital radiography owing to numerous benefits of digital image registration.

Intraoral radiographs comprise periapical, bitewing and occlusal radiographs.

The name "periapical" is related to visibility of periapical tissues of radiographed teeth which is a prerequisite of this kind of X-rays. Periapicals can be taken by means of two techniques—paralleling technique and bisected angle technique. The latter being historically older, and until recently quite heavily used, is at the same time encumbered with faults such as lack of repeatability of projection and susceptibility to geometrical errors depending on skills and abilities of an operator. Therefore paralleling technique is considered superior to the bisected angle one, but is not ideal, either. It is not possible to successfully practice this technique in patients with some anatomical conditions and pathological lesions, while a strong gagging reflex may be a handicap, too. There are numerous indications for taking periapical radiographs including dental caries, periapical lesions, endodontic treatment, dental trauma, periodontal bone disease, congenital dental anomalies, acquired dental lesions such as abrasion, attrition, erosion, follow-up of treatment, e.g. of implant placement. It has been estimated that periapicals belong to the most commonly prescribed radiographs in humans, especially in highly developed countries. During lifespan there is high chance that teeth (taking into consideration their relatively high amount) will require radiographs during dental treatment, and then follow-up, or even re-treatment.

On the contrary to periapical radiographs, bitewings do not demonstrate periapical tissues at all. The purpose of taking bitewing radiographs is to show crowns of upper and lower teeth at the same time, in one view at the expense of cropping the images of root apices. Depending on orientation of image sensor (usually with long axis horizontal, less commonly vertical), bitewings will present a smaller or larger portion of dental roots in their coronal parts. The main aim of prescribing a bitewing is to detect early caries on approximal surfaces which may be inaccessible to clinical evaluation, to diagnose the so-called hidden caries, i.e. carietic lesions in dentine undermining clinically unchanged enamel thus invisible in inspection as well as to diagnose early periodontal bone disease.

Finally, occlusal radiographs are the ones taken with image receptor placed in the oral cavity in the occlusal plane with X-ray tube aimed from below for mandibular projections and from the top for maxillary radiographs. Again, occlusal radiographs become less appreciated than before in the era of CBCT; however, their use still should be advocated. Some clinical problems may be solved by means of occlusals already in dental office without the necessity of referring a patient for additional examinations in a diagnostic imaging centre, and subjecting the patient to further, and possibly higher doses of ionising radiation. Indications for occlusal radiography include diagnostics of impacted, retained, supernumerary, and additional teeth, diagnostics of trauma, bone expansion in cysts and tumours, presence of periosteal new bone formation (especially in mandibular axial occlusal radiograph), shadows of salivary stones cast against radiolucent oral floor tissues (in the same type of radiograph). Occlusal radiograph may be an alternative to periapical radiography in patients who cannot support image receptors inside the oral cavity.

The most commonly applied extraoral radiographs are panoramics, which are tomographic (layer) images of curved structures. Apart from teeth located in the imaged plane, called focal trough, these radiographs cover a large portion of maxillofacial skeleton. However due to tomographic character and rotational movement occurring during exposure, panoramic radiographs are prone to many errors and artefacts. Indications to panoramic radiography include the following:

- Orthodontic assessment, including presence of teeth germs, stage of development of dentition, presence of supernumerary or retained and impacted teeth,
- Impacted third molars,
- Periodontal bone disease, offering simultaneous assessment of all teeth and the extent of periodontal bone defects,
- Lesions like cysts, tumours and other bone diseases that are too large to be fully imaged by means of periapical radiographs,
- Mandibular trauma,
- Initial stages of implant planning,
- Dental age estimation.

