22

Dental Radiography

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22.1 Preface

This chapter deals with two-dimensional (2D) radiography applied in dentistry. “Dentistry” is interpreted in this context to include radiographic 2D-imaging of the entire dento-maxillofacial anatomical complex: the maxilla, the mandible, and infraorbital region. Alternatively, this anatomical complex is also termed the “dentomaxillofacial region” (or “dentomaxillofacial complex”). In this chapter, the term dental radiography will be used for conciseness and consistency, although various alternative names are sometimes used. In this sense, dental radiography comprises all techniques included in dental and oral and maxillofacial radiography. Dental radiography has always played an integral role in the process of dental diagnostics and treatment. Assessment of early stages of carious lesions is a typical example for very basic and routine radiographic diagnostics. Many dental treatment procedures, such as endodontic (root canal) treatment, dental implant placement, or surgical removal of retained or ectopic teeth, rely on radiographic images as fundamental information, without which these treatments would hardly be feasible at all. Chair-side radiographic equipment is required to enable such treatment, which inherently relies on the radiographic assessment of intermediate and/or final treatment steps. These factors made dental radiographs in many countries to be the most frequently acquired radiographic images among all medical radiographs (European Commission 2008). Consequently, in many countries, roughly one-third of all radiographic images are related to dentistry (European Commission 2008). Given the global distribution of dental radiography and its extensive application in a high percentage of the global population, dental radiography largely contributes to the entire share of global medical X-ray imaging. The transition from film-based to digital techniques over the last two decades fundamentally changed techniques, and also their application in dental imaging. This chapter attempts to summarize the historical background of dental radiography, and to provide an overview of the anatomical targets that are involved with it. In addition, the two-dimensional (2D) techniques are explained together with their technical background, which is sometimes unique (e.g., in panoramic radiography). Dose issues as well as radiation protection measures are also discussed in this chapter. The chapter covers intra- as well as extraoral radiographic techniques, and also provides typical example images. It concludes with an outlook on future perspectives as they are foreseeable at the time of writing in the middle of the second decade of the twenty-first century.
Note that the chapter does not cover established three-dimensional techniques such as the oral and maxillofacial application of Cone Beam Computed Tomography (CBCT). The latter topic is extensively discussed in Chapters 35 and 42 of this book.

### 22.2 Historical Background of Dental Radiography

Only a couple of months after the pioneering discovery of X-rays by Wilhelm Conrad Röntgen in 1895, and only two weeks after Röntgen’s respective publication (Röntgen 1895), the German dentist Otto Walkhoff of Braunschweig produced the first dental radiograph acquired in a living person (Forrai 2007).

Walkhoff had asked the physicist Professor Giesel, in Braunschweig, to take an X-ray of his own molars (Forrai 2007). The exposure time was extremely long, amounting to a total of 25 minutes. This explains the unsharpness clearly evident in the radiograph (Figure 22.1). Walkhoff used small pieces of X-ray sensitive suspension-containing photographic glass plates wrapped in light-proof shielding, and placed these in the mouth of the patient (Forrai 2007). Only a few weeks later, the German physicist Professor Walter Koenig published a radiograph of maxillary and mandibular front teeth plus another 14 photographs with X-rays.

**FIGURE 22.1** The first dental radiograph, in 1896, produced in a living person by the German dentist Otto Walkhoff of Braunschweig. (Reproduced with permission from Courtesy Deutsches Röntgenmuseum, Remscheid, Germany.)
Dental Radiography (Forrai 2007). While these early applications represent the starting point for dental radiography, they were taken in a rather preliminary experimental setup rather than in a clinical setting. The introduction of wrapped dental radiographic films by Eastman Kodak in 1913 made handling easier, and certainly enhanced patient comfort. Forty-five years later, the introduction of panoramic radiography (Figure 22.2) in 1948 (see also Section 22.4.2.2.1) revolutionized dental radiography. With this technique, a full overview over the teeth in the lower and upper jaw, plus the jaws themselves, became possible by means of a convenient and patient-friendly method. The introduction of digital technology into dental radiography took until 1984, when Francis Mouyen from Toulouse, France filed his patent for an intraoral image capturing sensor (Mouyen 1984). Under the term RadioVisioGraphy the group around Mouyen in 1989 published their first experimental results (Mouyen et al. 1989). In the 1990s, the advance of digital technology enabled a number of interesting technological developments in radiography. For instance, tomosynthetic imaging (tomosynthesis) experienced a revival and substantial advancement, resulting in several medical applications (Dobbins and Godfrey 2003). Dental radiography played a major role in this advancement, as one special tomosynthetic imaging method was invented by the American dentist and physicist Richard L Webber: Tuned Aperture Computed Tomography (TACT) (Webber 1997; Webber et al. 1997). TACT was designed to acquire planar parallel slice-images through the object from an arbitrary number of 2D-radiographs exposed from a different angle. This novel technology is very flexible in nature and can be adapted to the task under investigation. Preliminary clinical studies indicated its high potential, for example in caries diagnostics (Webber and Messura 1999; Nair and Bezik 2006) or carious lesion detection (Shi et al. 2001). However, the advent of Cone Beam Computed Tomography (CBCT) and its successful marketing up to now impeded the further development and clinical application of the technique. CBCT certainly marked the latest fundamental milestone in dental radiography. It was first introduced in 1998 by the Italian group around Piero Mozzo of Verona, Italy (Mozzo et al. 1998) and the Japanese group around Yoshinori Arai from Nihon University, Tokyo (Arai et al. 1999). As stated above, however, CBCT as an inherently 3D technique does not fall within the scope of this chapter, and is discussed in detail in Chapter 35 and specifically, in Chapter 42 of this book.

22.3 Anatomical Targets in Dental Radiography

In a narrow sense, dental radiography only involves the teeth plus the jaw bones (mandible and maxilla). This narrow definition, however, is often incomplete, since it does not cover the adjacent anatomical structures of the facial bones that are also often of interest for dentists, oral surgeons, or orthodontists. In a more complete approach, the target region is commonly extended to the entire anatomical region, generally referred to as dentomaxillofacial complex (see above). It comprises the teeth, the jaws (maxilla and mandible), including the respective soft tissues (e.g., the tongue), plus the adjacent facial bones and soft tissues related to the oral cavity and the facial structures (Figure 22.3). The Dental Board of Australia (2010) defines the target area (Figure 22.4) as “hard and soft tissues of the oral and maxillofacial region, and […] other structures that are relevant for the proper assessment of oral conditions.”

FIGURE 22.2 Panoramic radiograph of a relatively young fully dentate person.

FIGURE 22.3 Lateral cephalometric radiograph collimated cranially to reduce dose. Note the clearly visible soft tissue profile representing a typical characteristic of this type of radiograph.

FIGURE 22.4 The dentomaxillofacial complex (marked in lighter shade) comprising the facial bones, which represent the anatomical target region of oral and maxillofacial radiology.
22.3.1 The Teeth

Obviously, the teeth are the predominant target for dental radiography. With a maximum number of 32 in the presence of a full set of wisdom teeth, dentists divide the set of teeth into four quadrants. The first quadrant represents the maximally eight teeth on the right side of the upper jaw (maxilla), the second quadrant those on the left upper side. Consequently, the third quadrant represents the maximally eight teeth located on the left side of the mandible, while the fourth quadrant denotes those eight teeth on the right mandible side. Sides are always denoted from the patient’s viewpoint. In other words, starting from the right upper side, the quadrants are assigned counter-clockwise (again from the patient’s viewpoint, see Figure 22.5).

22.3.2 The Mandible

The entire mandible lies within the focus of dental radiography. Its tooth-bearing alveolar process represents the major target of the mandible, since pathologies related to the teeth can be found here. The mandibular body from the chin to the ascending ramus may contain other pathologies such as cysts, tumors, metabolic or drug-related bone diseases, or fractures. At its dorsal cranial end, the condyles of the mandible form a primary radiological target. Inflammatory or traumatological diseases in the temporomandibular joint (TMJ) can be primarily detected by radiographic images. In this context, it is noteworthy to mention that the very widely found cranio-mandibular dysfunctions, in combination with pain, do not correlate to morphological changes in the joint. Thus, in these cases, as clearly pointed out in the European Guidelines for CBCT in general, “radiographs do not add information of relevance to management” (European Commission 2012) and should only be taken to rule out other causes. The condyilar process with the condyle at its distal end is a frequent site for fractures and, thus, also a primary target for radiography. On the other hand, the coronoid process is only of minor importance for radiographic evaluation, since it rarely fractures, and other pathologies are not commonly associated with it.

22.3.3 The Maxilla

The maxilla forms the upper jaw and, thus, a large part of the facial bones. Its structure is complex and it contains many regions of interest for radiographic examination. As in the mandible, the alveolar process lies within the predominant focus of a dentist and, as such, also of dental radiographic evaluation. The paired maxillary sinuses have strong effects on the posterior teeth (premolars, molars) as pathological conditions in the sinuses may also invade the teeth and vice versa. In addition, implant surgery often requires a specific procedure (sinus floor elevation) in which the basal part of the maxillary sinus has to be radiographically assessed before and sometimes also after surgery. Some radiographs are explicitly aiming at the maxilla. For instance, Waters projection (see Section 22.4.2.3.2.5) was developed to investigate the maxillary sinuses plus the sphenoidal (and frontal) sinuses. The maxillary bone is of complex geometry and forms the lateral wall and the floor of the nasal cavity. The latter may also lie in the focus of dental radiographic evaluation. As the maxilla also forms the bony floor of the orbits, radiographic examination will inherently expose the eye to some radiation. This is deemed critical, as the eye suffers from lens clouding (cataract). Recent evidence resulted in recommendations to lower the threshold for exposure once more (Stewart et al. 2012). The geometric shape and the proximity of different anatomical structures render radiographic evaluation of the maxilla a rather complex task. The paired palatal bones are located directly adjacent to the maxilla at its dorsal end and, thus, form the dorsal end of the hard palate. Even though they do not, in a strict anatomical sense, belong to the maxilla, in clinical terms they are often considered as being part of it. Maxillary and neighboring structures are a common locus for pathological conditions or dental procedures; hence, this anatomical region obviously represents a major focus for dental radiography.

22.3.4 The Facial Bones

The facial bones are also termed “viscerocranium” or “splanchnocranium.” Their counterpart is the neurocranium, which

![Teeth scheme used by dentists which sorts the teeth into four quadrants from the upper right (1st) quadrant clockwise to the lower right (4th). Within each quadrant, the teeth are numbered from the midline towards the posterior region.](image-url)
comprises those bones that essentially form the cranial cavity which contains the human brain. According to the most common definition, the facial bones (see Figure 22.4) consist of the following bones:

- Maxilla
- Mandible
- Nasal bones
- Palatine bones
- Lacrimal bones
- Vomer
- Zygomatic bones
- Inferior nasal conchae

As is obvious from this list, large parts (mandible, maxilla, palatine bones) of the facial skeleton/skull have been discussed as anatomical target areas in prior sections. However, the remaining parts (e.g., the nasal and lacrimal bones or the zygomatic bones) also represent important target regions for dental radiography. Extraoral projection radiography (Section 22.4.2.3, see also Table 22.4) focuses on imaging of these structures. Particularly trauma situations often require radiographic evaluation of the facial bones to identify or rule out fractures. In panoramic radiography (Section 22.4.2.2), some of the facial bony structures (e.g., the zygomatic bone) form a characteristic key image that is commonly used for evaluation. Measurements of facial anatomy, as carried out on cephalometric radiographs (Section 22.4.2.1), often include landmarks located in the anatomical region of the facial bones, yet outside the mandible or the maxilla.

22.4 Techniques

2D dental radiography comprises quite different techniques that can be distinguished into the two major subgroups intraoral radiography and extraoral radiography. This terminology refers to the position of the image receptor inside or outside the patient's mouth, respectively. Both intraoral and extraoral radiography comprise different specific techniques that will be described in detail in the following. Extraoral techniques define a relatively loose accumulation of all those radiographs acquired in dental radiography that do not belong to intraoral radiography.

22.4.1 Intraoral Radiography

Intraoral radiography is defined by an intraorally placed receptor and an extraorally positioned X-ray source. Intraoral radiographs, together with panoramic radiographs, represent the most common dental radiographs. It is generally believed that intraoral radiography is still the most common radiographic technique used in dental imaging (Vandenbergh et al. 2010). Technically speaking, in intraoral radiography a small anatomical region of the dentoalveolar process is projected onto a small detector placed in the oral cavity. Intraoral radiographs are required for many routine diagnostic and therapeutic daily-procedures such as endodontology, periodontal assessment and treatment, carious lesion detection, detection of periapical bony pathology, and so on. When taken with proper diagnostic quality, “intraoral images reveal evidence of disease that cannot otherwise be found” (Farman 2014). Three principle configurations are applied: bitewing radiography, periapical radiography, and occlusal radiography.

22.4.1.1 Intraoral Radiography—Targets

Obviously the main targets of intraoral radiography are the teeth. Intraoral radiographs aim at reproducing the tooth crowns (bitewing radiographs), the marginal alveolar bone, or, very commonly, the roots of the teeth (periapical radiographs) under investigation. In addition, intraoral radiography comprises occlusal projections. The anatomical targets of the latter in the case of maxillary occlusal radiography are the anterior hard palate, as well as anterior parts of the nasal cavity and the maxillary sinus. In some instances, also, the posterior parts of the hard palate are investigated with this type of radiograph. Mandibular occlusal radiography images the floor of the mouth as well as the anterior portion (and sometimes also the posterior portion) of the mandible in an axial direction.

Regarding potential pathology, intraoral radiography aims to detect hard tissue (teeth, bone) pathology that is otherwise hidden in the teeth or bone. Carious lesions are certainly the prime target in the tooth-crown or the cervical root region (bitewing radiographs, see below). Pathology in the root-surrounding bone (periapical, periapical) represents another major target of these radiographs in periapical projection. Other bony pathologies that can be visualized on intraoral radiographs (periapical projection, see below) include residual infections, cysts, tumors, and inherent bone pathology (e.g., osteomyelitis, osteonecrosis, metabolic bony alterations, etc.).

The challenge for intraoral radiography lies in the spatially constricted anatomical environment, in combination with some geometrical obstacles, for example the hard palate or the tongue. Correct aiming is also beset with difficulties, as small structures of interest (the teeth) have to be projected onto small area detectors that, to the largest part, are hidden inside the oral cavity of the patient. Patient collaboration is another limiting factor, since placement of the detector (see Figure 22.6) may be slightly painful. Some patients experience difficulties because of the pharyngeal reflex. These factors make correct acquisition of intraoral radiographs a challenging task that requires experience and substantial training.

