Evolution of radiographic imaging in periodontal diagnostics – A narrative review

A radiográfiai képalkotás fejlődése a parodontális diagnosztikában – narratív áttekintés

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Abstract
Utilizing radiographic imaging in healthcare, allows clinicians to view parts of the human body in ways that were impossible with naked eye. From the discovery of X-rays by Wilhelm Conrad Röntgen to the latest digital radiographic imaging, this narrative review provides a brief overview of radiographic methods used in periodontal diagnostics. After review of relevant literature, advantages and drawbacks of each method are discussed. Based on literature data and clinical experience, this study aims to provide guidelines to select the proper diagnostic procedure for specific clinical cases.

Keywords
 periodontal diagnostics, radiography, X-ray, intraoral radiographs, orthopantomography, cone-beam computed tomography

Kulcsszavak
parodontológiai diagnosztika, radiográfia, röntgen, intraorális röntgenfelvételek, ortopantomográfia, kúpos komputertomográfia

Introduction
Arguably one of the biggest achievements in modern medicine was the invention and constant development of various imaging modalities. Utilizing radiographic imagery in healthcare, allows clinicians to view parts of the human body in ways that are impossible with the naked eye. The starting point of radiographic imaging can be dated back to November 8th, 1895 when Wilhelm Conrad Röntgen, a German mechanical engineer and physicist discovered radiation in a wavelength between 10 pm and 10 nm and called it **X-ray.** With Röntgen's work it was possible to study parts of the human body that are not visible to the naked eye. Broken bones, skeletal disorders could now be viewed by using X-rays to see through flesh. A month after the discovery he held a public display featuring the very first X-ray image of his wife's hand. Technology spread rapidly to many different fields of medicine and was (still is) developing constantly over the course of the 20th (and 21st) century (Evans 1995). Discovery earned him the first ever Nobel Prize in physics in 1901.

Dentist very quickly recognised the diagnostic advantage of X-rays in their own field. Especially in dental surgery, significant progress was achieved with the new radiological examination. Soon after the publication of Röntgen's work a German dentist, Otto Walkhoff made the first intraoral X-ray of his own teeth. Due to the 25-minute exposure time and side effects, such as loss of hair a more practical protocol had to be developed. In 1896 Professor Walter König also published a radiograph of front teeth in upper and lower jaw published by S.A. Bart, Leipzig in 1896. König's device reduced the exposure time significantly. The 5-minute reduction was achieved with a new tube design. The König-tube differs in its

anticathode, which is made up with a platinum disc located at 45° of the of the convergence point. From this emergent point of the electrons, the X- rays spread out in every direction (Forrai 2007).

Louis Richard Chauvin and Félix Allard modified the protocol and introduce the practical application of dental X-rays (Friedman & Friedland 1998). One year following Röntgen's discovery dental radiography was used to detect periodontal bone loss by William James Morton Jr. He published the first dental radiographs in the USA in the Dental Cosmos of April 24, 1896. Until the late 1940s – early 1950s the standard technique for intraoral radiographs was the bisecting angle principle with a short anode – film distance. Various articles have suggested a use of a different protocol, because the quality of the radiographic images was affected by the angulation of the film and the distance between the object and the source (Fitzgerald 1947a, 1947b). Film has to be parallel to the object to avoid geometrical distortion of the image (Fitzgerald 1947b, Richards 1949, Updegrave 1951). To increase sharpness of the image, the distance between the object and the source has to be increased (Fitzgerald 1947a, Richards 1949). Based on these findings a new standardized technique for taking intraoral radiographs has been proposed, called: parallel long-cone technique (Fitzgerald 1947a, b, Updegrave 1951, Friedman 1958). This radiographic approach combined with direct clinical probing are the two main tools in periodontal diagnostics (Lang & Hill 1977, Listgarten 1980) until this day.