Panoramic radiography is not the method of choice for imaging of dental caries, periapical lesions, dental trauma as well as in endodontic treatment. Visualisation of temporomandibular joints may be challenging, too, as whole condylar heads may not fit within the focal trough. Even if they are fully imaged within the focal plane, angulation of long axis of right and left condylar head may be different leading to differences in radiographic image not caused by actual pathology. Moreover, panoramic radiograph is taken in “tête-à-tête” position of incisors which influences location of condylar heads—neither in open nor closed mouth position. Thus it is difficult, if not impossible, to correctly estimate condylar movement basing solely on these radiographs. Midfacial fractures and diseases of maxillary sinuses cannot be reliably diagnosed on panoramic radiographs as only parts of midface fall within the focal trough and lesions placed outside the focal trough are blurred or even invisible in panoramic radiographs. This may lead to underdiagnosis and mistakes in decision on treatment plan.

In some countries full mouth surveys including periapicals and bitewings are preferred to panoramic radiography. The reasons include wider availability of intraoral X-ray machines than panoramic ones, as well as higher image resolution and quality in intraoral radiography with far less artefacts and additional shadows than encountered in panoramic radiography.

In orthodontics and orthognathic surgery cephalometric radiography is employed, usually in the form of true lateral cephalometric radiographs and also postero-anterior cephalometric radiographs and cephalometric axial skull views, otherwise called submento-vertex projection.

A lot of panoramic machines are equipped with options allowing taking of tomographic radiographs other than panoramic, such as tomograms of temporomandibular joints, maxillary sinuses and cross-sectional images of alveolar processes. However, as mentioned before, growing availability of CBCT leads to loss of importance of these radiographic projections.

Even though dental radiographs are fairly frequently taken, they cannot be regarded "routine" or "survey" radiographs. For every X-ray exposure, even performed with a relatively low burden of ionising radiation, must be justified and optimised.

Cone-beam computed tomography is also an imaging technique basing on the use of ionising radiation, but in the course of exposure hundreds of X-rays are taken that later form the so-called volume. Image processing leads to creation of numerous slices in different planes (axial, coronal, sagittal, tangential, cross-sectional as well as oblique and drawn along a line or curve). Image resolution is a derivative of voxel size, i.e. length of side of the smallest three-dimensional element in the recorded volume. Fields of view (FoV) in Cone Beam CT can be small (from 3 × 4 cm) through medium (encompassing both upper and lower dental arches) up till large ones (even 30 × 30 cm). Smaller volumes can be virtually "stitched" to form larger ones and this way capacity of smaller image receptors is enhanced, but at the same time it must be remembered that in stitching mode more than one X-ray exposure is required. CBCT also offers a choice of resolutions from very high, e.g. 0.05 mm (important in evaluation of root canals) to lower (in the range of 0.3–0.4 mm) applied in large FoV to demonstrate big structures like maxillary sinuses where thin slices are redundant for diagnosis. Finally, CBCT varies in doses depending on protocols used—from ultralow dose imaging via standard dose to high doses in bigger FoVs, and also in smaller FoVs with very high resolution dedicated to endodontics.

Since the advent of CBCT over 20 years ago, numerous guidelines elaborated by different societies and associations have been published. The primary indication for CBCT which is the reason why this imaging method successfully entered dental offices was dental implant planning. But nowadays CBCT is advocated whenever correct diagnosis cannot be reached by two-dimensional radiography, in cases with non-specific or conflicting clinical signs and symptoms, and in all cases where medical CT had been used before, e.g. maxillofacial congenital anomalies, maxillofacial trauma, complicated cases of impacted and retained teeth, suspicion of close anatomical relationship between mandibular third molars and inferior alveolar nerve canal. Currently CBCT is not suitable for reliable diagnosis of soft tissues, and identification of carietic lesions is heavily influenced by the presence of image artefacts if present.

CBCT is used not only for diagnosis but also for virtual implant planning, also in conjunction with 3D printing of surgical guides and in CAD/CAM solutions for simultaneous planning of implants and prosthetic crowns produced in milling units. CBCT machine can be fitted with cameras allowing capturing of three-dimensional photographs that can be merged with CBCT data on teeth and skeleton as well as images from intraoral scanners.