22.4.1.2 Intraoral Radiography—Challenges

Intraoral radiography involves some challenges very specific to the technique itself. First, the small size image detector has to be placed inside the patient’s mouth, where it is generally not fully (in the region of the front teeth) visible or even hardly visible at all (e.g., in the region of the molar teeth). Second, the main targets, the teeth, are also small in size (approximately between 10 and 25 mm in length) and, thus, their relative orientation to the image receptor is hard to estimate. Third, the operator/radiographer is strongly dependent on the patient’s ability/will to cooperate. This is particularly important, since the patient may experience some pain when the image receptor is placed in the correct position, for example when the receptor is pressed into the floor of the mouth to guarantee an orientation roughly.
parallel to the tooth’s main axis. While the floor of the mouth due to its soft tissue composition is flexible, the hard palate in the maxilla represents a completely inflexible anatomical obstacle. This results in an inevitable angle between the image receptor and the tooth axis that cannot be avoided if a rigid solid-state detector is used for exposure (Roeder et al. 2010). If a non-rigid image receptor is applied, for example a storage phosphor or dental radiographic film, bending of the receptor is hard to avoid. Since many aiming devices (see below) for such detectors do not provide a rigid backing over the entire detector area, the use of the aiming device alone does not guarantee a flat (non-bended) receptor. A curved image plane, however, results in projective distortion that is no longer affine and cannot be rectified without additional references that provide sufficient information on the actual bending (Webber et al. 1984). All these obstacles result in a lack of reproducibility of projection geometry, particularly in periapical radiography, where the image receptor needs to be positioned in such that the root tips of the teeth under study can be projected onto it. Correct placement of the receptor and the cone, thus, requires some spatial sense of the radiographer.

For occlusal radiographs, receptor-damage may easily occur. Since the patient is asked to hold the receptor between the teeth of the upper and lower jaw by cautiously closing his/her mouth, high pressure may accidentally be impacted on the receptor. Due to the high costs, currently there are no solid-state detectors available in the required size for occlusal radiography (size 4, see Table 22.1). Thus, either film or storage phosphors are applied, which are both susceptible to mechanical damage that may occur if the patient uses excessive bite-force to hold the detector between the jaws.

These specific challenges are tackled by different approaches. Sufficient cooperation of the patient can often be achieved by suitable communication and guidance. For instance, the patient should be asked and instructed to relax his/her muscles during placement of the receptor. Regarding reproducibility of periapical and bitewing radiographs, specific aiming devices that reduce the number of degrees of freedom in the projection geometry were introduced many years ago. These will be discussed in the next section.

22.4.1.3 Intraoral Radiography—Devices

Dental X-ray sets for intraoral radiography (Figure 22.7) are compact X-ray sources with a tube-length of roughly >20 cm and a small field round collimation of approximately 6 cm. In other parts of the world, rectangular collimation represents the common standard. The collimating end-part of the tube is termed “cone” or “position indicating device” (PID).

The cone may come in different lengths, which translate to different source-to-object distances. Long cones may extend up to over 40 cm, while short cones are just above 20 cm. It appears that most manufacturers these days market shorter cones of just over 20 cm focal-spot-to-cone-end-distances, with a round opening of 6 cm. If the cone has a cylindrical shape (Figure 22.7), it collimates the beam by a round opening orientated towards the patient.

This round collimation covers a larger area than the film or a digital detector (for sizes, see Table 22.1). Despite the general rule in radiographic imaging that the beam should be collimated to detector size, round collimation, nevertheless, can be justified, since it has been repeatedly shown that in certain situations collimation to actual detector size may result in aiming errors (van Straaten and van Aken 1982; Wenzel and Møystad 2010). Tube voltage is commonly in the range of 60 to 70 kV, in some cases up to 80 kV. In most cases, only the exposure time can be controlled.
and altered by the operator. Of course, required exposure times depend on the detector. Approximately, they range between 0.15 and 0.35 seconds for film (up to 1 second for outdated D-speed films!) and between 0.06 and 0.20 seconds for solid-state digital detectors and storage phosphors.

At the time of writing this chapter, three technical types of intraoral image receptors are (still) in use:

- Radiographic film
- Solid-state digital detectors
- Storage phosphor plates

While radiographic film over the last 100 years has represented the common standard, today more and more film is being replaced by digital receptors or storage phosphor plates. Radiographic film used today starts from D-speed (slowest) over E-speed to film F-speed (fastest). Of course, radiation protection considerations suggest that, if intraoral radiographs are still acquired on radiographic film, then the fastest available film should be used (American Dental Association 2012). The percentage of dentists in the world still working with radiographic film for intraoral radiography may be estimated to range between 70% and 80%. Although there are no valid data available for the majority of countries, it is very likely that in most countries the transition from film to digital has increased in speed over the last few years. Intraoral radiographic films were typically grouped into five sizes (Table 22.1).

### TABLE 22.1

<table>
<thead>
<tr>
<th>Size No.</th>
<th>Size (mm²)</th>
<th>Typical Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>35 × 22</td>
<td>Periapical/bitewing (anterior)</td>
</tr>
<tr>
<td>1</td>
<td>40 × 24</td>
<td>Periapical/periapical</td>
</tr>
<tr>
<td>2</td>
<td>40.5 × 30.5</td>
<td>Periapical/bitewing</td>
</tr>
<tr>
<td>3</td>
<td>54 × 27</td>
<td>Bitewing</td>
</tr>
<tr>
<td>4</td>
<td>57 × 76</td>
<td>Occlusal radiography</td>
</tr>
</tbody>
</table>


In the digital era, two types of receptors have been established: storage phosphor plates (“computed radiography”) (see also Section I, Chapter 12 of this book) and solid-state digital detectors (“digital radiography”). As a first step into the digital world, storage phosphor plates are often preferred by the dentist, who had been trained on radiographic film and who is accustomed to a cable-less, thin, and flexible detector (Figure 22.8).

Solid-state digital receptors (Figure 22.9) started from CCD (charged-coupled-device) detector technology. Nowadays, more and more receptors based on CMOS (complementary metal oxide semiconductor) technology are marketed. Recently, active-pixel-detectors with built-in integrated circuits are becoming more and more popular.

A typical intraoral solid-state detector has an external size of ca. 3 × 4 cm² or smaller. The active detection area for technical reasons is somewhat smaller. The rigidity and thickness of solid-state detectors in combination with the cable necessary for data-transfer make this detector type challenging in intraoral applications. For obvious reasons, cable-less solid-state detectors have been the focus of many manufacturers for a long time. De facto, they had entered the market already in the early years of the new millennium. However, until recently, reliable
transmission of the radiographic image to the PC to which they are interfaced was problematic. In addition, sufficient battery power and durability for signal capture and transfer was a typical technical limitation, preventing a broad application of cable-less intraoral detectors. However, it can be expected that advanced battery-technology, together with further downsizing of electronic components, will help to overcome these limitations in the future. Until now, the cable-connection is certainly one major reason, among others (rigidity, thickness, in comparison to film or storage phosphor), why particularly dentists that have been trained on radiographic film often prefer storage phosphors as their first step into the digital world. Since patient-related application is very similar to radiographic film, switching from film to “digital” appears to be a simple procedure. It has been shown that patient comfort is higher using storage phosphors (Figure 22.8), when compared to solid-state receptors (Wenzel et al. 1999).

The difficulty in correct positioning and aiming when using solid-state receptor technology has also been proved in scientific patient studies (Versteeg et al. 1998; Bahrami et al. 2003). Incorrect aiming results in “cone cuts,” areas in the image that are not hit by the X-ray beam, while other areas of the patient are instead irradiated by the beam that doesn’t correctly impact on the receptor (Figure 22.10).

Despite these shortcomings, the author of this chapter, since 2001, has gained experience in using solid-stated receptors for intraoral radiographic images, with roughly 8000 such images acquired annually in the Dental School of the University Medical Center of Mainz, Germany. According to the experience in our clinic over more than 15 years, the combination of a preceding thorough training of the radiographic technicians and sole use of only this detector type makes it possible to reach an aiming-error level comparable to that of the film era. To facilitate proper positioning and aiming, whenever possible, an appropriate aiming device should be used (Figure 22.11).

Aiming devices contain a bite block on which the patient bites during exposure so that the aiming device is maintained in a fixed position relative to the teeth under investigation. These devices are designed to ensure a perpendicular orientation, plus a central impact of the central X-ray on the flat image detector. The rigidity and size of solid-state detectors, in combination with the anatomical situation (the hard palate), make it necessary in the maxilla to accept an angle between the receptor and tooth axis (Figure 22.12), which may be as large as 55° in the molar region of the maxilla (Roeder et al. 2010).

From these findings, it can be concluded that, for solid-state detectors, the requirements to aim for parallel alignment between tooth and image receptor should be relaxed. Instead, the concept of a “perpendicular technique” should be applied, which only requires a perpendicular impact of the central X-ray on the receptor. The latter is guaranteed by means of an appropriate aiming device. De facto the aiming devices on the market are constructed to exactly fulfill this prerequisite. In such, a best compromise imaging geometry is accomplished that can be achieved in the light of the existing anatomical obstacles. Regardless of its actual position in relation to the teeth the detector should always be positioned such that its cord-attaching side is orientated towards the mouth opening. Care has to be exercised in the frontal region of the mouth, where the vertically orientated detector with the cord attached is pressed against the hard palate or the floor of the mouth when the patient closes his mouth to fix the device. This may induce a sharp bending of the cord which, if happening repeatedly, in turn could easily harm the electric wires in the cord. To prevent this, a cotton wool role can be placed underneath the bite block to create additional space for the cable.

Storage phosphors have disadvantages, mainly in their susceptibility to mechanical damage, particularly to their surface (Bedard et al. 2004; Chiu et al. 2008). Everyday use means
frequent contact of the surface with, for example, the human hand, and also with the patient’s mouth and teeth or the aiming device. In addition, the readout process in the scanner also requires some sort of mechanical interaction, e.g., to fix the plate in the machine or to transport it relative to the laser beam. All these mechanical processes bear a risk of damage to its surface. Scratches or tooth marks are common occurrences of such damage. They will be visible in all radiographs subsequently produced with the plate. Scratches may mimic pathology or other relevant structures and, thus, need to be avoided (Chiu et al. 2008). One experimental study modeling a clinical setting observed that, within 10 weeks of frequent usage, 95% of the plates become undiagnostic (Bedard et al. 2004). This corresponded to only 50 cycles that each individual plate was used.

22.4.1.4 Intraoral Radiography—Techniques

Intraoral radiography comprises a variety of different techniques, each of which has its special applications, advantages, and disadvantages. The different techniques have evolved over the many years of clinical application of intraoral radiography in the light of the specific challenges this type of radiography inherently encounters. The three main techniques are bitewing radiography, periapical radiography, and occlusal radiography.

22.4.1.4.1 Bitewing Radiography

This type of intraoral radiography displays the crowns of the teeth of the mandible plus those of the maxillary counterpart, as well as the marginal alveolar crest of both regions (Figure 22.13).

Its name originates from the fact that the patient holds the film by occluding onto a tab or wing attached to the film. Bitewing films are a little longer than periapical films (ca. 27 × 54 mm²) so that they can be placed in horizontal orientation (landscape) in the oral cavity tangent to the oral side of the teeth. Of course, today storage phosphor plates and solid-state receptors are also used to acquire bitewing radiographs. Commonly bitewing radiographs are exposed in “paralleling technique” (Figure 22.14), which is possible for this type of intraoral radiographs, as no anatomical obstacles interfere with a parallel orientation of the image receptor relative to the crowns of the teeth.

Paralleling technique requires that the long axis of the tooth is parallel to the detector axis, with the central X-ray oriented orthogonally on both. Often, to further enhance visualization of the crowns, it is recommended that the central X-ray is directed with a downward angle of approximately 5° to 10° to the occlusal plane. In the horizontal direction, the central X-ray is aimed at 90° to the detector to avoid overlap of the teeth images in the regions in which the teeth are in close contact to one another. These regions, which are termed “interproximal regions” (or “approximal regions”) are particularly susceptible for caries. Initial (starting) caries is targeted on bitewing radiographs, mainly in these interproximal regions (Figure 22.13). Bitewing radiography was explicitly developed to assess carious lesions in the occlusal and/or approximal surfaces of the posterior teeth.

To achieve standardized imaging geometry as possible for optimal image quality and, thus, best possible readability, the use of a beam-aiming device is strongly recommended (Wenzel 2004). Sensitivity for carious lesion detection roughly ranges between 50% and 70% for lesions extending into the dentin (approximal and occlusal) of the tooth (Wenzel 2004). However, this fraction is considerably smaller for approximal lesions only affecting the enamel of the teeth (Wenzel 2004). A very recent systematic review supported this outcome and concluded that radiographic caries detection is very well suited for cavities and dental lesions, while it is less accurate for initial carious lesions (Schwendicke et al. 2015). A somewhat older systematic review
suggested that some digital receptors may offer small gains in sensitivity when compared to radiographic film (Bader et al. 2001). In many countries, repeated bitewing radiographs are recommended for individuals with high and moderate caries risk, and less frequently also for individuals with low caries risk (see e.g., European Commission 2004). The recommendations emphasize, however, that the actual frequency depends on individual caries risk and that “prescription of bitewing radiographs for caries diagnosis should be based upon caries risk assessment” (European Commission 2004).

22.4.1.4.2 Periapical Radiography

Periapical radiographs are acquired to assess pathologies of the tooth roots or within the surrounding bone (Figure 22.15).

Another common application is during endodontic treatment (Figure 22.16), where the focus lies on assessment of the length of the root or a root canal filling or the quality of the root canal filling.

Periapical radiographs are taken from all teeth/regions. A full mouth series/survey is a complete set of periapical radiographs covering all teeth. Full mouth series comprise 12, 14, or 15 radiographs, sometimes even up to 18 or 20. In general, front teeth (from canine to canine in both jaws) are exposed on a vertically (portrait) orientated detector, whereas the posterior teeth are projected onto a horizontally (landscape) orientated detector (Figure 22.17).

Optimum geometrical conditions for intraoral radiographs would be guaranteed if the radiographs were indeed exposed in paralleling technique. However, it had been shown already in 1959 that “true” parallel placement of the film relative to the tooth axis in the maxilla is hardly feasible (Barr and Gron 1959). In an experimental study using a replica of a solid-state intraoral detector, the authors even found angles ranging up to 55° in the molar region of the maxilla (Roeder et al. 2010). However, semantically the gerund “paralleling” only implies the attempt to make the two axes (longitudinal tooth axis and respective receptor axis) parallel and, thus, does not actually mean they are “truly parallel.” Aiming devices (Figure 22.11) only guarantee a roughly perpendicular orientation of the central X-ray on the center of the receptor.