Attempts to create a **radiographic image** of the entire lower and upper jaw were made as early as the 1920s, however development of a machine capable of a half-circle motion with an extraoral source began in the 1950s. In the early 1960s the first commercially available **orthopantomograph (OPT)** was marketed (Hallikainen 1996). In 1979 Allan M. Cormack and Godfrey N. Hounsfield received the Nobel Prize in Physiology and Medicine for the development of **computer assisted tomography (CT).** This and the invention of **magnetic resonance imaging (MRI)** by Paul C. Lauterbur (Lauterbur 1973) marked a new era in medical radiographic imaging. Both modalities are capable of three-dimensional imaging, therefore clinicians are able to view images in multiple orientations (sagittal, axial, coronal).

Conventional CT scans were used in dentistry and are still applied occasionally today, however due to the elevated radiation dose, low availability and relative high prize of the machine, it never became a routine diagnostic modality. The introduction of cone-beam computed tomography in 1996 (Europe) and 2001 (USA) offered higher quality images with less radiation dose (Hatcher 2010). Today it is one of the two most important tools (besides intraoral optical scanner) for acquiring 3D data. It is widely used in many fields of dentistry (oral surgery, implantology, endodontics, periodontology) (Jacobs et al. 2018).

Application of scans in periodontology have been proposed (Misch et al. 2006, Kasaj & Willershausen 2007, Walter et al. 2009) in cases where conventional periodontal diagnostic methods do not provide sufficient information on periodontal defect morphology (Eickholz et al. 1998, Christiaens et al. 2018), which is one of the primary factors that determine periodontal treatment (Cortellini 2012) and single tooth prognosis (Lang & Lindhe 2016).

The aim of this narrative review was to summarize the history of radiographic diagnostics modalities used in periodontology and to provide guidelines based on literature data and clinical experience for the selection of the proper diagnostic tool in specific clinical scenarios.

Intraoral Radiography

From the first application of radiographs in periodontology to the introduction of the long-cone parallel technique, intraoral radiographs had an important role in the treatment of periodontal patients. Additionally, to direct clinical measurement, clinicians use some sort of radiographic method (periapical radiographs, bitewing radiographs, panoramic x-rays, CBCT scans) as an additional source of information. To get the

most accurate depiction of periodontal defect morphologies, and to be able to monitor the patient's periodontal status during the treatment process a reliable and reproduceable radiographic method has to be utilized: long-cone parallel technique (Updegrave 1951) is recommended. According to the recommendation of the American Academy of Periodontology (AAP) and European Federation of Periodontology (EFP) a series of 14 periapical radiographs taken with long-cone parallel technique (periodontal status radiograph) should be used for periodontal diagnostics (Parameters of Care 2000, Greenwell 2001, Position Paper 2003) *(Figure 1.)*.
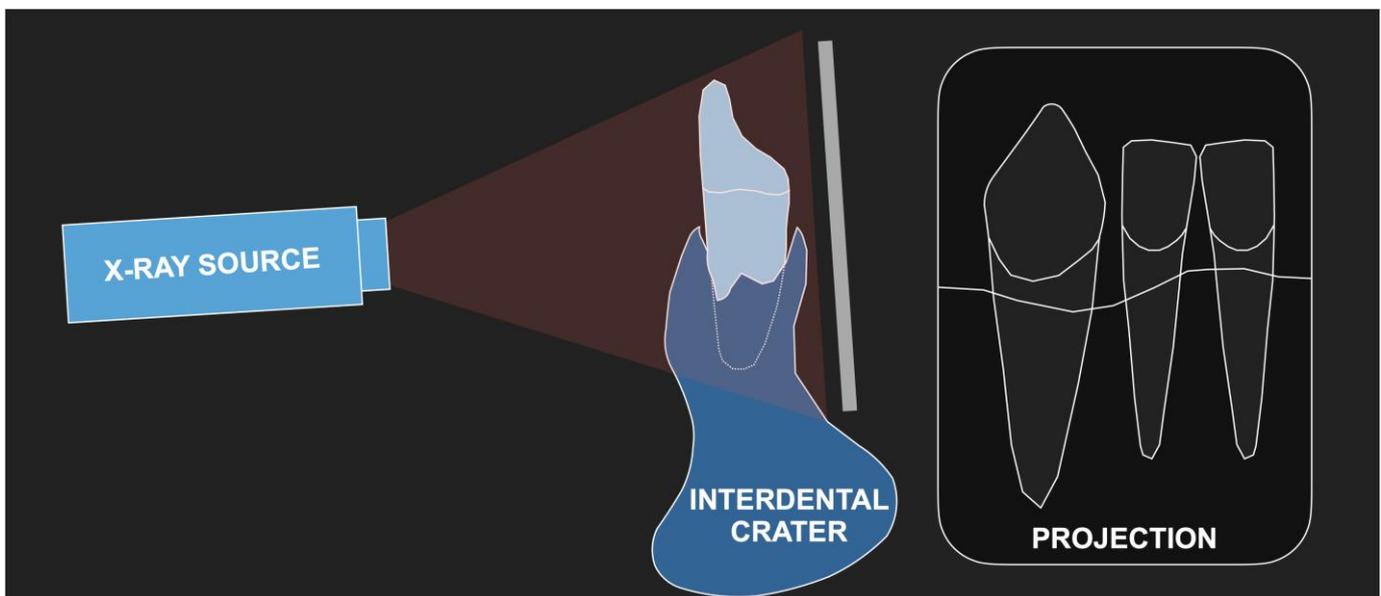
1. Figure Paralleling long-cone technique, demonstrating the limitations of 2D radiography