Albeit X-ray machines are very popular in dental offices, unfortunately not always all pieces of information from the images are retrieved. The reason is multifactorial. In the first instance, maxillofacial anatomy is complex and without fundamental knowledge of normal radiographic anatomy it is impossible to distinguish normal from abnormal findings. Secondly, within maxillofacial area there are found not only lesions which are specific for this region, mostly related to teeth and tooth-bearing structures, and also diseases which affect maxillofacial skeleton the same way they affect the rest of the axial skeleton as well as the appendicular skeleton. While diagnosis of dental-related diseases is fairly easy to a dentist, bone diseases are problematic as they are infrequent in basic dental care and when encountered may be missed or misdiagnosed, e.g. osteomyelitis or fibrous dysplasia. The latter diseases are on the other hand easy to be diagnosed by a radiologist, but at the same time medical radiologists usually possess little or even no knowledge on odontogenic lesions. There are not too many countries where dentomaxillofacial radiology is recognised as a specialty, and even in those where it is often the numbers of specialists are low. Depending on the quality of pregraduate training, dentists are with varying degrees prepared for reporting of dentomaxillofacial radiographs. Finally, not in every country it is mandatory to prepare a written report on a dental radiograph or even a CBCT volume. Therefore many dental radiographs are used only for the main purpose of the examination and other lesions are not reported or even missed. In case of the so-called incidental findings, their importance may be lower (like that of tonsilloliths), but when, for example, odontogenic tumour or oral cancer infiltration are not noted, they will progress and patient's prognosis deteriorate.

In conclusion, dentist should know how to take dental radiographs and CBCT volumes, how errors in radiographic technique can affect the resultant images and compromise diagnosis, how to differentiate normal anatomic landmarks and finally how to interpret radiographic images. Detailed knowledge on every single rare odontogenic tumour reported in literature in just a few cases is not mandatory for a general dentist, but it is essential to be able to identify a lesion in radiograph. If a dentist is not capable of reading and reporting of radiographs, he or she should either continue postgraduate education in this field, or establish cooperation with a knowledgeable specialist such as dentomaxillofacial radiologist, head and neck radiologist or another dentist appropriately trained in reading of dentomaxillofacial radiographic images and CBCT volumes.

Materials and Preparation for Dental Radiographs

2

Materials and machines necessary to take a dental radiograph, intraoral or panoramic:

- Intraoral (Fig. 2.1a) or panoramic X-ray machine (Fig. 2.1b),
- Digital image receptor (Figs. 2.2 and 2.3),
- dedicated scanner for indirect digital image sensors (Fig. 2.4),
- Whenever mandatory according to local legal provisions, a thyroid collar or shield (Fig. 2.4a) or a lead apron (Fig. 2.4b, c),
- Single-use plastic envelopes (Fig. 2.3b) or sleeves for image sensors, as well as for bite pieces in panoramic radiography and ear rods in cephalometric radiography,
- If intraoral radiograph is not taken in a dental chair, then special chair for dental X-rays with adjustable head support is recommended (Fig. 2.1),
- positioners for paralleling technique and bitewing radiographs (Fig. 2.1),
- Autoclave for sterilisation of multiple-use positioners,
- Disinfectant solutions or wipes
- PC with dedicated software (Fig. 2.5)
- Examination gloves.

Digital image sensors:

- In general they can be divided into direct and indirect receptors (Fig. 2.2), both are multiple-use types.
- Direct digital sensors include charge-coupled devices (CCD) and complementary metal oxide semiconductor (CMOS). These detectors are also called "solid-state" sensors.
- CCD device is a matrix of photostimulable elements registering electric signal proportional to inciding light from scintillator.
- CMOS is a system of photosensitive elements made of transistors built from metal, oxide and semiconductor.