Hence, such a technique for flat solid-state detectors is better termed “perpendicular technique.” Of course, aiming devices are also used with non-rigid detectors such as radiographic film and storage phosphors. However, here we must realize that often the fixation of the device by closing the jaws (i.e., biting on the bite block of the aiming device) may still result in considerable bending of the detector. This may be due to a too small backing of the film/storage phosphor. As the detector plane is bent in a more or less arbitrarily-curved shape, this will necessarily induce projective distortion, which cannot be easily corrected. Only if an appropriate reference object of known geometry that follows the bending-curve is also projected onto the image, these distortion effects could a posteriori be corrected (Webber et al. 1984). Since the latter is generally not available and particularly challenging for the small area intraoral detectors, such bending should be generally avoided. As a consequence, another technique had been introduced, that in special cases may also be applied for rigid solid-state receptors: the “Bisecting the angle technique.” This special technique makes use of the unavoidable angle between tooth and receptor, for example in the maxilla. By orienting the central X-ray perpendicular onto the plane that bisects this angle, a sort of best compromise geometry is achieved. The rationale behind this technique is that, for an

FIGURE 22.15 Periapical intraoral radiograph showing an erosive bony lesion between the teeth caused by invasive growth of a (malignant) squamous cell tumor.

FIGURE 22.16 Periapical intraoral radiograph taken for a very common purpose: endodontic treatment of a tooth (here No. 43), for example to evaluate the length of the root canal filling or to control its quality.
idealized scenario of parallel X-rays, a perpendicular orientation of the central X-ray onto the bisecting plane yields an isometric (yet distorted) image of the tooth. For the bisecting the angle technique, the patient holds the image receptor with the fingers/thumb of the contralateral hand. A cotton wool role is placed between (flexible) receptor and tooth, because it is imperative that also in this technique bending is strictly avoided. Correctly applied, the bisecting the angle technique can be an alternative when flexible receptors are used, since the latter may encounter significant bending when applied in aiming devices. In general, however, the use of an aiming device represents the state-of-the art in intraoral radiography, particularly when using solid-state receptors.

22.4.1.4.3 Occlusal Radiography

Using larger area detectors (ca. 7 × 5 cm²) occlusal radiographs are obtained by placing the detector between the occlusal tooth surfaces. The patient is instructed to slightly close his/her mouth to gently hold the detector in place. Care must be exercised that the patient does not force his/her bite, since this likely would damage the detector. Both film and storage phosphors are used for acquisition of occlusal radiographs. Unfortunately, however, to date solid-state detectors are not yet available, simply due to their very high costs in the required size. Depending on the region under investigation, the receptor may be placed either with its longitudinal axis parallel to the midsagittal plane or perpendicular to it. In relation to periapical and bitewing radiographs, occlusal radiographs are far less common and acquired only for special purposes. Their main indication is to obtain a view from a direction roughly orthogonally to the occlusal plane. Consequently, maxillary occlusal radiographs show the hard palate roughly back to the second molar. The posterior occlusal may even reach back to the wisdom teeth. Here, the angle between the detector and the central X-ray is ca. 60° to 70°. A more orthogonal orientation would interfere with the frontal bone of the skull, which would then be superimposed over the hard palate, thereby disguising the structures of interest. For the less frequently used posterior maxillary occlusal, the X-ray should be orientated even more obliquely (around 75°). The patient is seated with the occlusal plane roughly parallel to the horizontal plane. The dental X-ray cone is placed with its aperture centered on the nasal bone and the central X-ray orientated roughly onto the sagittal midline of the patient in the region of the first upper molar (Figure 22.18).
Maxillary occlusal radiographs (Figure 22.19) are taken, for example to localize retained teeth in the hard palate, to obtain a roughly axial view on suspected pathologies, such as cysts of the nasal duct or odontogenic cysts dorsally extending into the hard palate.

It seems obvious that, with the wide availability of CBCT-devices nowadays, these radiographs are declining in numbers, as for such diagnostic tasks a 3D-radiography has its natural advantages. In addition, the oblique orientation of the beam onto the detector necessarily (Figure 22.18a) induces distortion and projective effects, that may, if not carefully considered by the clinician, also result in erroneous assumptions.

For instance, retained canines located cranially of the root tips of the regular front teeth due to the projection geometry will be dorsally projected towards the hard palate. Despite this shortcoming, anterior occlusal radiographs are still frequently used in combination with a periapical projection for parallax localization of canines.

Mandibular occlusal projections are taken at roughly right angles between central X-ray and detector. As in maxillary occlusals, an anterior and a posterior version of this type of radiography exists. The patient is asked to bend his neck backwards so that the cone can be orientated from beneath, with the central ray perpendicular to the receptor (Figure 22.18b).

Mandibular occlusal radiographs are indicated, for example to locate (radio-opaque) sialoliths in the floor of the mouth (Figure 22.20), display fractures (as orthogonal view of the mandible to a panoramic radiograph), mandibular tori, or foreign bodies suspected in the floor of the mouth.

Sometimes, they are also used for localization purposes of retained teeth (e.g., the posterior version for retained wisdom teeth). However, for some of these purposes today, 3D-radiography (CBCT) has become more and more a common standard. For diagnosis of sialoliths in the floor of the mouth, today sonography represents the primary diagnostic tool. Only in cases with clinically suspected sialolith, yet lacking sonographic proof, can a mandibular occlusal radiograph be indicated.

### 22.4.1.5 Typical Errors in Intraoral Radiography

Apart from the well-known processing errors for radiographic film, there are some typical errors for intraoral radiography very specific to the technique (Table 22.2). For flexible receptors such as radiographic film and storage phosphor plates, bending of the receptor due to anatomical restrictions/obstacles is very common. Bending necessarily results in distorted images. The complicated intraoral application often results in other geometric errors in the images (cone cuts, superimposition of structures under investigation), and also frequently gives rise to retakes. Scratching of the detector surface is a common problem in film and storage phosphor technology. Particularly in occlusal radiography in which the patient fixes the receptor between his jaws by gently biting on it, mechanical surface damage is hard to avoid.

### Table 22.2

**Typical Errors in Intraoral Radiography**

<table>
<thead>
<tr>
<th>Error</th>
<th>Influence on Radiographic Image</th>
<th>Measures to Avoid the Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric errors</td>
<td>Superimposition of structures, cone cuts</td>
<td>• Use of aiming device whenever possible</td>
</tr>
<tr>
<td>Bending of flexible receptors</td>
<td>(Massive) distortion, magnification</td>
<td>• Appropriate aiming devices supporting the entire detector,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Application of cotton wool roles to minimize bending</td>
</tr>
<tr>
<td></td>
<td></td>
<td>when patient holds film/plate with fingers</td>
</tr>
<tr>
<td>Mechanical damage of film</td>
<td>Visible dark lines (e.g., finger nail pressure marks,</td>
<td>• Careful handling of films (e.g., avoid long finger nails)</td>
</tr>
<tr>
<td>surface</td>
<td>scratches)</td>
<td>• Careful handling of plates (finger nails!)</td>
</tr>
<tr>
<td>Mechanical damage of storage</td>
<td>Visible bright lines or structures in the</td>
<td>• Replacement of damaged plates</td>
</tr>
<tr>
<td>phosphor surface</td>
<td>radiograph reproducible in each radiograph acquired</td>
<td></td>
</tr>
<tr>
<td></td>
<td>with the plate</td>
<td></td>
</tr>
</tbody>
</table>
22.4.2 Extraoral Radiography

Dental extraoral radiography often (panoramic radiography, cephalometric radiography) also aims at the major targets in dental radiography: the teeth. Yet, also the jaw bones and the other facial bones represent common targets. Extraoral dental radiography comprises panoramic and cephalometric radiography, as well as other specific extraoral projection radiographs. Although the main focus of this section is intended to explain the two most frequently used extraoral radiographs in dentistry (i.e., panoramic and lateral cephalometric radiography), the other extraoral projection radiographs will also be briefly discussed.

22.4.2.1 Extraoral Radiography—Devices

The two major representatives, panoramic and cephalometric radiography, require very specific devices which will be discussed in the respective sections below.

The remaining dental extraoral projection radiographs are often acquired in hospital settings where typical medical radiographic devices are available. For instance, ceiling or floor mounted X-ray tubes, in combination with a Bucky-table and/or a chest stand, are typical representatives (see Section II, Chapter 26 of this book). However, most of the dental extraoral projection radiographs can also be exposed with dental X-ray equipment, such as a panoramic machine with integrated cephalostat (different skull projections) or intraoral dental X-ray set (TMJ projections, lateral oblique projections).

The required detector size area is relatively large, commonly ranging between $5 \times 7$ and $8 \times 10$ inches$^2$. In metric terminology, common formats range between $18 \times 24$ cm$^2$ and $24 \times 30$ cm$^2$.

As a matter of course, intensifying screens should always be used to reduce the radiation dose in film-based extraoral projection radiography.

22.4.2.2 Panoramic Radiography

Panoramic radiography is an extremely common technique in the dental world, providing an overview over the dental arch (teeth and the tooth-bearing parts of the maxilla plus the mandible) on a wide landscape-formatted radiograph (Figure 22.21).

Panoramic radiography produces a layer of sharp image out of the entire object, by deliberately exploiting the relative speed of the beam, object, and detector to one another. This automatically implies that it is a non-static projection radiography system with moving source and detector. The principal underlying assumption is that, if the speed of the “object shadow” (i.e., the radiographic image of an object) exactly matches the speed of the detector plane, an object will be depicted without blur. However, if those two speeds don’t match, the object image will be blurred as a function of the relative speed between object image and detector. The speed of the “object shadow” is determined by the speed of the X-ray beam traversing it. Panoramic radiographic systems utilize a narrow vertical fan beam (Figure 22.22).

In a narrow sense the anatomical target for panoramic radiography is the teeth and the supporting bony tissue (maxilla and mandible). These structures in an axial view form a paraboloid-shaped layer (Figure 22.23) that requires to be sharply depicted, whereas anatomical structures outside this layer should be blurred in a way that they seem “invisible.”

The image is formed by a technique termed linear tomography by means of a moving source-detector unit (see Section 22.4.2.2.2). Today linear tomography in radiology is hardly found anywhere else apart from dentistry. In dental radiography, however, panoramic radiography still represents a standard radiographic imaging technique to obtain an overview over the patient’s dental status plus the mandible and maxilla.

22.4.2.2.1 History of Panoramic Radiography

The aim of depicting the entire dental arch on one radiographic image certainly was the thriving factor for the development of panoramic radiography. In 1922, the American Alvin Frank Zulauf in New York patented a “Panoramic X-ray apparatus” (Zulauf 1922) where the U-shaped film was placed intraorally and the narrow beam was moved relative to the patient by means of a carriage. This invention was not a layer-forming...
technique in the sense of the “real” panoramic radiography discussed in this section. Rather, it was a radiograph projected in a step-wise fashion onto a curved film-plane that resembled the curve of the dental arch. With this patented technique real radiographic images were never acquired. It was 1933 when Hisatugu Numata of Japan (Numata 1933, 1934) developed the first practically operating rotational panoramic radiography machine. However, Numata also applied an orally positioned bent film and a source (narrow beam) that was step-by-step moved around the patient. Obviously, this was also not a layer-forming technique and resulted in a composite panoramic view made up of many strip-like single (steady) projections. Anatomic structures superimposed over the teeth/dental arch rendered this method insufficient for many clinical purposes.

A different approach that was technically much closer to what we term panoramic radiography today was patented also in 1922 by the French physician Bocage (1921). The interesting aspect in his patent was that Bocage had an idea on how to produce the radiographic image of a curved layer within the object. By moving a source-detector system fixed to one another a single fixed plane lying at a certain depth between these components exists for which the images of the points in this plane are always projected onto the same location on the detector. This is the fundamental principal forming the layer in panoramic radiography. A German, Heckmann (1939), had suggested a layer-forming technique by a suitable movement and a narrow beam. A Finnish engineer, Paatero (1946) developed a very similar machine. He was unaware of the German publication of Heckmann (1939), who had suggested a setting with stationary X-ray source and slit collimator in combination with a coordinated movement of object and film (Heckmann 1939). Today, Paatero is commonly considered the inventor of modern panoramic radiography, since he, in 1949, developed a modified technique in which the film was placed extraorally attached to the patient’s face. The patient (and film) was then rotated through a stationary beam. In doing so, it was only possible to produce an image of the facial layer of the skull (i.e., the anatomic feature the film was closely fixed to). From these early attempts that did not really provide a layer-forming technique, the concept of modern panoramic radiography was derived. In 1949, Paatero developed a technique he termed “pantomography” (Paatero 1949), which was applying a concept that is still in use for panoramic radiography today. At that time, Paatero used a stationary fan beam, whilst the patient plus the film were moved. The film was bent into the shape of the mandible in such that it, plus the projected parts of the mandible, had equal speed during the exposure. At this stage, only one stationary rotation axis was applied. Later on, Paatero added two additional rotation axes to obtain a more sufficient projection geometry in relation to the dental arch (Paatero 1961).

The commercial production of the machines started in 1960 with single assembled units. Some years later it proceeded into a large-scale production by a manufacturer called Palomex (Panoramic Layer Observing Machine for Export) (Hallikainen 1996). The engineers collaborated with Siemens, the company which for some years also marketed the equipment (Hallikainen 1996). Other companies also started producing panoramic radiography machines, for example the S. S. White Dental Manufacturing Company in the U.S. under the name “Panorex.”

In 1985, when the film-based panoramic radiography technique had already been widely accepted and was spread all over the world, the first computed system was introduced by Kashima et al. (1985) of Japan. By simply replacing the radiographic film with a storage phosphor made of an europium-activated barium fluorohalide compound in a conventional panoramic machine, the procedure was straight forward. A laser scanning readout system for the storage phosphor was developed. The authors found the resulting images to be of higher-resolution and overall quality when compared to their film-based counterparts (Kashima et al. 1985). Building on the platform of a model OP10 Orthopantomograph panoramic X-ray machine (Instrumentarium Imaging, Helsinki, Finland), the group around William Doss MacDavid introduced the first digital system in 1991 (McDavid et al. 1991). This prototype already produced very promising images. One year later the authors published a more elaborate series of testing results (Dove et al. 1992). They concluded that there is a great potential for dose reduction in the digital acquisition mode, while only a minimal reduction of available spatial resolution was found in comparison to a film-based machine. In addition, the general advantage of digital radiographs regarding post-processing with respect to contrast and gray-scale response-curve was highlighted. Dimensional reproduction of this newly introduced digital panoramic machine was subsequently evaluated by the authors in the same year (McDavid et al. 1993).

It seems quite obvious that image formation from a geometrical point of view does not generally differ between analog (film-based) and digital acquisition mode. Consequently, the mathematically predicted values were similar to their experimentally acquired counterpart. Systems using charged-coupled-devices (CCD) as digital image receptors had been introduced to the market by several manufacturers in the mid-1990s: the Digipan (Trophy Radiologie, Vincennes, France, in conjunction with Instrumentarium, Tuusula, Finland), the Planmeca Digital System (Helsinki, Finland), and the Orthophos Digital (Siemens AG, Bensheim, Germany) (Farman et al. 1997).