One of the primary factors, when that determine periodontal treatment (Cortellini 2012) and pretherapeutic single tooth prognosis (Lang & Lindhe 2016) is the periodontal defect morphology. If the morphology of the defect cannot be visualized accurately, an unfavorable treatment may be executed, that can compromise treatment outcome. Intraoral periapical radiographs (and panoramic x-rays) provide an orthoradial two-dimensional projection of three-dimensional objects *(Figure 2.)*.
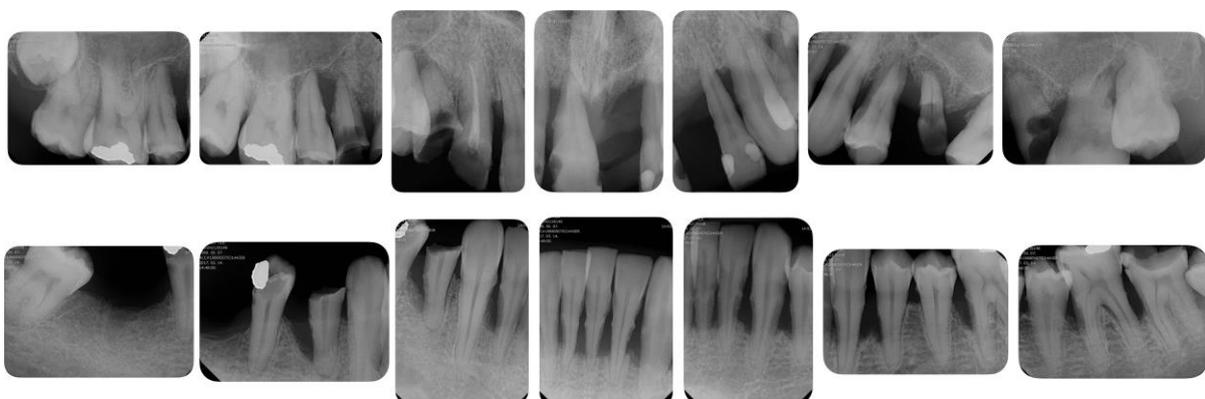
2. Figure Periodontal status radiograph

In conclusion, it is best suited for the detection of periodontal defects, where bony walls are not overlapping in an oro-vestibular orientation (Eickholz et al. 1998). Horizontal defects, one- and two wall proximal vertical defects and Class III furcation defects of lower molars can be detected easily

Othopantomography (Panoramic X-ray)

Orthopantomography is a form of focal plane tomography. Images are taken of multiple planes with a moving extraoral x-ray source. Then they are combined to generate the composite panoramic image. Due to the motion unsharpness, structures that are not in the focus become blurry. Similar to intraoral radiographs OPT scans also provides 2D information. Compared to intraoral radiographs image resolutions are much lower, therefore small details are difficult to see. Modern digital panoramic x-rays can provide higher resolution images with the possibility to magnify specific areas. Other substantial drawback is the different vertical magnification of teeth within a single scan, which makes it difficult to accurately determine the level of bone loss (Thanyakarn et al. 1992) *(Figure 3.)*.