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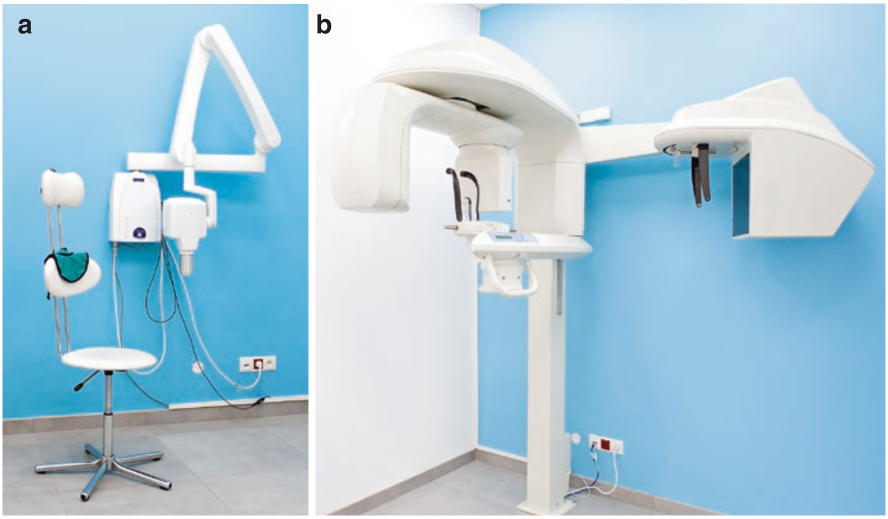

Fig. 2.1 X-ray machines. (**a**) Intraoral with a dedicated chair for dental X-rays. (**b**) Panoramic with cephalometric appliance and two digital image detectors

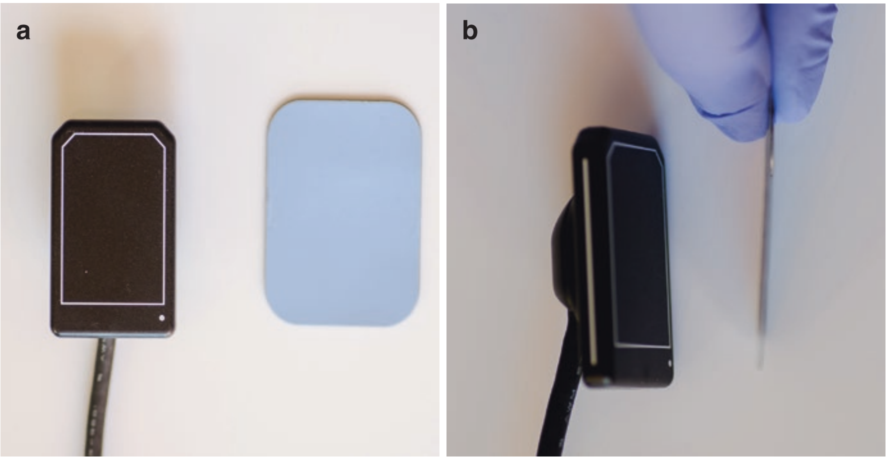

Fig. 2.2 Digital image sensors for intraoral radiography—rigid sensor with a wire and a photostimulable storage phosphor plate (**a**) tube side and (**b**) lateral aspect

– Photostimulable storage phosphor plates (PSP or SPP)—are covered with photostimulable storage phosphor materials that store absorbed energy of the X-ray beam (hence the name storage) in the form of a latent image. When they are subjected to laser energy (HeNe) in a dedicated scanner, the stored energy is released as light photons. This luminescence is detected by a photomultiplier tube which produces an electronic signal. The obtained signal is then converted