In the context of panoramic radiography, an interim technique also requires mentioning, which was termed “Status-X.”
It applied a pencil-shaped X-ray source placed intraorally in combination with a bent film attached to the patient’s facial skin. Introduced by the German Company Siemens in the 1970s, the technique had been developed to project one entire jaw from the oral cavity onto a film positioned outside the mouth of the patient. In such, Status-X-technique produced a magnified and distorted radiographic image of the jaw of interest. As the film touched the skin of the patient’s facial soft tissue and, thus, followed the natural anatomic curve of the face in the region of the jaw, the significant bending yielded heavily distorted radiographs of the teeth and the selected jaw (Figure 22.24).

In addition, as evident from Figure 22.24, the radiographic image was also very much magnified. Another significant drawback of the Status-X-technique was a high surface dose applied on the intraoral mucosa. These disadvantages and the fact that panoramic radiography was widely available already at that time made the Status-X-technique disappear soon after its introduction in the 1980s.

22.4.2.2.2 Technique of Panoramic Radiography

Still utilizing Paatero’s (1961) initial idea, panoramic radiography is a zonographic radiographic technique that depicts a curved layer out of the patient’s head. Panoramic radiography belongs to the technical class of linear tomography, in which the focal-spot and the detector move around a fixed point, termed the pivot point or fulcrum. This fulcrum lies within the plane of interest within the object. Since a predefined layer and not a single point has to be imaged, the position of the fulcrum continuously changes during the acquisition of the tomography (see Figure 22.25).

The layer is shaped in such a way as to incorporate the average dental arch (Figure 22.23).

It represents a distinct depth zone out of the entire exposed area and is, thus, also commonly termed the “focal trough.” The underlying principle is to match the relative speed of the object image and the film/storage phosphor or the detector readout (for solid-state detectors), respectively. As a consequence, objects located within the zone of “zero-relative-speed” remain in sharp focus, whereas object outside this zone are blurred. The amount of blur increases with the relative speed, such as the distance of the object relative to the zone of “zero-relative-speed.” Obviously, true zero-relative-speed can only be expected for infinitesimally thin objects. Thus, in reality, the relative speed between detector and object image should be small, so that the image will appear in focus. The technique uses a vertically orientated narrow fan beam, which is produced by a narrow slit collimator placed in the beam close to the source (Figure 22.22). In the radiographic film era, the latter had to be moved in a way to match the speed the objects under investigation were traversed by the vertical fan beam. When using a digital image receptor, the matching process relates to the readout-speed of the detector (McDavid et al. 1993).

Radiographic images of structures that are being projected by the narrow fan beam with identical (or nearly identical) speed as the detector moves (or is being read out, respectively) are depicted sharply. The larger the relative speed difference between images (“shadows”) and detector, the more the image of a structure is blurred. The relative speed, $V_p$, of the structure’s projection in relation to the detector according to Welander et al. (1990) is given by:

$$V_p = \frac{A r_c \omega \cos \phi}{D - r + r_f \cos \phi}$$  \hspace{1cm} (22.1)

where $r$ represents the distance from the effective rotation center of the eccentric movement to the central object plane, and $r_f$ the...
distance between effective rotation center and a point P under investigation. A is the source-to-detector distance, D the distance between source and effective rotation center, and $\phi$ denotes the angle between the central ray of the beam and P (for illustration, see Figure 22.26).

The extent of blurring strongly depends on the width of the beam and on the length of the rotation radius. Both parameters in rotational panoramic radiography are of such an extent that the image de facto is more a zonography than a true tomography (Nyström and Welander 1972). That means that zones close to the (infinitesimally thin) sharp image layer are only minimally blurred and, hence, the technique only suffices if the target structures are not enclosed by adjacent absorbing objects (Nyström and Welander 1972). This prerequisite, however, is perfectly fulfilled, since a “free space” is surrounding the dental arch on both sides.

What today is considered as a “panoramic radiograph” in dentistry is acquired by means of rotational panoramic radiography. The unit consisting of X-ray source and detector rotates in a complex way around the patient’s head. Modern devices use a permanently shifted (sliding) rotation center, resulting in an eccentric rotation (Welander et al. 1990) (Figure 22.25).

The source-receptor unit of today’s panoramic machines typically travels an angle of around 270° during exposure. For many machines, the starting position is somewhere in the region of the right cheek of the patient. From there, the X-ray source travels along its path behind the patient’s neck to the opposite side (endpoint: left cheek of the patient). The image receptor that is linked to the source as described above travels the same path just on the opposite patient side during exposure. To understand the resulting image, it is important to realize that, according to this motion pattern, structures positioned laterally in the exposed region will likely be imaged twice, since they are traversed by the beam from both sides of the path. This is important, for example to understand why earrings produce ghost shadows (see Section 22.4.2.2.5) on both sides (see below). Vice-versa, structures in the frontal region of the jaws or the surrounding soft tissue are only once traversed by the X-ray beam when the source is traveling behind the neck of the patient.

22.4.2.2.3 Panoramic Radiography—Devices
Panoramic radiography can only be performed in specific panoramic machines. These comprise a floor mounted (plus-sometimes additionally wall-mounted) stand in which the unit consisting of X-ray tube and image receptor is integrated. In modern machines, these two compounds are mounted opposite to each other in a c-arm-like arrangement (see Figure 22.27).

To accommodate a continuous shift of the effective center of rotation in this arrangement, commonly the c-arm is mounted to another arm, which can itself conduct translational motion simultaneously. The image receptor is either a film or storage phosphor of ca. 10 cm (to 15 cm) × 30 cm or a solid-state detector of some ca. 5 mm width and a height of ca. 10 to 15 cm. All panoramic

![FIGURE 22.26 Schematic representation of the geometry typical for a rotational panoramic radiography system with sliding rotation center. Labels are explained in the text. (Adapted from Welander, U. et al. 1990. Oral Radiology 6:69–88.)](image-url)
machines utilize a vertically orientated fan beam geometry that is directed slightly in upward direction. Most machines start exposing when the tube is positioned roughly in front of the right patient-cheek and, thereafter, travel on a horizontal path behind the patient’s neck to the opposite patient side. Panoramic radiographic devices often include a cephalostat, such as a laterally extending arm with a positioning device for proper patient positioning in which cephalometric radiographs can be acquired in a standardized fashion. In addition, or as a single solution, recently more and more panoramic machines are being marketed with an integrated cone beam computed tomography function. These combination devices are cost- and space-effective and, thus, very convenient for the user. They have, however, some technical drawbacks lying in the different technical requirements for the relatively complex panoramic motion described above versus the circular yet very accurate motion necessary for CBCT-acquisition. Also, these devices are commonly standing devices (i.e., the patient is standing during exposure), which makes the patient more prone to move during the several seconds of image acquisition in CBCT. To date, it can only be speculated which technical solutions in the future may be introduced to circumnavigate these shortcomings inherent in such combination machines.

Regarding exposure parameters, most panoramic machines operate between 60 and 90 kV. Milliamperes commonly range between 5 and 10 mA. The exposure time in panoramic imaging is fixed for a specific machine and program. Times range between 5 seconds and 16 to 20 seconds. To ensure sufficient beam energy when the cervical spine needs to be penetrated (i.e., when the X-ray source travels behind the patient’s neck and the front is being depicted), many manufacturers slightly increase the kilovoltage automatically during this period. Manufacturers also developed techniques to provide an automated exposure control (Frosio and Borghese 2006). These use the column-by-column acquisition technique in panoramic radiography to modulate the exposure settings in a way that a homogeneous exposure at detector level is guaranteed (Frosio and Borghese 2006). This can help to limit the overall dose to the patient.

**FIGURE 22.27** Patient positioned in digital panoramic machine with the linear detector array (#1) opposite to the X-ray tube (#2). The front teeth bite into the respective groove of the bite block. A horizontal laser beam indicates the orientation of the Frankfort plane, a vertical beam the midsagittal plane.

### 22.4.2.2.4 Detectors Used for Panoramic Radiography

Cassette-based devices usually utilize a vertically orientated fan beam geometry that is directed slightly in upward direction. Most machines start exposing when the tube is positioned roughly in front of the right patient-cheek and, thereafter, travel on a horizontal path behind the patient’s neck to the opposite patient side. Panoramic radiographic devices often include a cephalostat, such as a laterally extending arm with a positioning device for proper patient positioning in which cephalometric radiographs can be acquired in a standardized fashion. In addition, or as a single solution, recently more and more panoramic machines are being marketed with an integrated cone beam computed tomography function. These combination devices are cost- and space-effective and, thus, very convenient for the user. They have, however, some technical drawbacks lying in the different technical requirements for the relatively complex panoramic motion described above versus the circular yet very accurate motion necessary for CBCT-acquisition. Also, these devices are commonly standing devices (i.e., the patient is standing during exposure), which makes the patient more prone to move during the several seconds of image acquisition in CBCT. To date, it can only be speculated which technical solutions in the future may be introduced to circumnavigate these shortcomings inherent in such combination machines.

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### 22.4.2.2.5 Image Characteristics of Panoramic Radiography

Due to the underlying tomographic principle of image formation, panoramic radiographs inherently have very special magnification and distortion characteristics. Contrary to other radiographic images, horizontal and vertical magnification have to be considered separately. Vertical magnification follows simple geometrical rules (theorem of intersecting lines) well-known from perspective geometry. However, horizontal magnification is a function of the specific device-motion relative to the depicted structure at the moment when this structure is captured on the image receptor. As discussed before, the latter again is a function of relative position within the exposure geometry or, more specifically, for those objects located in the sharp image layer, the position of the structure within the sharp layer-of-interest. Only in the (infinitesimally thin) center plane of the sharp layer are the horizontal and vertical magnifications equal (Tronje et al. 1981). As a consequence, horizontal magnification varies significantly.
with varying distance (depth) of the object from the central plane of the sharp layer (Tronje et al. 1985a). In contrast, due to its projective nature, vertical magnification remains relatively constant within the sharp layer (Tronje et al. 1985b). As is apparent from Figure 22.28, this results in severe differences in the panoramic image of identical objects, even for only slightly different object depths.

As a consequence of the different magnitude of magnification in the two spatial dimensions, distortion necessarily occurs. Distortion of structures captured on panoramic radiographs is, thus, very common and one important characteristic of this type of radiographs. Another very important feature is the inevitable existence of what is termed “ghost image” or “ghost shadow.” Ghost shadows are distorted and blurred images of objects (and anatomy) that are (a) located outside the zone of the sharp image layer during exposition, and (b) radio-dense enough to produce a radiographic shadow. To consistently term such images “ghost” or “ghost image” was suggested in a seminal paper published in 1987 (Kaugars and Collett 1987). Very typical ghost images are produced, for example if a radio-dense (metallic) earring is kept in position during the acquisition (Figure 22.29).

![Figure 22.29](image)

**FIGURE 22.29** Typical ghost images in a panoramic radiograph produced by metallic earrings. Equal numbers indicate the real image (sharp, without arrow indicator) as well as the corresponding ghost image (with arrows) of each earring.

It is noteworthy that radio-dense anatomical structures such as the ascending mandibular ramus also produce inherent ghost shadows in the panoramic radiograph. To avoid disturbing ghost images caused by metal, the patient should be asked to remove removable metallic objects, particularly if they are located laterally, such as earrings.

### 22.4.2.2.6 Patient Positioning in Panoramic Radiography

In order to ensure the patient’s anatomical structures of interest (the dental arch) are placed where the sharp layer-of-interest of the respective machine is located, a patient has to be carefully positioned within the machine (Figure 22.27). For this purpose, different anatomical planes are utilized to enable proper positioning. To define the position relative to the horizontal plane, the Frankfort plane is commonly applied as a reference. This plane is defined as the plane through the cranial margin of the external acoustic pores and the infraorbital margin. As a vertical reference, commonly the midsagittal plane is used. Panoramic machines of the first generation did not have special aiming devices, thus in these days it was rather difficult to find an appropriate position of the patient. As a consequence, soon specifically designed bite blocks, chin- and head-rests were employed (Figure 22.27) that, in combination, already allowed rather accurate positioning. Subsequently, these aiming devices were supplemented with light beams indicating, for example, the orientation of the Frankfort plane and the sagittal plane. These light beams made accurate positioning of the patients much easier. Modern panoramic machines, while still relying on the mechanical positioning aids (bite block, chin-/head-rest), have replaced the light by laser beams. It is noteworthy to emphasize that, as of today, all panoramic machines still assume some sort of mean-value anatomy of the expected dental arch, therefore, no machine de facto exactly measures the individual dental arch and conducts a coordinated motion derived from individual assessments to exactly fit the individual anatomy. Often modern devices use the head-rest to also assess the distance between the temporal bones of the patient. Based on these data, an appropriate mean motion selected from a database of several possible motions is selected to provide a sort of “individualized” motion adapted to the patient’s anatomy. However, even though panoramic radiographs acquired with such devices certainly are far better in quality and layer-position than those from earlier-generation devices, they are still based on mean-value anatomy. This is an important aspect of clinical relevance, which will be further discussed in the next subsection (Section 22.4.2.2.7).

### 22.4.2.2.7 The Panoramic Radiograph from a Clinical Perspective

Since its introduction into the market in the 1960s, panoramic radiography has developed as a standard in dental imaging. Today it is widely available and used in dental offices and hospitals all around the world. The main indication of panoramic radiographs is to obtain an overview over the jaws and the teeth in one radiographic image (Figure 22.21). Since the dose involved with digital panoramic machines is rather low, it seems quite likely that this type of radiograph, together with intraoral radiography, will remain a standard also for the future of dental imaging.

Panoramic radiographs, apart from the mandible, the maxilla, and the maxillary sinuses plus the teeth, display a multitude of additional anatomical structures of relevance (Figure 22.30).
Dental Radiography

FIGURE 22.30 Anatomic features displayed on panoramic radiographs: (1) orbitae; (2) nasal cavity; (3) maxillary sinuses; (4) hard palate; (5) upper surface of tongue; (6) anterior nasal spine; (7) marginal alveolar bone of maxilla; (8) external acoustic pore; (9) mandible; (10) styloid process (including partially calcified stylomandibular ligament); (11) hyoid bone.

They are often acquired to visualize retained (wisdom) teeth, to assess the tooth-surrounding bone and possible dentoalveolar bone pathology or to obtain an overview over the existing bony support for dental implants. In addition, the rough shape of the condyle of the temporomandibular joint can be evaluated and a crude general survey of the maxillary sinuses is feasible. In the case of trauma, panoramic radiographs are frequently used as initial radiographic evaluation if no clear signs for fractures are present. Today, however, if a fracture is highly suspected or obvious, commonly 3D techniques such as computed tomography (CT) or CBCT are applied to evaluate the 3D morphology and position/pose of the fragments. Panoramic radiographs may also be useful in depicting calcified carotid artery atheroma. It has been shown that these can be identified on panoramic radiographs, with relatively high sensitivity yet moderate specificity (Alves et al. 2014). Such atheromas manifest themselves as hyperdense, commonly vertically orientated structures depicted in the lower third close to the lateral boundaries of panoramic radiographs. More specifically, they appear “as curvilinear irregular parallel radiopacities about 1.5 to 2.5 cm inferior-posterior to the angle of the mandible adjacent to the cervical spine, at or below the third and fourth cervical vertebrae and inferior and lateral to the hyoid bone, posterior to the oropharyngeal airway space” (MacDonald et al. 2012) (Figure 22.31).