3. Figure orthopantomogramm (OPT, panoramic x-ray)

Handful of publications state that high quality panoramic x-rays provide the same diagnostic information on periodontal defect morphologies as a series of periapical radiographs with sometimes even lower radiation dose (Tugnait et al. 2000, 2005, Corbet et al. 2009).

In conclusion, OPT scans provide a general overview of a patient's periodontal condition, and might be used during recall therapy, to check occasional relapses. However, it is not suitable for the planning of complex periodontal rehabilitation and surgical procedures.

Conventional computed tomography

The invention of computer assisted tomography (CT) opened a new dimension of radiographic imaging. Compared to orthopantomography, in this case not only the x-ray source is moving, but the detector also rotates. This allows to view structures in multiple orientations (sagittal, coronal, axial). Due to the superiority of cone-beam computed tomography in dental imaging, it is rarely used today. Biggest drawback of conventional CT is the relatively large voxel size, ranging from 1 mm to 3 mm or above. This thickness is more suitable for the imaging of larger areas, however a small area, such as the periodontium cannot be

viewed precisely *(Figure 4.)*. Additionally, the elevated radiation dose, the inconvenience during imaging and the high prize of the machine prevented it from becoming a routine diagnostic modality in dentistry (Kumar et al. 2007, Jacobs et al. 2018).

It can be concluded, that conventional CT scans should not be used for periodontal diagnostic purposes, due to the better, cheaper and more accessible alternatives.
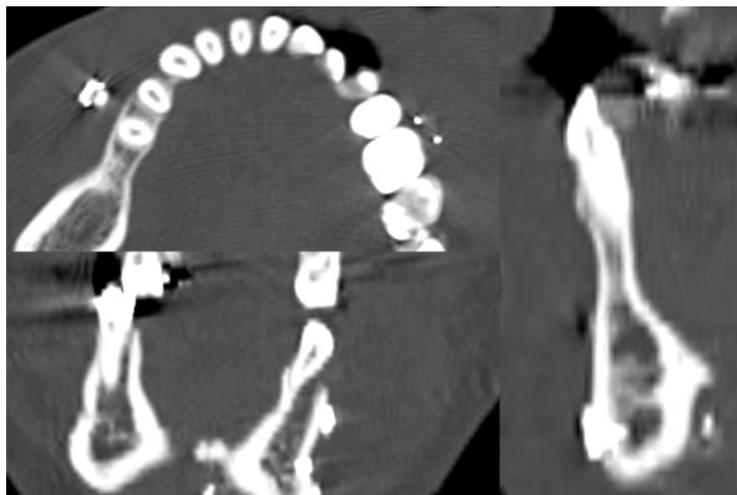
4. Figure Conventional computed tomography