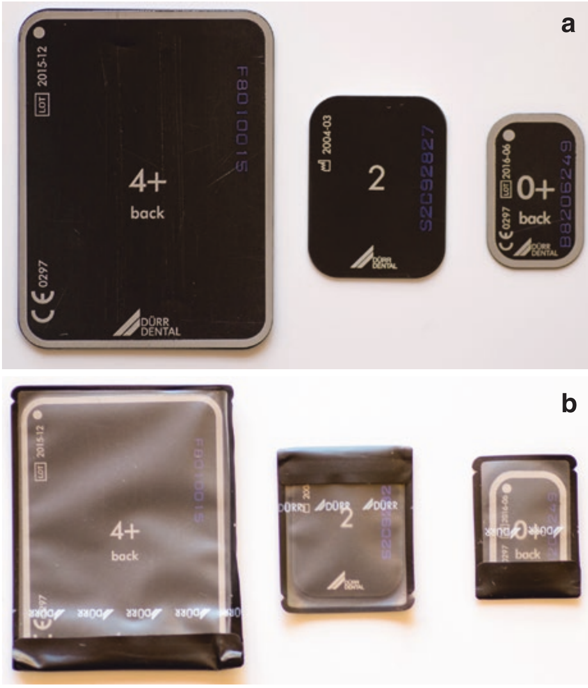

Fig. 2.3 PSP plates in different sizes: 0—paediatric, 2—adult, 4—occlusal. (**a**) Rear view. (**b**) Wrapped in protective plastic envelopes

Fig. 2.4 Laser scanner for intraoral indirect digital radiography

to a digital image on screen. After read out in the scanner, the latent image is wiped out and the plate is used for the next exposure.

– Image intensifiers are used in some cephalometric machines, the "one-shot" type. They transform photons of X-rays (electromagnetic radiation) to a stream of electrons which are cast on a screen and produce luminescence.

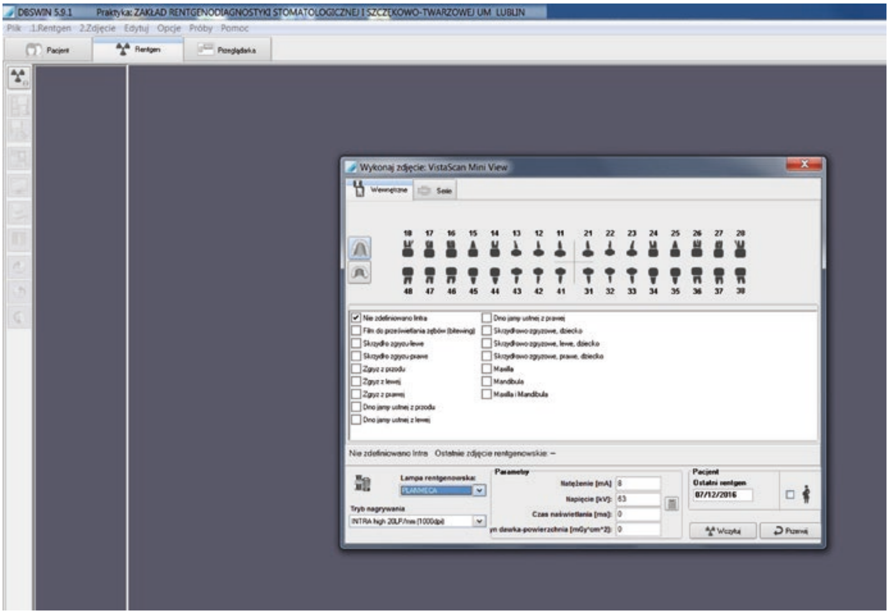

Fig. 2.5 Example of digital radiography software

Features of direct digital systems (Figs. 2.1b and 2.2):

- Image sensor must be directly linked with a computer by means of a wire or WiFi router.
- Directly after exposure image is shown on screen in intraoral radiography, and shortly after exposure in panoramic and other extraoral radiographic techniques once data is uploaded from X-ray machine to a linked computer or server.
- In some extraoral machines image preview appears on screen already during exposure which is helpful in case patient movement is noted or major positioning error occurred. Then preview helps in taking a decision on terminating the exposure before it ends as the faulty radiograph will have to be retaken.
- Obtained radiograph automatically is diverted to an open patient's file without further actions from the operator.
- Intraoral solid-state sensors are less comfortable to patient and more demanding for the operator to manipulate in the oral cavity as these image detectors are rigid and thicker than PSP plates or analogue film packets. Moreover a wire protrudes from the rear side of the sensor making it even thicker in this area and the whole image detector more bulky. This may produce more intense discomfort to a patient and more severe gagging reflex. Positioning devices for direct digital sensors are different from the ones used for PSP plates and film packets as they must accommodate thicker detectors of variable sizes.