Despite the rather large fraction of false-positive findings that may be seen in this region on a panoramic radiograph, it has lately been concluded from the published evidence available that the “dental practitioner is responsible for the identification of lateral neck calcifications that occur incidentally on images that are used for dental diagnosis” (MacDonald et al. 2012).

From a clinical perspective, some drawbacks of panoramic radiography need to be discussed. First, they provide considerably lower spatial resolution (around a maximum of 4 line pairs/mm [Farman et al. 1997]) when compared to intraoral radiographs (for digital systems at a maximum of around 20 line pairs/mm [Farman and Farman 2005]).

Furthermore, the distinct distortion characteristics of panoramic radiographs are of high relevance, particularly in cases where panoramic radiographs are evaluated in a quantitative sense with respect to distances and/or angles. For instance, in implantology planning, the available bone should be known before insertion of the implant. This relates to both the vertical and the horizontal dimension. If a panoramic radiograph is utilized for such dimensional assessment, a reference body needs to be applied. In order to be of any use, the reference body needs to be positioned in the respective location, in which the implant later will be inserted. Of course, as that location would be inside the alveolar bone, the exact location cannot be used. Instead, a position as close as possible yet directly above/below this location is selected. Commonly, metal ball bearings (e.g., 5.0 mm in diameter) function as reference bodies. They can be easily placed and held in position by means of dental wax. By application of the rule of proportion, their image can then be used for a rough estimation of the bony dimensions at that location (Figure 22.32).

Because no real patient-adapted motion-curve has yet been applied, today’s panoramic images cannot provide correct information on magnification or distortion. This is an important aspect, as many manufacturers, nevertheless, state exact magnitudes of magnification in their panoramic radiographs. Of course, the latter can easily be computed (and stated) for each point within the sharp image layer. However, as long as it remains unknown where the structure under study exactly was located within this layer during exposure, unfortunately such data are meaningless and obviously do not provide any information on the true magnification the image of the structure suffers. For specific targets and applications, some additional special programs are available.

FIGURE 22.31 Calcified atheroma in the carotid artery can be detected on panoramic radiography. They produce characteristic images (arrows) displayed at the lower lateral border of the radiograph. Although the specificity is rather low, as calcifications (arrows) in this area represent typical risks for stroke, these findings should nevertheless be identified by the general dentist.

FIGURE 22.32 Panoramic radiograph with two ball bearings as reference objects to estimate local magnification and distortion.
in many modern panoramic machines, which will be discussed in the following paragraph.

22.4.2.2.8 Special Programs Acquired with Panoramic Machines

Modern panoramic radiographic machines offer a wide variety of special programs, all of which acquiring a tomographic radiograph of a selected region or structure. For instance, the maxillary sinuses may be displayed separately. Another commonly used feature is a tomographic radiograph of the temporomandibular joint (TMJ). For the latter, pseudo-functional imaging can be conducted, for example by depicting the TMJ in closed-mouth and/or open mouth position (Figure 22.33).

In addition, many modern machines allow for partial panoramic radiographs of the jaws and teeth by applying the technique only to the quadrant (or even parts of it) under study. Such collimated panoramic radiographs are often very helpful to reduce radiation dose, while still producing a panoramic radiograph of a small region of interest.

22.4.2.2.9 Tomosynthetic Methods in Combination with Panoramic Radiography

Lately, tomosynthetic approaches have been introduced in panoramic radiography to supplement the images (Ogawa et al. 2010). The authors apply a high-speed detector and make use of the fact that, with such a detector, many strip-shaped images can be acquired for each location during the regular panoramic motion of the unit. Here it is noteworthy to realize that, during the regular panoramic exposure process in the lateral jaw regions, projections are sampled through both the layer side under investigation as well as the contralateral side. This additional information, in combination with several strip-like images of each region in the layer-of-interest side, can be used to produce a tomosynthetic image, for example by a simple shift-and-add-algorithm (Ogawa et al. 2010). Manufacturers implement these methods, for example by enabling a posteriori modification/adaptation of the sharp image layer. More precisely, in a display of the axial aspect of the image layer, the user can interactively select a certain position of the center of the sharp layer. Subsequently the machine will, by means of the shift-and-add-algorithm, compute a novel panoramic image which is centered on the manually selected layer-center (Figure 22.34).

More complex mathematical methods use the additional projection information to produce a volumetric image with limited 3D-information. The latter is caused by the incomplete angular as well as incomplete frequency sampling process. Supplemented by prior information (e.g., smoothness), the additional projection information is used to iteratively compute transverse slices with limited 3D-information (Spartiotis and Pantsar 2008).
An imaging device with optional tomosynthetic reconstructions, for example of transversal views (Figure 22.35), was marketed in 2009 by a Scandinavian manufacturer (VT, Instrumentarium Oy, Tuusula, Finland) as an add-on to a panoramic machine (Cederlund et al. 2009).

This device makes use of projections acquired from a panoramic radiograph plus five to 11 additional projection radiographs centered to the region of interest. Technically, this is facilitated by a combination of a rotational and a linear movement and a subsequent iterative frequency-based reconstruction technique (Cederlund et al. 2009). From a reconstruction point of view, the projections add some additional information yet not additional angular information, since they are acquired almost from the same angle (view) as the projections used for the panoramic image. This results in what is termed a “limited angle reconstruction” (for further information see Siltanen et al. 2003). The method was extended in 2010 by a group of Finnish mathematicians and engineers. They also used panoramic radiography as a basis to produce a limited angle tomographic imaging system basing on supplementary information (Hyvönen et al. 2010). The authors propose to supplement the projection data acquired for a panoramic radiograph with a few (<12) projections that are directed roughly perpendicular to the panoramic ones, approximately parallel to the dental arch in the region of interest. This approach adds additional angular information for the reconstruction. De facto, the sampling angle is almost complete, yet the object is only sampled sparsely (see reconstruction from sparse projection data [e.g., Siltanen et al. 2003]) with few projections. To accommodate the reconstruction task for such a problem, the authors propose Tikhonov regularization (smoothness constraint) for their iterative reconstruction process (Hyvönen et al. 2010). Transversal and axial reconstructions of ex vivo specimens are presented, and the authors demonstrate that the supplemented reconstructions are superior in quality to those solely based on panoramic projection data. In their conclusions, the authors suggest with their method a digital panoramic has a strong possibility to “perform as the sole tool of an implantologist for three-dimensional X-ray imaging” (Hyvönen et al. 2010).

22.4.2.2.10 Typical Errors in Panoramic Radiography

Panoramic radiography also exhibits errors very typical and specific to the technique (Table 22.3). Due to its technical construction, patient positioning errors are predominant. For instance, often the Frankfort plane is not correctly applied by estimating the infraorbital margin too far inferiorly. This results in a backward inclination of the patient’s head, and often a blurred image in the front. Sideward misplacement is also quite common, resulting in noticeable side differences in horizontal magnifications (tooth width) of the premolar and molar teeth. Ghost images caused by metallic jewelry not removed during exposure is another source of error in panoramic radiography. Thus, jewelry such as earrings, as well as metallic prostheses should be removed prior to exposure. There is a lack of evidence on whether lead protection should be used for panoramic radiography. Yet, if applied, care has to be exercised that no part of the lead barrier material lies within the primary beam. However, some ghost images sometimes cannot be avoided when resulting from implants or other devices that cannot be removed for image acquisition (e.g., metallic fixations in the cervical spine, metallic osteosynthetic plates placed in the mandibular ascending ramus for fracture treatment, hearing-aid, etc.). In some cases, the source-detector unit may interfere with the patient’s anatomy (shoulders) during the circulation. This results in obvious offset of the depicted anatomy, for example the lower boundary of the mandible. If more severe, the imaging process may completely stop at this position. Another common error may occur if the

FIGURE 22.35 Transversal views of an implant-site/implant generated with an iterative tomosynthetic frequency-based reconstruction technique implemented as add-on to a panoramic machine. (Orthopantomograph OP 200 D; Instrumentarium Oy, Tuusula, Finland. Photo: Dr. Jörg Mudrak, Ludwigsau, Germany.)
<table>
<thead>
<tr>
<th>Error</th>
<th>Influence on Radiographic Image</th>
<th>Measures to Avoid the Error</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positioning errors</td>
<td>Distortion of anatomy—unsharpness/blurring of anatomy</td>
<td>• Proper positioning using aiming devices according to specifications of manufacturer</td>
<td>Patient was positioned rotated with right side further away from detector as left patient side</td>
</tr>
<tr>
<td>Ghost images</td>
<td>Blurred bright images superimposed over anatomy</td>
<td>• Remove metallic and other highly-dense structures, artwork, devices from imaged area</td>
<td>Ghost image from lead apron which was dorsally placed too high up at the patient's neck</td>
</tr>
<tr>
<td>Interference of device with patient’s anatomy during exposure</td>
<td>• Offset in anatomic structures such as lower border of mandible • Stripes</td>
<td>• Proper placement of patient in device • Proper instruction of patient</td>
<td>Massive contact between X-ray source-detector unit and patient resulting in a completely unreadable panoramic radiograph</td>
</tr>
<tr>
<td>Airway space image</td>
<td>Dark (hypodense) sickle-shaped image superimposed over maxillary teeth</td>
<td>• Instruct patient to press entire tongue flat against the palate during exposure</td>
<td>Clearly visible airway space projected over maxilla interfering with the visibility of the teeth/bone in that region</td>
</tr>
</tbody>
</table>
patient does not completely press his/her tongue to the hard palate. Caused by the air enclosed between tongue and hard palate, a hypodense zone is superimposed over the maxillary teeth. This zone may considerably reduce the effective contrast in this region and, thus, interfere with the diagnosis in that anatomical region.

22.4.2.3 Extraoral Projection Radiography

Extraoral projection radiographs are those radiographs used in dental radiography that show large parts of the human skull or the entire skull from different perspectives. These are often used to assess the shape of bony structures, assess pathologies, or in the case of suspected fractures. Some of these radiographs (e.g., lateral oblique views, see below) can be applied as substitution of intraoral radiographs in cases when the latter are not possible due to disabilities or non-compliance.

To define the orientation of these radiographs, knowledge on the orientation of some specific anatomical planes is helpful. Particularly the Frankfort plane and the midsagittal plane are commonly used to characterize the orientation of the projection radiograph relative to the patient’s head. The Frankfort plane is a horizontal plane through the infraorbital margin and the upper margin of the external acoustic pore. The midsagittal plane is the vertical plane that divides the human being in two halves.

The following sections describe the most common extraoral projection radiographs summarized in Table 22.4.

22.4.2.3.1 Cephalometric Radiography

Cephalometric radiography, or more specifically lateral cephalometric radiography, represents the most common dental extraoral projection radiography. Technically speaking, cephalometric radiography is as highly standardized, reproducible projection radiography of the human skull to facilitate distance and angle measurements for orthodontic treatment and diagnosis. In most cases, these radiographs that are also termed “cephalograms” are exposed from a lateral aspect (lateral cephalometric radiography). Less frequently, however, also posterior–anterior cephalograms (“frontal cephalograms”) are acquired. These are used to evaluate transverse skeletal and dentoalveolar relationships of the facial bones (Ghafari et al. 1995). Much more common is their lateral counterpart: lateral cephalometric radiography. Technically spoken, a lateral cephalometric radiograph is a projection radiograph of the craniofacial bones plus the soft tissue profile exposed from a lateral aspect. It should be noted, however, that cephalometry also includes some landmarks that are located outside the facial bones, for example within the neurocranium (e.g., the sella turcica, see point “S” in Figure 22.36).

Literally spoken, cephalometry means “measurement of the head.” The ancient Greek word “kefalikos” translates to “capital.” In radiography, the term “head” is often used synonymously to “skull,” even though mainly the bony parts of the head (the skull) can be clearly visualized in a radiograph. Nevertheless, as a very unique characteristic of the lateral cephalometric radiograph, the lateral cephalogram also includes a radiographic image of the soft tissue facial profile (Figure 22.37, see below).

The latter is of interest for the orthodontist or an oral and maxillofacial surgeon to determine the relation between bony and soft tissue anatomy. Since this relationship is aesthetically relevant, it is important for therapy planning and control.

22.4.2.3.1.1 History of Cephalometric Radiography

Cephalometric radiography was introduced by the American dentist and orthodontist Birdsall Holly Broadbent in 1931 (Broadbent 1931). By coincidence, in the same year the German Orthodontist Herbert Hofrath from Düsseldorf independently came up with a very similar idea (Hofrath 1931). The basic innovative concept was to use bony reference points and angles instead of soft tissue references to assess the position of the jaws, the teeth, and their spatial relationship. It is also interesting to note that Herbert Hofrath, in his seminal paper (Hofrath 1931), elaborated that a distance between receptor and focus (with the lateral side of the patient’s face resting on the film-cassette) of at least 2 m is required to avoid significant distortion and magnification. Broadbent experimentally determined a minimum distance of 5 feet (1.524 m) sufficient for assessment of the reference points in a clinical setting. One major contribution of Broadbent was the introduction of a standardized headholder (termed “craniostat”) to achieve a reproducible exposure geometry. Later, such head holding devices were termed cephalostat. Broadbent’s suggestions of cephalometric landmark points on lateral cephalometric radiographs acquired with a cephalostat constituted modern cephalometry. In Orthodontics, cephalometry refers to the study and dimensional assessment of the human skull on standardized projection radiographs. The group around the American Orthodontist Robert M. Ricketts later suggested that the lateral view (= lateral cephalometric radiograph) alone is sufficient for cephalometric analysis (Ricketts and Bench 1970). From the very beginning, landmarks identified on film-based cephalometric radiographs were regularly traced on transparent overlaying media for analysis. Many different approaches for cephalometric analysis were introduced (see Thomas et al. (1984) and references therein). As computers became available, in the late 1960s Ricketts suggested computerized cephalometric analysis as a next step (Ricketts 1969). One of the first researchers suggesting a real large-scale computer-based mathematical analysis of cephalometric data to statistically assess growth patterns, skeletal deformations, or surgery outcome in a large sample size was Walker (1972).

22.4.2.3.1.2 Technique of Lateral Cephalometric Radiography

Modern cephalometric radiography commonly is performed with panoramic radiography devices integrating a cephalometric unit (Figure 22.38).