Cone-beam Computed Tomography

Cone beam technology was first introduced in 1996 (QR s.r.l. NewTom 9000). The original members of the research group were Attilio Tacconi, Piero Mozzo, Daniele Godi and Giordano Ronca. CBCT uses a divergent cone-shaped beam (similar to 2D x-ray units), obtaining multiplanar projections in a single rotation. After the images are taken, computers reconstruct 3D information from the acquired data by raw image reconstruction algorithms. This is very similar **to multidetector computed tomography (MCT)**, that uses flat, fan-shaped beams (Koong 2010). CBCT is widely used in many fields of dentistry, to acquire volumetric data, even though it is not considered a routing imaging modality in periodontology, it's use is more and more suggested as an alternative to conventional radiographic methods. A series of in vitro and in vivo studies have demonstrated that CBCT is superior to IRs???? in the detection of certain periodontal defects (i.e., furcation defects, three wall intrabony defects, midbuccal intrabony defects, or dehiscence-type defects) (Vandenberghe et al. 2007, 2008, Grimard et al. 2009, de Faria Vasconcelos et al. 2012, Bagis et al. 2015) *(Figure 5.)*.
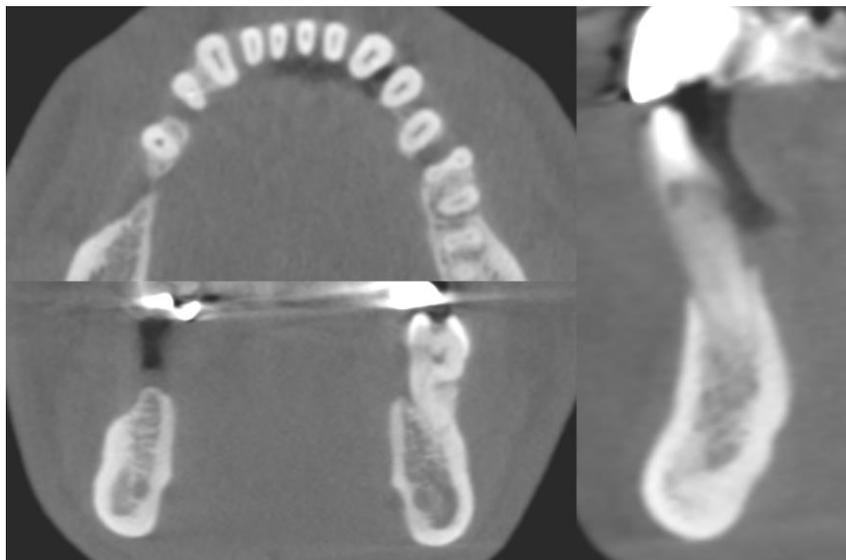
5. ábra Figure Cone-beam computed tomography

However, it has been concluded by systematic reviews that it is difficult to justify the cost-benefit ratio of the higher irradiation dose (Walter et al. 2016, Woebler et al. 2018, Assiri et al. 2020). It must be noted, that in the studies summarized by the systematic reviews 2D images of the CBCT dataset were viewed individually in different orientations, instead of viewing 3D reconstructions of the datasets.

Multiple factors determine the quality of CBCT scans, thus influencing the diagnostic capabilities of the images. Biggest drawback of CBCT images compared to conventional radiographic methods is the higher levels of artefacts and scattering that are caused by metal restorations. During scanning it is possible to apply metal artefact reduction (MAR) algorithms (Queiroz 2018). However permanent restorations, that the patient has, often have to be changed during complex periodontal treatment. Therefore, to reduce artefacts, these restorations should be removed prior to CBCT imaging *(Figure 6.)*. Voxel size should also be considered, the smaller the voxel size, the higher resolution the CBCT image will be (Spin-Neto et al. 2013). The smallest voxel size of CBCT scans is 75 microns, however this voxel size is possible only with small field-of-view (FOV) scans. In complex periodontal treatment all the teeth have to be visible to plan the complete process, therefore a larger FOV CBCT scan should be taken with the smallest possible voxel size. According to literature data (Fleiner et al. 2013) and clinical experience the best result with a large FOV CBCT scan is possible with a voxel size of 120-150 microns.

6. Figure Importance of voxel size A: Baseline CBCT scan with 300 micron voxel size, B: Fooowup CBCT scan with 120 micron voxel size

One of the major complains of the use of CBCT scans in periodontology is the elevated a radiation dose. The effective radiation dose of large FOV scans, depending on the machine is between 80-100 µSv (Pauwels et al. 2014) which is only two times the dosage of a full-mouth intraoral periodontal status radiograph, reported to be about 40 µSv (Ludlow et al. 2008).

In conclusion, CBCT scans should be used in periodontal diagnostics as a third modality if conventional methods do not provide sufficient information on defect morphologies. With the proper imaging technique, CBCT is best suited for the diagnosis of three-walled intrabony defects, midbuccal, midlingual/ midpalatal vertical defects, dehiscence type defects, furcation defects and interdental craters.