- Active area of a direct digital image sensor is smaller than the whole device, and also smaller than a PSP plate active area as well as of a conventional film packet.
- Solid-state image sensor is not sensitive to light, so it can be exposed to natural or external sources of light without threat of wiping out information on X-ray attenuation.

Features of indirect digital systems (Figs. 2.2, 2.3, and 2.4):

- Apart from image sensors, a dedicated laser scanner must be purchased.
- Time from the exposure to obtaining the radiographs on screen is slightly longer than in direct digital radiography due to the need of performing the read out in the scanner.
- Exposed PSP plates do not differ from the unexposed ones, so if attention is not paid to separating used and ready for use PSP plates, they can be confused—e.g. one already exposed can be applied for the second exposure (see—Fig. 7.26).
- One scanner can be used for multiple X-ray tubes installed at different dental chairs or in separate X-ray labs.
- PSP plates are available in several sizes, from paediatric to occlusal.
- Active area of a PSP plate is comparable to that of an analogue film package and is larger than for a solid-state receptor.
- PSP plate is thin and somewhat flexible which makes it easier for positioning in oral cavity and reduces patient discomfort during intraoral radiography.
- PSP plates are more prone to mechanical damage than solid-state detectors as the layer of storage phosphor can be easily scratched with a nail, prosthesis attachment, sharp margin of a tooth and even slot of positioning device.
- Use of PSP in extraoral radiography requires larger scanners, so in dental radiography PSPs are nowadays less frequently used for panoramics and cephalometric radiographs than solid-state sensors.
- PSP plate is not as sensitive to light as a conventional film, therefore darkroom conditions are not required for processing of image from a plate. However, prolonged exposure to light (natural or artificial) can cause decrease of image quality after some time, and even lead to overall loss of the latent image.

Advantages of digital radiography in comparison with analogue radiography:

- Considerable reduction in time between exposure and ready radiograph, especially in direct digital systems.
- Decrease in exposure dose from radiography.
- Elimination of chemical film processing resulting in environmental protection as well as no need to supervise quality of film processing systems.
- Image postprocessing options—image contrast and brightness adjustments, application of image filters.

- After calibration precise linear and angular measurements can be carried out, especially in intraoral paralleling technique periapicals.
- Digital archive of radiographs—less physical storage space needed, easy retrieval of previously taken radiographs for comparison, possibility of generation of multiple copies of every radiograph without loss of image quality.
- Teleradiology—image transfer and reporting done via secure picture archiving and communication systems (PACS).
- High image resolution.
- Wider dynamic range of X-ray which means that digital image receptors react to X-ray exposure and produce data in a wider range of X-ray exposure values.

Disadvantages of digital radiography in comparison with conventional X-ray film:

- One-time higher cost of implementation of the digital system.
- Necessity of protection of stored sensitive patient's data according to the General Data Protection Regulation (GDPR) in the European Union and similar local legal provisions in other areas of the world.
- Some inconveniences in positioning of intraoral solid-state detectors.
- Lack of control over radiographs of inferior quality—too many retakes are performed which ironically leads to increase in overall exposure dose to a patient, although a single exposure dose in digital radiography is lower than that for film radiography.
- Possibility of tampering of digital radiographic image owing to computer image processing software.
- Hardware malfunction and lack of Internet connection makes it impossible to take radiographs and retrieve images from digital archive. Dedicated technical support must be provided.

Materials and preparation for analogue dental X-rays will not be discussed as the technique becomes obsolete, and information on analogue radiography can be found in many older sources.

Suggested Reading

1. Farman AG, editor. editor. Panoramic radiology. Seminars on maxillofacial imaging and interpretation. Berlin: Springer; 2007.
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3. Miles DA, Van Dis ML, Williamson GF, Jensen CW. Radiographic imaging for the dental team. St Louis: Elsevier; 2009.
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5. White SC, Pharoah MJ. Oral radiology. Principles and interpretation. St Louis: Mosby; 2014.