This construction provides a source-to-object distance (midsagittal plane of patient) of $\geq 1.5$ m. Assuming a realistic distance between the midsagittal plane of the patient and the image receptor of 15 cm, this setup amounts to a (mean) magnification, m, expressed by

$$m = \frac{\text{SDD}}{\text{SPD}} = 165 \text{ cm}/150 \text{ cm} = 1.1,$$

where SDD represents the source-detector distance and SPD the source-patient-distance.

22.4.2.3.1.3 Detectors

Conventional cephalograms were acquired with radiographic film. In the early days of the digital era many of these systems simply replaced the film by a storage phosphor in the sense of computed radiography (see Section I, Chapter 12 of this book). Both “traditional” systems are still
<table>
<thead>
<tr>
<th>Type</th>
<th>Indications</th>
<th>Acquisition Geometry</th>
<th>Example</th>
</tr>
</thead>
</table>
| Lateral cephalometric radiograph | • Orthodontics, cephalometry, dimensional assessments within sagittal direction | • Central X-ray perpendicular to receptor  
• Midsagittal plane of patient’s head parallel to receptor plane  
• Source-to-object distance of $\geq 1.5$ m | ![Image](image1.jpg) |
| Posterior–anterior cephalometric radiograph | • Orthodontics, cephalometry, dimensional assessments within coronal (transverse) direction | • Central X-ray perpendicular to receptor  
• Receptor touching patient’s nose  
• Source-to-object distance of $\geq 1.5$ m | ![Image](image2.jpg) |
| Posterior–anterior view          | • Non-angled overview over the skull in posterior–anterior direction (e.g., for control of fracture(s) or asymmetry) | • Central X-ray parallel to the OrbitoMeatal Line roughly centered to the external acoustic meati  
• Head upright with OrbitoMeatal Line parallel to horizontal plane  
• Source-to-receptor distance = 1 m | ![Image](image3.jpg) |

(Continued)
<table>
<thead>
<tr>
<th>Type</th>
<th>Indications</th>
<th>Acquisition Geometry</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submentovertex projection</td>
<td>- Trauma:</td>
<td>- Central X-ray enters in the center between mandibular angles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Depiction of the zygomatic arches</td>
<td>• Head bent maximally in backward direction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Axial overview over anatomy in the axial plane</td>
<td>• Source-to-receptor distance = 1 m</td>
<td></td>
</tr>
<tr>
<td>Waters projection</td>
<td>- Evaluation of the paranasal sinuses, particularly the maxillary sinuses</td>
<td>- Central X-ray perpendicular on detector, enters occipital bone aiming at maxillary sinus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Trauma to midface</td>
<td>• Head faces receptor and is inclined backwardly</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Chin touches the receptor</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Mouth wide open</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Source-to-receptor distance = 1 cm</td>
<td></td>
</tr>
<tr>
<td>Towne projection (half-axial anterior–posterior)</td>
<td>- Evaluation of mandibular body, the ascending rami, the condyles and the condylar necks Also:  • Mastoids  • Maxillary sinuses  • Sphenoidal sinuses</td>
<td>- Central X-ray perpendicular to receptor at level of external auditory meatus  • Patient sits so he/she faces the X-ray tube  • Back of head touches receptor  • Head is tilted roughly 30° downwardly  • Source-to-receptor distance = 1 m</td>
<td></td>
</tr>
<tr>
<td>Reverse Towne projection (Clementschitsch projection)</td>
<td>- Evaluation of mandible and condyles (trauma)  • Maxillary sinuses</td>
<td>- The central X-ray enters the neck and passes through the external auditory meati  • Patient faces the detector  • Head tilted downwards (ca. 30°)  • Forehead touches the detector  • Mouth of the patient is wide open  • Source-to-receptor distance = 1 m</td>
<td></td>
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(Continued)
### TABLE 22.4 (Continued)

<table>
<thead>
<tr>
<th>Type</th>
<th>Indications</th>
<th>Acquisition Geometry</th>
<th>Example</th>
</tr>
</thead>
</table>
| Lateral oblique mandible view | Evaluation of lateral mandible (plus teeth) and parts of maxilla (plus teeth) of side close to detector (in cases where intraoral or panoramic radiography is not feasible) | - Central X-ray is coming from below the ear of the contralateral mandibular side slightly behind contralateral mandibular angle  
- Image receptor placed tangentially to the cheek of the patient and held by the patient  
- Patient has to bring mandible forward  
- Source-to-receptor distance ca. 30–35 cm | ![Image](image1.png) |
| Oblique transcranial TMJ projection (Schüller) | TMJ, condyle                                                               | - Central X-ray enters the contralateral side ca. 25° to 30° from cranially  
- TMJ under study close to the detector  
- Source-to-detector distance is around 1 m | ![Image](image2.png) |
| Transpharyngeal projection (Parma) | TMJ, condyle, column                                                        | - Central X-ray enters the tragus on the contralateral side  
- TMJ under study close to the detector  
- Short source-to-object distance (e.g., dental cone attached to the facial skin) | ![Image](image3.png) |
widely being used and certainly represent the standard in a global sense. Digital cephalometric units integrated in panoramic systems to save costs commonly use the panoramic line detector also for the cephalograms. In such systems, the detector can often be unplugged from one unit and replugged into the other. The X-ray beam is collimated by a slit into a fan beam. A secondary collimator close to the patient’s head and the linear detector array during image acquisition sweep the patient’s head in a coordinated linear motion in either a vertical or a horizontal direction.

The problem with such scanning systems is the long acquisition time up to 16 seconds or more (Chadwick et al. 2009), during which the patient may move. This resulted in an alternative approach by one manufacturer, marketing a machine that utilizes a CCD-sensor for instant acquisition. A Swiss-based publication (Menzel and Gebauer 2009) assessed patient motion in a cephalostat as a function of time. They found maximum amplitudes of several millimeters in all directions for scan-times exceeding 10 seconds (Menzel and Gebauer 2009). As cephalometric radiographs are inherently used for dimensional assessments, it seems obvious that, for accurate measurements, these radiographs should be acquired in the shortest possible time. Consequently, one-shot machines have an inherent advantage over scanning devices.

A special feature of lateral cephalometric radiographs is that they display the soft tissue profile of the face, which is also used for the cephalometric analysis. This is commonly achieved by a wedge-shaped aluminum filter placed in that part of the X-ray beam that traverses the facial soft tissue profile of the patient (Christensen and Melsen 2004) (Figure 22.38).

In digital cephalometric radiography, this filter may be replaced by post-processing algorithms that enhance the soft tissue contrast in the required region. Due to the highly standardized positioning of the patient’s head in the cephalostat, this region in the image is always located in a reproducible similar position so that the post-processing can be applied locally to only this region within the image.

For the lateral cephalometric radiograph, the patient is usually positioned with his/her right side close to the detector (Christensen and Melsen 2004) (Figure 22.39). The teeth are brought into maximal occlusion to ensure a fixed position of the mandible relative to the skull. A three-point fixation of the head is used to guarantee a reproducible and standardized position: two ear rods are placed in the external ear canals and the nasal support touches the skin in the nasion region. These fixation aids are integrated into the cephalostat in such that they ensure a horizontal orientation of the Frankfort plane. The central X-ray traverses the ear rods and impinges the detector plane at right angles. This configuration is intended to provide an image in “natural head position” (NHP), which is defined as the position when a standing person’s visual axis is horizontal (Leitão and Nanda 2000). The NHP is believed to be the “natural” pose of the human head in a standing person. Although there is a small degree of deviation between Frankfort plane and NHP (Leitão and Nanda 2000),
the former has been found to be the best approximation of the NHP (Moorrees and Kean 1958). Note that the NHP-concept is also applied for posterior-anterior cephalograms.

22.4.2.3.1.4 Application of Cephalometric Radiography As stated above, the use of the lateral version of cephalometric radiography is much more widespread, whereas the frontal (posterior–anterior-, pa-) cephalogram seems to be only scarcely used. Posterior–anterior cephalograms are applied for evaluating transverse skeletal and dentoalveolar relationships (Figure 22.40).

Transverse refers to the coronal or frontal plane—a plane parallel to the body’s long axis that divides the body into a dorsal and a frontal half. In other words, pa-cephalograms are essentially produced to measure the width of the facial bones. Typically, asymmetry occurring in this dimension can be assessed on them. As the pa-version is inherently orthogonal to its lateral counterpart, the two directions form a natural pair to define skull dimensions in the three anatomical planes. The lateral cephalogram displays a side-view of the facial bones, and is exposed with the central X-ray perpendicular to the sagittal plane. The latter is the plane orientated parallel to the body’s main axis and separates the human body into left and right. Consequently, lateral cephalograms enable metric assessments within the sagittal plane.

Orthodontists use cephalometric radiographs to perform an analysis termed “cephalometry.” In the orthodontic context this is defined as a metric analysis of the facial bones based on landmark points for assessment of spatial relations (Figure 22.36) and for assessment of growth. This also includes the soft tissue facial profile. In a more general sense, cephalometry refers to the analysis of lateral cephalograms. That means that the majority of cephalometric evaluations assess the sagittal direction in the skull (Figure 22.36). It is quite obvious why the position of the head during exposure is of fundamental importance: first of all, soft tissue may follow gravity and, thus, change their relative position to the underlying bone and, second, the position of the mandible may also be different in relation to the facial bones. Cephalometry is based on reference points, some of which can be readily found in a dry skull. Many of these points are located in the midsagittal plane. However, there are also reference points which are located bilaterally on the skull. Depending on the type of analysis, reference points are connected to form different reference lines which may intersect at angles that are also used for the analysis. In order to perform the cephalometric analysis, cephalometric radiographs are commonly traced, for example by means of a computer program to obtain an overlay image with the landmarks, lines, and angles required for analysis.

22.4.2.3.1.5 Typical Errors in Cephalometric Radiography Due to their acquisition technique in a highly standardized fashion, gross errors are not really common in cephalometric radiography (Table 22.5). Lateral misplacement/tilt of the patient’s head would result in oblique projection of anatomy. This may disguise some reference points/distances. Generally, it has been found that an incorrect head position may result in double contours and a shift of reference points (Spolyar 1987). Another error may result if the patient does not close his/her mouth in normal occlusion during exposure. Such errors may yield incorrect relative position of the mandible relative to the skull. If cephalograms are acquired with equipment that sweeps the patient’s head with a fan beam in combination of a line detector, patient motion may be recorded and disguise/displace reference points.

FIGURE 22.39 Aluminum wedge as soft tissue filter used in lateral cephalometric radiography to visualize the soft tissue profile of the patient’s facial bones. (Adapted from Christensen, H.C. and B. Melsen. 2004. Roentgencephalometry. Department of Orthodontics, Aarhus University, School of Dentistry.)

FIGURE 22.40 Sketch of some landmarks used in posterior–anterior (pa-) cephalometric radiography used to measure the transversal dimensions of the facial bones.
TABLE 22.5

Typical Errors in Cephalometric Radiography

<table>
<thead>
<tr>
<th>Error</th>
<th>Influence on Radiographic Image</th>
<th>Measures to Avoid the Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect head position</td>
<td>Displacement of reference structures</td>
<td>• Properly use Frankfort plane and positioning aids of equipment</td>
</tr>
<tr>
<td>Cephalometric radiograph acquired in non-occlusion</td>
<td>Incorrect relative position of jaws to one another</td>
<td>• Double contours</td>
</tr>
<tr>
<td>Motion during scanning procedure (direct digital cephalometric equipment with sweeping fan beam)</td>
<td>Displacement of reference structures</td>
<td>• Ask patient to bite on his lateral teeth during exposure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Instruct patient to keep steady during exposure time (alternatively, use non-scanning equipment)</td>
</tr>
</tbody>
</table>

22.4.2.3.2 Other Extraoral Projection Radiography Techniques

Many extraoral projection radiography techniques have been developed in times when no three-dimensional radiographic technique was available. While they were quite commonly acquired for medical indications, these radiographs also had and still have some specific indications for dental use. However, they were never really very frequently used by general dental practitioners, rather by specialists like orthodontists or oral surgeons. Nowadays they are not very common any more, as many of these radiographs are now replaced by CBCT- or CT-scans, allowing for a three-dimensional analysis. Superimposition of anatomy as a typical characteristic of projection radiography often compromises the diagnostic informative value of the skull projections. Nevertheless, in some instances these techniques represent a low-dose alternative to 3D techniques and should, thus, not be completely discarded. The most common extraoral projection techniques are summarized in the following.

22.4.2.3.2.1 Devices and Hardware

Extraoral skull radiography for dental applications was conventionally carried out with the intraoral X-ray set, simply because no other machine is available in a dental office (Schiff and McDavid 1985). Obviously, acquiring such radiographs with medical equipment such as a Bucky-table provides higher quality and is less challenging. Moving anti-scatter grids and rigid standardized positioning facilities render Bucky-equipment optimal also for this type of radiography. However, these medical devices are hardly available in a dental office. Thus, mostly intraoral X-ray sets are used. However, typical source-to-detector distances of 100 cm make correct positioning of the cone of the intraoral X-ray set a challenging task. Thus, special aiming devices were suggested (Schiff and McDavid 1985). Later, the cephalometric unit of panoramic machines was introduced also for the purpose of exposing the different extraoral skull projections. In the past and even commonly today, radiographic film plus intensifier screens were used to acquire skull projections. Typically, film sizes for extraoral skull projections are 24 × 30 cm² or 18 × 24 cm². While, in hospitals today, solid-state detectors of similar size are also in use, these are hardly found in dental offices due to their high costs. Instead, computed radiography using storage phosphor technology represents a typical solution for such purposes.

22.4.2.3.2 Skull Projections

The following section describes various typical skull projections as acquired for dental or oral and maxillofacial radiological tasks. In this context it should be noted that most of these projections are also used in other medical fields. Due to diverging diagnostic questions, however, dental skull projections may sometimes be acquired in a slightly different mode. In addition, these dental skull projections can be acquired with typical dental radiographic equipment that itself may require specific acquisition modes and geometries. As a consequence, it should be born in mind that some of the following skull projections, even if they operate under the identical name as those acquired for other medical professions, are indeed very specific and may, thus, not be identical to their medical counterparts.

22.4.2.3.2.3 Posterior–Anterior View

The posterior–anterior (pa) view (Figure 22.41) is a simple non-angled projection of the skull from posteriorly.

The forehead is placed upright with the OrbitoMeatal Line (radiographic baseline) parallel to the horizontal plane. The central X-ray is parallel to the OrbitoMeatal Line roughly centered to the external acoustic meati and impacts on the receptor at right angles (Figure 22.42).

The source-to-receptor distance is roughly 1 m, and the detector size around 24 × 30 cm² (width × height).

