2 Basic Principles of Intraoral Radiography

Antigoni Delantoni and Kaan Orhan

2.1 Basic Principles of Intraoral Radiography

X-ray production is made through an **X-rays** tube, which is a vacuum tube that uses a high voltage to accelerate the electrons released by a hot cathode at a high velocity. The high velocity electrons collide with a metal target, the anode, creating the **X-rays**. Basically, the Xrays production occurs in the anode from the energy produced in the anode, only a fraction has enough energy for the production of diagnostic X-rays. Dental X-ray tubes use a static anode unlike medical machines that have a rotating anode. The major difference is that the energy production from a static anode is much lower than that of the rotating anode. As with all machines the amount of milliamperes and Kilovolts has significant effect on image production.

The authors state that the chapter does not contain any information or images or other third party material that is not copyrighted by the authors.

A. Delantoni (✉)
Department of Dentoalveolar Surgery, Implant Surgery and Radiology, Faculty of Dentistry, Aristotle University of Thessaloniki, Thessaloniki, Greece
e-mail: andelant@dent.auth.gr

K. Orhan
Department of DentoMaxillofacial Radiology, Faculty of Dentistry, Ankara University, Ankara, Turkey
e-mail: knorhan@dentistry.ankara.edu.tr

The control of mA regulates the amount of current that passes from the cathode, and this circuit is known as low voltage circuit of the tube. A higher value of mA results to a rise in filament temperature which results to more electrons being released leading in turn to higher quantity of X-rays. As the mA affects the quantity of produced X-rays an increase in the mA leads to more electrons produced which in turn leads to more photons falling on the image plate.

The difference in kilovoltage refers to the levels of thousands of Volts between the cathode and the anode. When more electrons are released and accelerated through the cathode and are attracted to the anode target, a current is formed. The quality of X-rays produced is determined from the KV. The maximum difference is known as the peak of KV through the cathode and anode, thus the KVp. Differences under the KVp accelerate electrons to a smaller degree. Thus X-rays of higher KVp penetrate the tissues easier, leading to a slight increase of the radiographic density. Smaller KVp rays are more likely to get absorbed from the tissues and not give the image we need on the film after they reach it.

Besides the KVp and the mA the time of exposure is of high significance and basically alters the basic features of the image. The exposure time and mA affect the quantity of X-rays produced and we use the time of exposure to regulate the quantity of produced radiation, and in conclusion the density of the image produced.

A. Delantoni, K. Orhan (eds.), *Atlas of Dentomaxillofacial Anatomical Imaging*,
https://doi.org/10.1007/978-3-030-96840-3_2

Besides the production of X-rays and the basic principles the film is the second element that serves to the production of the final image.

Radiographic films are a special design containing chemical radiosensitive materials which are used as the recording media of the image, those chemicals after the effect of radiation undergo a latent chemical alteration, which to become identified, need the additional effect of other chemical agents (developers and fixers) during their manipulation on the dark room.

The major characteristic of intraoral radiographs is that the receptor or film which is the means to produce the image is placed within the oral cavity. Regarding plain film or digital images, the basics of both methods is the same. The only significant difference that may present upon the radiographs themselves is that in direct digital radiography the use of the sensor, in many cases has a smaller size of active area than the corresponding films or PSP plates.

In 1989 Trophy made a major change in the digitization of intraoral radiographs, with the use of CCD sensors. The first research presented on the new sensors was made by Wenzel and Moystadand Van der Stelt at the same time.

The question that arises in relation to digital intraoral radiography is what the disadvantages of conventional radiographic systems are, and whether they should be replaced by a digital system and for which reason.

The disadvantages of conventional film are as follows:

- Cost (films and processing materials).
- Investment cost from the existence of a darkroom.
- Time for the appearance and maintenance of the machine.
- Time for storing and archiving the material.
- Environmental costs from the use of chemicals.
- Reproducing the image where needed requires time and multiple processes while the copy of the tile is of lower quality than the original.
- Quality materials are rarely of a high standard in everyday practice.
- The main disadvantage remains the significantly higher radiation dose to which the patient receives when taking a conventional X-ray compared to the corresponding digital X-ray.

Digital images are made up of digits and are essentially distinct in terms of the resolution of the image elements (pixels) and in terms of the different shades of gray of each element (pixels) of the image. Essentially a digital image consists of horizontal and vertical pixel arrays. Each pixel has a column and row mapping in the image that marks its position in the image and represents a shade of gray.