Three-dimensional image reconstruction
Most of the articles investigating the use of CBCT scans for periodontal diagnostics, used the 2D images of the dataset and the 3D renderings, that imaging software automatically provide are low quality and are not suitable for diagnostic purposes. However, CBCT datasets can be digitally reconstructed (segmentation), to acquire realistic three-dimensional models of alveolar and dental structures. Segmentation is the process where 3D virtual models are generated to facilitate easier analysis of the clinical situation *(Figure 7.)*.
With this method most of the limitations of CBCT scans can be bypassed and the true diagnostic potential of CBCT scans can be accessed.
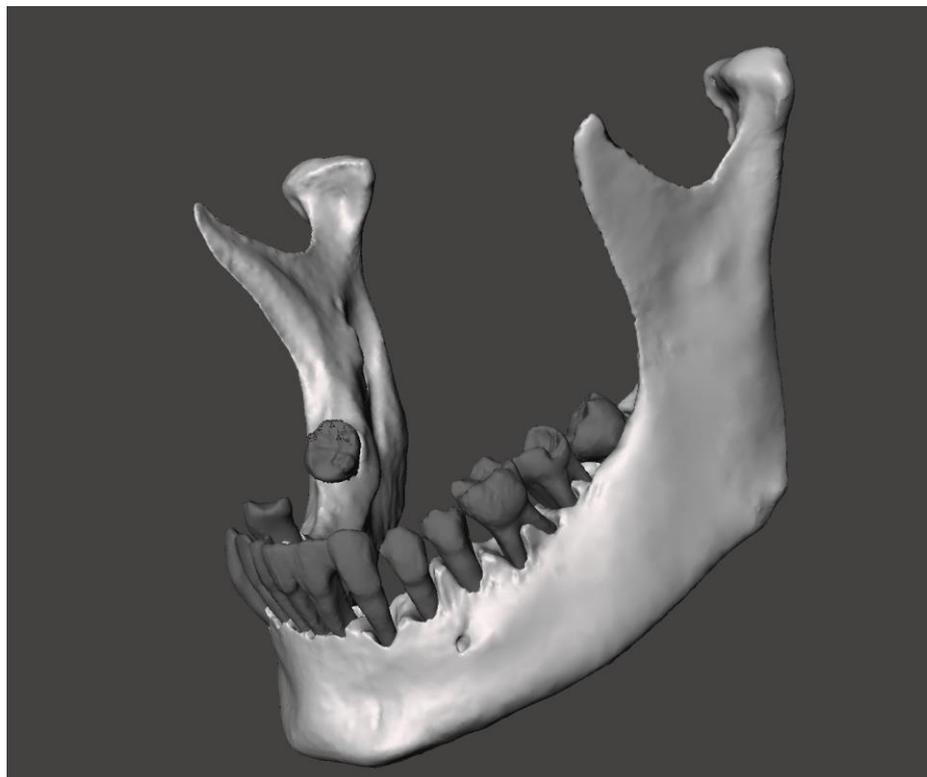
7. **Figure 3D reconstruction of CBCT dataset**

Conclusion

Radiographic diagnostic methods have developed immensely over the course of the past 100 years. Protocols and methods have changed following the development of technology. The aim of this article was to summarize the most frequently used radiographic methods. Reviewing the literature, it can be concluded, that the number one radiographic diagnostic modality in periodontology is the periodontal status radiograph, that consists of 14 periapical radiographs, taken with the parallel long-cone technique. Articles have pointed out the limitations of it and suggested the use of CBCT scans. Due to the limitations of CBCT scans (higher radiation dose, relatively low resolution, metal artefacts) it is only recommended in very specific scenarios. However, with radiographic image segmentation the limitations can be bypassed, and CBCT scans can be used reliably for periodontal diagnostics.

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Figure legends

Figure 1. Paralleling long-cone technique, demonstrating the limitations of 2D radiography

Figure 2. Periodontal status radiograph

Figure 3. Orthopantomogramm (OPT, panoramic x-ray)

Figure 4. Conventional computed tomography

Figure 5. Cone-beam computed tomography

Figure 6. Importance of voxel size
        6 a: Baseline CBCT scan with 300 micron voxel size
        6 b: Followup CBCT scan with 120 micron voxel size

Figure 7. 3D reconstruction of CBCT dataset