FIGURE 22.41 Posterior–anterior (pa-) projection radiograph of the skull.
The pa-view is a very general projection radiograph of the skull used in many medical indications. Particular dental indications for the pa-view include, for example:

- Overview over the facial bones in posterior-anterior direction
- Any pathology or growth abnormalities visible in the transverse (coronal) plane
- Trauma

### 22.4.2.3.2.4 Submentovertex Projection

The submentovertex projection is a skull projection along the body’s long axis. In other words, the skull is exposed from a caudo-cranial direction along its long axis. The head of the patient is maximally bent backwardly with the top (vertex) of the skull touching the vertically placed receptor. The patient’s midsagittal plane is oriented perpendicularly to the detector. The central X-ray lies within the midsagittal plane and enters in the midline between the angles of the mandible. It is slightly coming from below (ca. 5° relative to the horizontal plane) (Figure 22.43).

For purposes in dental radiography, this projection is often collimated to the more anterior part of the skull, since one of the main indications is the depiction of the zygomatic arches. These are displayed in a way that reminds of the jugs of a pot, thus this type of radiographs it is often termed “jug handle view” (Figure 22.44).

### 22.4.2.3.2.5 Waters Projection (Occipitomental Projection)

Waters projection (Waters view, sinus view) is one of the more popular extraoral skull radiographs in dental radiography. It is often also termed “paranasal sinus projection.” Obviously, its main indication is the evaluation of the paranasal sinuses, particularly the maxillary sinuses plus the frontal sinuses (Figure 22.45).

The sphenoidal sinuses are also displayed on this posterior-anterior projection if it is exposed with a wide open mouth. The Waters projection represents the standard radiographic projection image for the maxillary sinuses. However, since the advent of CT and also CBCT, its significance has dramatically decreased. Waters projection was developed by Waters and Waldron (1915) on the basis of the occipito-frontal projection.

The patient is positioned with his/her midsagittal plane oriented perpendicularly to the image receptor. The head faces the image receptor and is inclined backwards so that the chin touches the receptor. This raises the radiographic baseline (OrbitoMeatal line) ca. 45° in relation to the body’s longitudinal axis. Slight modifications of this angle may be applied to fine-tune the projection to the respective indication. In the majority of applications, the patient has to open his/her mouth widely for this radiography to allow for visualization of the sphenoidal sinuses. To accommodate this, auxiliary-means like a cork can be applied. The central X-ray is directed perpendicularly to the detector and enters the occipital bone aiming at the maxillary sinus (Figure 22.46).

The receptor is placed in portrait (vertical) orientation and has a size of approximately 18 × 24 cm² (width × height). The source-to-receptor distance is 100 cm.

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**FIGURE 22.42** Sketch of the geometry for a posterior–anterior radiograph of the skull.

**FIGURE 22.43** Projection geometry for a submentovertex projection radiograph.

**FIGURE 22.44** Submentovertex projection radiograph clearly displaying the zygomatic arch in an axial view.
Waters projection is mostly used for assessment of the maxillary, the frontal, and the sphenoidal sinuses. Waters projections provide a good initial diagnostic tool if infections (sinusitis), fractures, or other pathology are suspected. In this context it appears noteworthy that, from a radiation protection point of view, such radiographic techniques with their low radiation dose can often serve as a low-dose initial evaluation tool, before, if there is evidence that requires further evaluation, dose-intensive 3D techniques such as CT or CBCT are applied as a next step.

22.4.2.3.2.6 Towne Projection (Half-Axial Anterior–Posterior) The original Towne projection is an anterior-posterior (cranio-caudal) projection of the mandible to assess the mandibular body, the ascending rami, the condyles, and the condylar necks in an oblique half-axial view (Figure 22.47).

Synonymously, it is also termed “30°-fronto-occipital” or “frontonuchal” projection. Before the advent of CT (and now CBCT) it has been frequently used to display mandibular fractures as a second (perpendicular) aspect of the mandible in combination with a panoramic radiograph. It also demonstrates the mastoids, the maxillary sinuses, and the sphenoidal sinuses. The Towne projection certainly is only rarely used in dental extraoral radiography. Much more common is its reverse counterpart, the Reverse Towne View (see below).

For the original Towne projection, the central X-ray has to be tilted downwardly at an angle of roughly 30°. The patient sits so he/she faces the X-ray tube and the back of his/her head touches the image receptor. The midsagittal plane is orientated vertically and perpendicular to the receptor. The patient is asked to lower his/her chin as much as possible, so that the head is additionally tilted roughly 30° downwardly (Figure 22.48). In that way, the mandible is projected in an aspect slightly tilted to the axial direction.

22.4.2.3.2.7 Reverse Towne Projection (Clementschitsch Projection) The Reverse Towne projection is a very similar projection to the Towne projection, yet with an inverse beam direction. More specifically, the Reverse Towne projection is defined as posterior-anterior skull projection with open mouth to freely project the mandible and the condyles (Figure 22.49).

Waters projection is mostly used for assessment of the maxillary, the frontal, and the sphenoidal sinuses. Waters projections provide a good initial diagnostic tool if infections (sinusitis), fractures, or other pathology are suspected. In this context it appears noteworthy that, from a radiation protection point of view, such radiographic techniques with their low radiation dose can often serve as a low-dose initial evaluation tool, before, if there is evidence that requires further evaluation, dose-intensive 3D techniques such as CT or CBCT are applied as a next step.
In addition, the maxillary sinuses can be evaluated in a crani-frontal aspect. To achieve these goals, the rationale behind the radiograph is to move the back of the head upwards plus to move the condyles out of the fossae. The patient faces the detector, and tilts the head downwards in an angle of ca. 30° so that his/her forehead touches the detector and the nose is roughly 2 to 3 cm distant to the detector. The mouth of the patient is opened as widely as possible, for example by inserting a cork (Figure 22.50).

From a distance of approximately 1 m the central X-ray enters the patient’s neck. It is aligned with the midsagittal plane and impacts at right angles on the image receptor (Figure 22.50). The anterior-posterior version of this projection represents the Towne projection; however, the latter is not commonly used in dental applications.

Main indications of the reverse Towne projections are:

- Fractures of the mandibular condyles or the caput mandibulae
- Deformations or large bony pathologies of the mandible
- Maxillary sinus evaluation in a frontal aspect

### 22.4.2.3.2.8 Lateral Oblique Mandible View

Lateral oblique radiographs are extraoral projection radiographs (Figure 22.51), showing the mandible and parts of the maxilla from an inferior position and an oblique angle. The latter is selected in order to freely project the anatomical regions of the mandible and maxilla close to the detector without superimposition of their contralateral counterparts. Before the advent of panoramic radiography, such projections were very helpful. Nowadays, their indication is rather limited; however, they may still be useful in disabled or non-cooperative patients that do not accept the acquisition procedure required for a panoramic radiograph.

The dental cone can be used to expose lateral oblique radiographs. The image receptor is placed tangentially to the cheek of the patient on the side of the region under investigation. It is held by the patient and is placed in a slightly oblique position to his/her midsagittal plane (Figure 22.52) so that its lower end extends roughly 2 cm below the mandible border at that side.

The patient is asked to protrude his/her mandible and extend his/her neck to bring the mandible forward and, thus, away from
the cervical spine. The head is tilted towards the side that is being examined. The central X-ray is coming from below the ear of the contralateral mandibular side slightly behind the contralateral mandibular angle. It has to aim through the “key hole” between mandible and cervical spine to freely project the receptor close mandibular side. In consequence, the central X-ray is directed roughly 10° to 15° from below the horizontal plane, and enters the receptor in a vertical angle of around 70° (Figure 22.52).

22.4.2.3.2.9 Special TMJ Projections  In general, conventional projection radiography plays a limited role in the evaluation of the temporomandibular joint. However, it may be used as an initial imaging tool for a crude overview over the bony structures of the TMJ (the condyle and the articulate fossa). The articular disc cannot be visualized in these radiographs. The challenge in imaging the TMJ by means of radiographic projection images lies in its anatomical niche bounded laterally by the zygomatic arch and medially by the petrous ridge of the temporal bone. As a consequence, a projection radiograph of the TMJ requires a beam direction suitable to produce the least superimposition of the surrounding tissues to enable discrimination of the condyle and its articulate fossa. One solution to visualize its anterior-posterior aspect lies in the (Reverse) Towne’s projection discussed above. For the lateral aspect of the TMJ, two main projection radiographies have been established:

- Transcranial oblique lateral projection
- Transpharyngeal projection
The transcranial oblique lateral projection (TOLP) has long been used to assess the lateral aspect of the TMJ. The TOLP in general can be taken in open as well as in closed position. The patient's midsagittal plane is orientated parallel to the receptor, which is placed tangentially to the skin at the side under investigation. The central X-ray is aiming at the condyle and coming from the opposite side of the patient’s head roughly 20° to 25° from cranially, so that it is aiming in a downward direction. The central and medial portions of the joint are, thus, projected downwards, superimposing on the rest of the condylar process (Brooks et al. 1997).

A slightly more eccentric variation of the TOLP is the eccentric Transcranial Radiograph modified by Schüller (Schüller Projection; Schüller 1905; Figure 22.53).

This is an oblique transcranial projection normally taken in open mouth position to freely project the TMJ of the patient’s detector close side. Depending on the clinical diagnostic task, the Schüller-projection sometimes is also acquired in closed-mouth position. The central X-ray enters the contralateral side ca. 25° to 30° from cranially (entering the skull roughly 4 cm above the external acoustic meatus) to avoid superimposition of both TMJs (Figure 22.54).

TMJ projection images are normally acquired on a vertical (portrait) orientated receptor of sufficient size (e.g., 18 × 24 cm²) and collimated to a field-size of ca. 12 × 15 cm² (also portrait). The source-to-detector distance for the transcranial projection is around or slightly exceeds 100 cm.
Transpharyngeal projection (Parma) represents another projection radiograph specifically designed for evaluation of the TMJ. The transpharyngeal projection aims to visualize the mandibular column and condyle, as well as the ascending ramus of the mandible. Like the transcranial projection it displays a lateral aspect of the side close to the image receptor. This projection is acquired with open mouth, with the image receptor placed adjacent laterally to the patient’s face parallel to the midsagittal plane. The central X-ray enters the tragus on the contralateral side and aims at the tragus of the side under investigation, which is the side adjacent to the image receptor (Figure 22.55).

The main characteristic of the Parma projection is that it is exposed with a close source-to-object distance—a dental cone placed adjacent to the contralateral facial side of the patient. The rationale behind this specific imaging geometry is the resulting huge magnification of the contralateral TMJ and bony structures caused by the short distance of these structures to the radiation source. As a consequence, these structures are sort of “disguised” on the resulting projection image, while those close to the receptor are clearly displayed with limited disturbing superimposition (Figure 22.56).

If the mouth is opened sufficiently, the transpharyngeal radiograph allows for a relatively good view on the condyle close to the receptor. As evident from Figure 22.56, however, the superimposed structures of the pyramid of the cranial base make it hard to clearly identify all aspects of the condyle. As stated before, these drawbacks clearly limit the use of the transcranial and transpharyngeal TMJ projection radiographs.

22.4.2.3.2.10 Sialography in Dental Radiography The salivary glands as soft tissue organs cannot be directly imaged by means of radiographs. As an indirect radiographic evaluation, sialography was established long ago. The salivary glands are indirectly displayed by means of a radiopaque contrast agent injected into the natural duct of the gland. The technique shows the architecture of the salivary duct system, the ductules, and parenchyma of the salivary gland of interest. Strictures can, thus, also be visualized. A radiopaque contrast medium is injected into the excretory duct of the respective gland. Sialography is also conducted in dental radiography, most commonly to assess the radiographic pattern of the submandibular gland or the parotid gland. It is helpful to visualize potential duct obstructions or the
duct pattern of the gland and its interior. Due to the advances in ultrasonography, today sonographic evaluation of the salivary glands represents the standard means of diagnostics. However, recent reports still advocate a role of sialography in patients presenting with sialadenitis (Hasson 2010). The involvement of the salivary glands in systemic diseases such as Sjögren’s syndrome may also be successfully diagnosed by sialography, with high sensitivity and specificity if an experienced and skilled observer is performing the procedure (Kalk et al. 2002). Radiographic techniques applied for sialography mainly comprise the lateral oblique mandible view (see Section 22.4.2.3.2.8) or panoramic radiography (Figure 22.57).

The parotid gland can also be assessed by posterior-anterior skull radiography (Kalk et al. 2002). Lately, CBCT has also been successfully applied for sialography (Jadu et al. 2010; Kroll et al. 2015). As standard agents, iodine salt compositions dissolved in an oil or water solution are employed. While water soluble solutions due to their lower viscosity are somewhat easier to apply, they are rapidly diluted by the saliva and also become immediately absorbed by the glands. The consequence may be poor radiographic density and, thus, poor contrast. However, due to their easy application they still tend to be used rather frequently. The more complicated to handle oil-/fat-soluble contrast agents are not easily diluted or absorbed by the salivary gland. Thus, at least in theory they provide better and longer-lasting contrast for sialography.

Therapeutic radiological techniques regarding sialoliths like stone retrieval and balloon sialoplasty may also be conducted by dentists or dental radiologists.

22.4.2.3.2.11 Hand-Wrist Radiography At first glance, it may appear strange why dental radiography also comprises hand radiographs. Nevertheless, hand-wrist radiographs (Figure 22.58) are well established for skeletal maturation determination in Orthodontics.

Of course, hand-wrist radiographs are also used for other purposes in medicine. As its name indicates, this type of radiograph displays the hand plus its wrist bones, which form a complex anatomical structure. It is well known that chronological age is not a good descriptor of skeletal growth velocity or skeletal maturity (Flores-Mir et al. 2004). Thus, other methods to estimate the latter are required. One such method is based on the evaluation of hand-wrist radiographs. Age determination from skeletal analysis was already investigated in the middle of the twentieth century (Bayley 1946). The origins of the analysis of hand-wrist radiographs for estimation of growth and biological age lie in the pioneering work of Todd (1937). By comparison of the radiograph with tabulated drawings of the different stages of maturation of the hand-skeleton as well as by determination of defined stages of maturation of specific ossification-centers, a biological skeletal age is determined (Björk 1972).

Hand-wrist radiography may be indicated whenever the information on the actual skeletal maturation status or a prognosis of (future) skeletal maturation derived from its analysis appears helpful to indicate or predict the best time for orthodontic intervention. For instance, this is important in surgical cases to predict the best possible time for the surgical intervention. In addition, the remaining treatment time can be estimated.

Hand-wrist radiographs are exposed on a ca. 18 × 24 cm² detector (film, storage phosphor plate, or solid-state receptor). Using a source-to-receptor distance of around 70 to 80 cm (Tanner 1962), the hand is placed with its palm resting on the detector so that the central X-ray aims at the center of the back of the hand and impinges perpendicularly in the center of the...
receptor. Longer source-to-receptor distances have also been suggested (Kiran et al. 2013). To enable clear visualization of the sesamoid bones, the thumb should be deflected by 30° and the fingers of the hand should also be spread apart. Hand-wrist radiographs can be exposed in dental panoramic units (see Safer et al. 2015) or by means of the dental cone (Schopf 1978).