2.2 How the Digital Image Is Produced

The production of the digital image requires certain steps that start with the conversion of the image from analog to digital (analog to digital conversion) according to the amount of radiation received. This value is stored on the computer and represents the image. This defines the parameters and monitors the images during their production. The difference in this absorption is detected and recorded by special detectors, which are located directly opposite to the X-ray tube.

2.3 How the Doctor Sees the Picture

The detectors convert the absorption into an electrical signal, which with the appropriate amplification is transferred to the computer. The computer organizes and assigns the pixels to their correct position. There the absorption data is converted into a digital signal, which, after being processed by the computer, gives the image of the predetermined section of the body that has been selected. To store the image, the computer uses eight memory locations (8 bits = 1 byte). Each byte can represent 256 [1] shades of gray, from value 0 to value 255 [2, 3]. After processing with a computer, each number corresponding to a different shades of gray is converted into an image. The final image consists of a set of small squares called pixels (picture element). Each of these elements has, as mentioned, values that express the absorption of radiation that passes through the specific tissues and thus the diagnostic information which is included in the original image. This defines a value of gray from 0 to 256 which corresponds to the number initially determined based on the amount of radiation absorbed. But the ability to see the data depends not only on the image but also on the lighting in the space [4–6].

2.4 Digital Screen

The screen on which it is projected plays an important role in the presentation of a digital image. Although the gold standard for the assessment of image quality remains the conventional radiological film, mainly in terms of resolution, (spatial resolution) when it is projected in a proper transparency and in an area with dim lighting [7].

This is interpreted simply by saying that the screen displays the data it receives from the receiver accurately. But what is this data?

This data is detailed data that to be displayed correctly on the screen, the pixels of the receiver must be matched with the pixels of the screen. Ideally, there should be a 1:1 correlation and ratio at diagnosis [8, 9].

These data, therefore, based on the value they have in their mapping when displayed on the screen, correspond to differences in optical density, contrast, and resolution. This is in levels and shades of gray and is a function of the "screen depth" like the number of bits used to represent the shade of a pixel (bit depth or bits per pixel) [4, 10].

The screen is good to have a depth of 12 bits, i.e., to be able to display 4096 (212) instead of 256 shades of gray in the images produced and to have increased contrast resolution as well as allows the dentist to use if he wants special programs advanced diagnostics such as for caries etc [7].

Ideally the screen dentists use to view radiographs, should correspond to the diagnostic screens used by radiologists when they view radiographic images. This is because the dentist must have the same criteria as doctors, since it is thim, who sets the radiographic diagnosis (plays the role of the patient's radiologist). The differences between medical screens and conventional screens are that special medical screens give a maximum brightness of 600–900 cd/m^2 as opposed to the good conventional screens on the market which give only about 235 cd/m^2 [11–14].

Finally, in relation to the screens it should be noted that the special medical screens are available in the market while there are also dual performance screens where it can be adjusted with a scale for the diagnostic display and a second scale for the patient data and other data.

Also, the elements of the existing lighting of the room where the image is projected are particularly important.

The basic combinations that the dentist should know are the following three: [15–17].

- Bright screen and low room lighting give us a high-quality diagnostic result.
- Bright screen and medium power room lighting gives us a lower quality diagnostic result.
- Bright screen and high-power room lighting gives us a low quality diagnostic result.

2.5 Types of Dental Digital X-Ray

Direct digital detectors are CCD (Charge Coupled Device) and CMOS (Complementary Metal-oxide Semiconductors) where the receptor is connected to the computer directly, and and there is an image produced simultaneously [18, 19].

Indirect digital systems are PSP (Photostimulable Phosphor) also known as SPS (Storage Phosphor Systems) where the image must be "scanned digitally to be dispayed" and there is a small time difference from receiving the image and presenting it on the screen (closer as a technique to conventional intraoral X-ray) [1, 20–24].

As for direct digital systems, CMOS technology is newer technology than CCD and both have been in the market since 1967, although CMOS were introduced into dental X-rays only in recent years by Trophy and Schick [12, 20, 25, 26].

CCD receptors are generally considered better for dental radiology while CMOS are still under research [27].

In general, CCD receptors have a better light response with the X-ray photons used for this, they are more efficient than CMOS, but CMOS receptors have a better "optical" package (microfiches and scintillators) with similar efficiencies, although this makes them more expensive [28, 29].

CMOS sockets are the basis of video operation and are the same as silicon-based CCD semiconductors but differ in the way the pixel is read since in CMOS each pixel is isolated from the neighbors and directly connected to the transducer [30].

The key features of digital receivers are:

- Contrast resolution,
- Spatial resolution,
- Detector latitude,
- Detector sensitivity.