As a description of the relatively complex analysis of maturation stages for biological age estimation would exceed the scope of this chapter, the interested reader is referred to Greulich and Pyle (1950) and Björk (1972). Age estimation in orthodontics is mainly based on the Björk (1972) methodology. For this analysis, several distinct regions of some carpal bones and the phalanx are evaluated with regards to their maturation status. A very common such analysis is based on the suggestion of Greulich and Pyle (1950), which derives a mean skeletal age by averaging the skeletal ages over each bone age in the hand-wrist using an atlas made of typical hand-wrist radiographs that are displayed at 6-month-intervals. Björk (1972) defined eight stages of interest during the age-period between 9 and 17 years that is of main interest in orthodontic treatment (Schopf 1978).

The validity of using hand-wrist radiographs for skeletal maturity assessment in relation to overall skeletal growth velocity has been proved for various ethnic groups (Flores-Mir et al. 2004). More recently, however, the general value of hand-wrist radiographs has often been questioned, and alternative methods have been suggested. For instance, it has been observed that general conclusions on skeletal age based on hand-wrist radiographs are questionable, owing to the significant inter-individual variation in growth patterns (Verma et al. 2009). A systematic review from 2004 concluded that skeletal maturity analysis of hand-wrist radiographs in order to predict facial growth velocity should be based on both bone staging and ossification events (Flores-Mir et al. 2004). More recently, the analysis of the radiographic pattern of the cervical vertebrae has been suggested as alternative (Hassel and Farman 1995; Danai et al. 2014). This evaluation has the advantage that the cervical spine in general is automatically included in regular lateral cephalograms (see Figure 22.37, Section 22.4.2.2.1) and, thus, no additional image (and radiation) is required.

### 22.5 Dose Issues and Radiation Protection in Dental and Maxillofacial Radiography

In general, the doses for the conventional (2D) dental and maxillofacial radiographs are low compared to doses used in other medical radiographic applications (see Section IV, Chapter 66 of this book). However, on the other hand dental radiography is a high-volume procedure (European Commission 2004) representing a large share of the total volume of radiographic applications in man. For instance, dental radiographs in the European Union account for more than one third (>33%) of all radiographs (European Commission 2008). In the U.S., an annual number of over 100 million intraoral radiographs is reported (U.S. Food and Drug Administration 2003). It is also well known that doses used in medical X-ray exposure continue to increase (Hujoel et al. 2015). In the light of these figures and the general trend, the current world-wide discussion on expected increase in dose induced by a massive increase in CBCT-usage in dental radiography appears well-founded and comprehensible. Another important aspect is that dental radiography is also commonly applied in young patients. For instance, bitewing radiographs are regularly prescribed for young patients with high caries risk (European Commission 2004). Effective doses for 2D dental radiography are in the low micro Sievert range (Table 22.6). Nevertheless, some epidemiological studies observed an increased risk of brain (Preston-Martin and White 1990; Longstreth et al. 1993), salivary gland (Preston-Martin and White 1990; Horn-Ross et al. 1997), and thyroid (Hallquist et al. 1994; Wingren et al. 1997; Memon et al. 2010; Hershman 2013) tumors for repeated dental radiography.

Single intraoral radiographs can start at around 1 μSv (Table 22.6). However, as it is well-known that beam collimation strongly influences patient dose, such low values are only achieved for a rectangular collimation (European Commission 2004). This can be simply estimated from the apertures: the typical 6 cm diameter round collimation covers an area of 28.27 cm², whereas a rectangular collimation to film size (size No 2: 3 × 4 cm², see Table 22.1) only covers 12 cm. Mathematically, this represents an increase of 156% when round collimation is used instead of rectangular collimation. Consequently, the effective dose can be considerably reduced by using rectangular collimation (Cederberg et al. 1997; Kitafusa et al. 2006). An average effective dose for typical small scale (bitewing, periapical) intraoral radiography typically is in the range of 5 μSv (European Commission 2004) (Table 22.6). Data for occlusal projections are rare, yet the European guidelines on radiation protection in dental radiography (European Commission 2004) suggest an effective dose of ca. 8 μSv for maxillary occlusals (Dula et al. 2001) (Table 22.6). Although, to the best of the author’s knowledge, no data are available for mandibular occlusal radiographs, from the direction of the beam it seems likely, that mandibular occlusal projections yield slightly lower effective doses. Apart from beam collimation, appropriate shielding provides a simple yet effective measure to lower the dose to critical organs. Particularly, the thyroid is one of the more radiosensitive organs in the head and neck region. In intraoral radiography, the thyroid can be shielded effectively by means of a protective thyroid collar or shield (Figure 22.59), which may also be integrated into a lead apron.

| TABLE 22.6 |
| Effective Doses for Different Dental and Maxillofacial Radiographs |

<table>
<thead>
<tr>
<th>Radiograph</th>
<th>Effective Dose (μSv)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panoramic radiograph</td>
<td>2.7–37.8</td>
<td>European Commission (2004), European Commission (2012), Lee et al. (2013), Shin et al. (2014)</td>
</tr>
<tr>
<td>Lateral cephalometric radiograph</td>
<td>2–5.6</td>
<td>European Commission (2004), Ludlow et al. (2008)</td>
</tr>
<tr>
<td>Maxillary occlusal radiograph</td>
<td>8</td>
<td>Dula et al. (2001)</td>
</tr>
</tbody>
</table>

*Figures strongly depending on collimation: rectangular collimation decreases the dose down to one fifth compared to round collimation.*


†Figures strongly depending on collimation: rectangular collimation decreases the dose down to one fifth compared to round collimation.
There is no general agreement if for intraoral radiography lead aprons generally should be worn regularly during exposure. However, it has recently been suggested by some authors that a higher risk for thyroid cancer is found in patients with a history of repeated 2D dental radiographs (Memon et al. 2010; Hershman 2013). As long as there is no proof of the opposite, if possible a thyroid shield should be provided during exposure.

Effective dose values of panoramic radiography on average are on average are below 20 μSv (Table 22.6). When comparing the data from the literature (European Commission 2004; Lee et al. 2013), it appears that using digital (solid-state detectors and storage phosphors) (Lee et al. 2013) does not necessarily lower the dose when compared to film-based panoramic radiography (European Commission 2004). This may either be caused by a lack of awareness of the manufacturers of the equipment or by the general trend to produce “high-quality” radiographs in the sense of a beautifully looking image. Patient shielding in panoramic radiography remains an issue of controversial discussion. While some guidelines or reports (European Commission 2004; Australian Government 2005; American Thyroid Association 2013) suggest shielding with aprons is not necessary, since the dose to the body of the patient is negligible, others (White and Schulze 2014) nevertheless recommend application of lead aprons. In panoramic radiography, one particular problem in using a shielding-device exists: lead aprons may physically interfere with the primary beam and, thus, degrade image quality (Brezen and Brooks 1987). This refers to the collar closing at the neck of the patient, which, if positioned too far cranially, may lie in the primary beam when the source travels behind the patient’s neck and the front teeth are being recorded. In addition, as described earlier (see Section 22.4.2.2), panoramic radiography inherently utilizes a beam with a slight upward direction, which traverses the patient’s head on a strictly horizontal path. Consequently, the body of the patient will not be hit by the primary beam. However, the effect of secondary (scattered) radiation is often neglected in such considerations. Interestingly, experimental data on the effect of shielding in panoramic radiography on patient dose are scarce (Horner 1994; Kelaranta et al. 2016). Recently an article was published suggesting that the skin-dose to the female breast may be decreased on average up to 18-fold when a lead apron is applied (Schulze et al. 2016). Correct positioning of an appropriate lead apron can be practically achieved by placing its collar a bit below the beam entry position. By rotating the source-detector unit manually so that the source is behind the patient’s neck, the correct position of the collar can be easily controlled prior to exposure. According to the experience of the author, non-interference can be achieved without many difficulties and in a reasonable time if the staff have been sufficiently trained for this procedure.

Doses in cephalometric radiography range between 2 and 6 μSv (European Commission 2004; Ludlow et al. 2008) (Table 22.6). Although this dose range again is very low, it has to be considered that most of the cephalometric radiographs are acquired in children and juveniles. In addition, the thyroid as a critical organ may be in the primary beam if not appropriately shielded (Hoogeveen et al. 2015). As orthodontic treatment often extends over several years, often more than one cephalometric radiograph may be required during this period. These factors in combination make radiographs acquired during orthodontic treatment a considerable source of radiation among young patients in the U.S. (Hujoel et al. 2008), and most probably also in other industrialized countries.

22.6 Future Perspective in Dental Radiography

The tendency for more three-dimensional radiography is also evident for dental radiography. Very certainly, the share of CBCT-scans among all dental radiographs will further increase. However, as there are some disadvantages to 3D techniques that cannot be neglected (high costs, higher radiation dose and drastically reduced spatial resolution when compared to intraoral radiographs), it is not very likely that CBCT will completely replace 2D dental radiography within the foreseeable future. With respect to CBCT it is already apparent that “low-dose” protocols are gaining more and more importance (see Ludlow and Walker 2013). Radiation protection in the light of the many radiographs produced in dentistry is an inevitable prerequisite. As a consequence, the dental community will very certainly continue to be involved in discussions regarding radiation protection.

As in other medical applications (mammography, chest radiography), techniques producing incomplete 3D-information such as tomosynthesis will likely find their niche application also in dental radiography. As described in Section 22.4.2.2.9, there are already a number of panoramic radiography devices on the market that provide tomosynthetic reconstructions. However, one can imagine some additional functions, for example further enhanced transversal images of the jaws with low radiation dose. Theoretical work has been developed and published regarding such technology (Kolehmainen et al. 2003; Siltanen et al. 2003). The workgroup of the author has also developed a reference-based method to extract 3D-information from very few radiographs that may be acquired in a geometrically non-constrained setting (Schulze et al. 2008). With this technique until today only ex vivo results have been obtained (Figure 22.60).

With further evolving information technology and increasing computational speed, there are various options for future
development of such niche techniques. They all require complex mathematical methods to extract image information and to generate (limited) 3D-information from it. If and when such techniques successfully enter the clinical stage, however, will strongly depend on acquisition complexity and comfort in a clinical setting. Only if these requirements are met and the potential benefit for the clinician and the patient is high, it is likely that such a novel (niche) technique will successfully enter the market and can be established as a routine diagnostic tool. In dental radiography, the success of such niche techniques may also depend on future radiation dose development in CBCT.

Already widely used in clinical dentistry and related disciplines is to combine image information from different modalities. This is often termed “matching,” where photographic images are registered to 3D-radiographic images for various purposes. A better term for this process is “image fusion.” Technically two or more image data are registered into one coordinate system. This can provide the operator with additional visual information or may make the conceptual understanding of the information easier than if it were displayed in separate images. Registration of different image modalities into one image can be applied to any existing imaging modality (see Dranischnikow et al. 2009) and, thus, offers a wide variety of clinical applications. For instance, optical surface scans producing a 3D-surface of the teeth or the alveolar ridge can be registered to a CBCT-scan for planning of dental implants (Kernen et al. 2015; Yang et al. 2015). Another approach is to register dynamic jaw motion data to an existing CBCT to obtain realistic motion patterns of the mandible (Hanssen et al. 2014). These examples are only a small overview over the great variety of options exhibited by registration of data obtained from different modalities. As we are only at the very beginning of applying such methods, it seems quite likely that dental imaging in the future will further exploit registration methods for diagnostic purposes, therapy planning, or assessment of treatment outcome.

As for many radiological applications, phase-contrast imaging will determine another revolution in medical and dental X-ray imaging. As this technique is extensively discussed in Chapters 49 to 53 of this book, in this chapter only a brief summarizing paragraph is included. Until now, medical radiography in a clinical context has always only measured attenuation of the beam. Phase-contrast means that the phase-shift the X-rays undergo during their transit through the object is detected and used as a tissue-discriminating signal. Phase-contrast has been a matter of scientific investigation for some decades already.

**FIGURE 22.60** Surface reconstruction of a dry human mandible generated from only nine projection radiographs (exposed on storage phosphor plates) by means of a regularized iterative reconstruction technique (Schulze et al. 2008). The radiographs had been acquired by means of a dental cone in different, non-constrained geometrical settings. For registration purposes, three spherical reference bodies (visible in this image as ball-like structures) had been attached to the mandible.
Until quite recently, however, synchrotron sources were needed to generate highly parallel and monochromatic X-rays (see Section I, Chapter 8 of this book). Obviously, such sources are not available in a clinical setting and, thus, phase-contrast X-ray imaging has for a long time never left the status of laboratory investigations. In the middle of the first decade of the millennium years, the first papers introducing alternative methods by application of conventional X-ray tubes were published (Pfeiffer et al. 2005; Pfeiffer et al. 2006). Particularly the latter method using gratings in the low micrometer-scale to infer the phase-shift is promising, and yields excellent results in a laboratory environment. Preliminary results obtained in a close-to-clinical setting have been published recently for mammography (Scherer et al. 2015). The major advantage of phase-contrast X-ray imaging over conventional absorption radiography lies in its discriminative power within soft tissues. In theory, this additional signal can be acquired without enlarging the dose (Pfeiffer et al. 2006). It will be exciting to see this revolutionary technique entering the clinical stage within the next decade.

Alternative methods not using ionizing radiation are also being developed further. Some of them indicate promising future perspectives; for instance, dental magnetic resonance imaging (MRI), using small intraoral coils, recently already produced excellent results in vivo (Ludwig et al. 2016). This novel approach particularly allows for higher spatial resolution, while still keeping the acquisition time within clinically feasible limits (Ludwig et al. 2016). Ultrasound is another further evolving imaging technique that may play a larger role in dental imaging. Intraoral applications for soft tissues and also the periodontium have been demonstrated (see Salmon and Le Denmat 2012). 3D applications for soft tissue investigation within the oral cavity may be envisioned for the near future. Other promising non-ionizing radiation imaging techniques for the oral cavity include optical coherence tomography (Fernandes et al. 2016) or infrared thermography (Batinjan et al. 2014; Christensen et al. 2014).

Regardless of the fact that dental radiography has been used for almost the same time that X-rays have been known to mankind, their clinical importance and significance remains unbroken. The transition from film-based to digital radiography resulted in a multitude of novel options, since modern information technology can now make use of methods involving complex computations, many of which have been developed decades ago. Many researchers believe that we are still in the beginning of a developmental pathway utilizing the advantages and options offered by modern information technology and fast digital image receptors. As all medical applications, dental X-ray imaging will surely benefit from such technical developments yet to come. The future of dental imaging in general and dental radiography looks promising, yet also challenging, since the technical complexity of the devices seems to be ever increasing. For the dental practitioner, this means more options yet also advanced knowledge requirements on technique and applications. The dental community has to prepare itself by sufficiently implementing appropriate education both in the undergraduate as well as in postgraduate training. If these prerequisites are met, dental radiographic imaging with all its novel facets will continue to play an important role in the entire radiographic imaging community.

### REFERENCES


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