Contrast analysis is the ability to distinguish different optical frequencies in the radiographic image.

It is a function of the following factors:

- The effect of tissue weakening characteristics depicted.
- The ability of the receptor to distinguish differences in the number of X-ray protons coming from different parts of the object being irradiated.
- The ability of the computer screen to show differences in density.
- The ability of the observer to recognize the differences presented on the screen by the system.

The receptors receive the data at 8- or 16-bit depth, and thus theoretically receive 256 [1] or 65,536 (216) different shades of gray, respectively, although the exact number of shades they cover is limited by inaccuracies in image capture (noise) [4, 31–34]. Respectively, the conventional screens where the images are projected can only display 256 tones of gray and are usually 8 bit images [3].

Spatial resolution is the ability to discern detail (resolution). A theoretical limitation in digital imaging is the function of the pixel size of the image measured in line pairs per millimeter [4, 5]. Theoretically the image analysis is based on the size of the pixels only, not taking into account the data loss due to diffusion from the scintillator, and the electronic systems of the receptor. At the highest CCD resolution, 20 μm per pixel have been measured corresponding to a ratio of 8 μm Ag grain. At these receptors, 20 μm per pixel gives a theoretical resolution of 25 pairs of lines per millimeter [5]. So because the human eye can distinguish 6 pairs of lines per millimeter most digital systems perform very well (more than 7 pairs of lines per millimeter).

The limitations of digital image resolution become visible and apparent when an image is magnified (often in cases over ten) where at very large magnifications a square image corresponding to the "pixel" image of the image is observed.

In such cases of very large magnification of the image it has been observed that we do not have a diagnostic improvement but often the observer dentist may have more difficulty in diagnosis [9].

Receptor amplitude is the ability of a receptor to receive a range of radon photon energy, which clinically varies from the gums to the enamel and allows slight variations in radius permeability to be apparent in the image.

Receptor sensitivity is the ability to respond to small amounts of radiation. In conventional tiles this has been categorized based on the velocity system of the tile (A to F) according to criteria of the International Organization of Standardization (International Organization of Standardization) while the extra film has a corresponding classification based on the Kodak system while there is no corresponding classification for digital receptors [35].

2.6 Image Manipulation

Digital image processing is called whichever function improves, analyzes or modifies the original image in any way.

Some of those image modifications and enhancements are included in the image acquisition by the manufacturers, but are not all known to the user since as in many programs, they are often fixed functions of the machine operating programs. Still others are controlled by the program user in order to improve the image and analyze its content.

2.7 Image Restoration

The image is restored because in many cases the original data is not ready for storage or presentation. This often requires a series of pre-processing steps to be displayed on the computer screen. These steps are programmed by the manufacturers and are NOT changed or modified. However, it is necessary to correct the image from known defects (defective pixels) as well as to improve the image for optimal presentation [36].

2.8 Saving the Image

The image is stored in sizes from 200 KB for intraoral X-rays to about 6 MB for high-resolution panoramic X-rays. Although storage is becoming more and more economical nowadays, in many cases it needs to be compressed.

The image is compressed without the loss of image elements in the format (TIFF/JPEG) for compression up to 3:1 and in CBCT files (conical beam computed tomography) which are automatically saved by compression without loss of data [2]. The image is compressed with data loss in cases where the files are in JPEG format and are not in the original desired format [37].

However, the evidence for image compression in dentistry is insufficient as there are currently only few literature with the first from Eraso that showed that compression of the original image at a final rate of 2% had to be made to have significant loss of diagnostic data and the detection of peripheral lesions [38]. For this reason and until there are sufficient studies regarding the images compression, it is best to keep all the image files in their original form or in a form that does not have compression or possible loss of the elements of the original image.

2.9 Advantages of Digital Radiography

Digital X-ray has several advantages which are mentioned by Farman and Farman [39, 40] in the files of the American Society of Maxillofacial Diagnosis and are as follows:

- Immediacy in image production, resulting in better ergonomics (for CCD and CMOS sensors) [41].
- The presentation of the image on the computer helps the patient to understand the disease.
- Ease of storing images and archiving them.
- Ease of making copies where necessary.
- The simplification of the measurements required mainly for endodontics.
- There are no chemicals or other materials in the doctor's office.
- Ability to communicate with colleagues and discuss the diagnosis.
- The low radiation dose.

2.10 Disadvantages of Digital Radiography

The main disadvantages of intraoral digital radiography are as follows:

- The lack of knowledge of the programs by the staff and lack of familiarity with the sensors which may result to multiple repetitions in the production of the images.
- The technique of digital radiography has low sensitivity in cases where the patient is irradiated more than he should be (although it is not easy

since many radiological machines now have a choice of digital or non-digital image) [42].

- When the image is printed on plain paper diagnostically there may be loss of original image info.
- It is possible to modify and edit the image so that digital images are not accepted as evidence.
- This in the future can be solved as a problem with techniques such as in medical radiological files where after the image is entered in the program it is not possible to process the image.

2.11 Conclusions

In conclusion, we can say that technology is evolving rapidly, and the dentist must monitor it.

Sensors must be capable of producing high-resolution X-rays with radiation doses lower than conventional films, the time required to produce the image should be less than that required with conventional films, and the images stored in safe and accurate formats. Files that have no data loss. Dentists must emphasize not only the purely radiological part of the machine but also the image taken and the screen on which it is projected.

References

1. Huda W, Rill LN, Benn DK, et al. Comparison of a photo stimulable phosphor system with film for dental radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1997;83(6):725–31.
2. Frederiksen NL. Specialized radiographic techniques. In: Pharoah MJ, White SC, editors. Oral radiology principles and interpretation. 4th ed. St. Louis: Mosby; 2000. p. 223–4.
3. Fifadara DH, Averbukh A, Channin DS, Badano A. Effect of viewing angle on luminance and contrast for a five-million-pixel monochrome display and a nine-million-pixel color liquid crystal display. J Digit Imaging. 2004;17(4):264–70.
4. Fetterly KA, Blume HR, Flynn MJ, Samei E. Introduction to grayscale calibration and related aspects of medical imaging grade liquid crystal displays. J Digit Imaging. 2008;21(2):193–207.
5. Bushong SC. Radiologic science for thecnologists: physics, biology, and protection. 7th ed. St. Louis: CV Mosby; 2001. p. 374.
6. van der Stelt PF. Principles of digital imaging. Miles DA. Applications of digital imaging modalities for dentistry. 2000;44(2):237–248.
7. Sim L, Manthey K, Stuckey S. Comparison of performance of computer display monitors for radiological diagnosis; "diagnostic" high brightness monochrome LCD, 3MP vs "clinical review" colour LCD, 2MP. Australas Phys Eng Sci Med. 2007;30(2):101–4.
8. Abreu M Jr, Tyndall DA, Ludlow JB. Detection of caries with conventional digital imaging and tuned aperture computed tomography using CRT monitor and laptop displays. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1999;88(2):234–8.
9. Krupinski EA, Roehrig H, Dallas W, Fan J. Differential use of image enhancement techniques by experienced and inexperienced observers. J Digit Imaging. 2005;18(4):311–5.
10. Heo MS, Choi DH, Benavides E, Huh KH, Yi WJ, Lee SS, Choi SC. Effect of bit depth and kVp of digital radiography for detection of subtle differences. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;108(2):278–83.
11. Ludlow JB, Abreu M Jr. Performance of film, desktop monitor and laptop displays in caries detection. Dentomaxillofac Radiol. 1999;28(1):26–30.
12. Lacević A, Vranić E, Bosn J. Different digital imaging techniques in dental practice. Basic Med Sci. 2004;4(2):37–40.
13. Park CM, Lee HJ, Goo JM, Han DH, Kim JH, Lim KY, Kim SH, Kang JJ, Kim KG, Lee CH, Chun EJ, Im JG. Comparison of observer performance on soft-copy reading of digital chest radiographs: high resolution liquid-crystal display monitors versus cathode-ray tube monitors. Eur J Radiol. 2008;66(1):13–8.
14. Liang H, Park S, Gallas BD, Myers KJ, Badano A. Image browsing in slow medical liquid crystal displays. Acad Radiol. 2008;15(3):370–82.
15. Langer S, Fetterly K, Mandrekar J, Harmsen S, Bartholmai B, Patton C, Bishop A, McCannel C. ROC study of four LCD displays under typical medical center lighting conditions. J Digit Imaging. 2006;19(1):30–40.
16. Geijer H, Geijer M, Forsberg L, Kheddache S, Sund P. Comparison of color LCD and medical-grade monochrome LCD displays in diagnostic radiology. J Digit Imaging. 2007;20(2):114–21.
17. Krupinski E, Roehrig H, Furukawa T. Influence of film and monitor display luminance on observer performance and visual search. Acad Radiol. 1999;6(7):411–8.
18. Sanderink GC, Miles DA. Intraoral detectors CCD, CMOS, TFT, and other devices. Dent Clin N Am. 2000;44(2):249–55.
19. Paurazas SB, Geist JR, Pink FE, Hoen MM, Steiman HR. Comparison of diagnostic accuracy of digital imaging by using CCD and CMOS-APS sensors with E-speed film in the detection of periapical bony lesions. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2000;89(3):356–62.

20. Gröndahl HG. New radiographic imaging technologies: a challenge for the dental profession. Oral Surg Oral Med Oral Pathol. 1994;77(5):437.
21. Borg E. Some characteristics of solid-state and photostimulable phosphor detectors for intra-oral radiography. Swed Dent J Suppl. 2000;139:i–viii:1–67.
22. Svanaes DB, Møystad A, Sisnes S, et al. Intraoral storage phosphor radiography for approximal caries detection and effect of image magnification: comparison with conventional radiography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1996 Jul;82(1):94–100.
23. Cederberg RA, Tidwell E, Frederiksen NL, et al. Endodontic working length assessment: comparison of storage phosphor digital imaging and radiographic film. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998;85(3):325–8.
24. Benediktsdottir IS, Hintze H, Petersen JK, Wenzel A. Image quality of two solid-state and three photostimulable phosphor plate digital panoramic systems, and treatment planning of mandibular third molar removal. Dentomaxillofac Radiol. 2003;32:39–44.
25. Mouyen M, Benz C, Sonnabend E, et al. Presentations and physical evaluation of RadioVisioGraphy. Oral Surg Oral Med Oral Pathol. 1989;68(2):238–42.
26. Williams CP. Digital radiography sensors: CCD, CMOS, and PSP. Pract Proced Aesthet Dent. 2001;13(5):395–6.
27. Wallace JA, Nair MK, Colaco MF, et al. A comparative evaluation of the diagnostic efficacy of film and digital sensors for detection of simulated periapical lesions. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2001;92(1):93–7.
28. Kitagawa H, Scheetz JP, Farman AG. Comparison of complementary metal oxide semiconductor and charge-coupled device intraoral X-ray detectors using subjective image quality. Dentomaxillofac Radiol. 2003;32:408–11.
29. Tsau JN, Mupparapu M. Reliability of CCD and CMOS (APS) digital sensors compared with D and E-plus-speed films in the detection of dental pathology: an in vitro study. Penn Dent J (Phila). 2001;101:10–1.
30. Hellén-Halme K, Rohlin M, Petersson A. Dental digital radiography: a survey of quality aspects. Swed Dent J. 2005;29(2):81–7.
31. Samei E, Ranger NT, Delong DM. A comparative contrast-detail study of five medical displays. Med Phys. 2008;35(4):1358–64.
32. Samei E, Wright SL. Viewing angle performance of medical liquid crystal displays. Med Phys. 2006;33(3):645–54.
33. Saunders RS Jr, Samei E. Resolution and noise measurements of five CRT and LCD medical displays. Med Phys. 2006;33(2):308–19.
34. Schulze D, Rother UJ, Fuhrmann AW, Tietke M. A comparison of two intraoral CCD sensor systems in terms of image quality and interobserver agreement. Int J Comput Dent. 2003;6:141–50.
35. Nair MK, Nair UP. An in-vitro evaluation of Kodak Insight and Ektaspeed Plus film with a CMOS detector for natural proximal caries: ROC analysis. Caries Res. 2001;35(5):354–9.
36. Kimpe T. Defective pixels in medical LCD displays: problem analysis and fundamental solution. J Digit Imaging. 2006;19(1):76–84.
37. Schulze RKW, Richter A, d'Hoedt B. The effect of wavelet and discrete cosine transform compression of digital radiographs on the detection of subtle proximal caries. ROC analysis. Caries Res. 2008;42:334–9. https://doi.org/10.1159/000151328.
38. Eraso FE, Analoui M, Watson AB, Rebeschini R. Impact of lossy compression on diagnostic accuracy of radiographs for periapical lesions. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2002;93:621–5.
39. Farman AG, Farman TT. A comparison of 18 different x-ray detectors currently used in dentistry. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2005;99(4):485–9.
40. Farman AG, Farman TT. Extraoral and panoramic systems. In: Miles D, editor. Applications of dental imaging modalities in dentistry. Dent Clin N Am. 2000;44(2):257–72, v-vi.
41. Miles DA. Imaging using solid-state detectors. In: Miles DA, Van Dis ML, (Eds). Advances in dental imaging. Dent Clin N Am. 1993;37:531–40.
42. Webber RL, Messura JK. An in vivo comparison of diagnostic information obtained from tuned-aperture computed tomography and conventional dental radiographic imaging modalities. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1999;88(2):239–47.