Digital Radiography

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Any method of X-ray image formation that uses a computer to store and manipulate data is termed as "Digital Radiography".

Digital imaging offers some distinct advantages over film, but like any emerging technology, it presents with new and different challenges for the practitioner to overcome.
The first direct digital imaging system, RadioVisioGraphy (RVG), was invented by Dr. Frances Mouyens for use in dentistry and manufactured by Trophy Radiologie (Vincennes, France) in 1987.
Basic elements

1. X-ray machine
2. An electronic sensor or detector
3. An analog to digital converter
4. A computer
5. A monitor
Digital system
Principles of digital imaging:

- In digital radiography, instead of the silver halide grain the image is constructed using pixels or small light sensitive elements.

- These pixels can be a range of shades of grey depending on the exposure, and are arranged in grids and rows on the sensor, unlike the random distribution of crystals in standard film.
Fig. 30.3 Typical design of a solid-state detector, where a regular grid of square pixels (in rows and columns) is measuring incident radiation and the electric signal is transmitted by a data cable.
Digital imaging is the result of x-ray interaction with electrons in electronic sensor pixels (picture elements), conversion of analog data to digital data, computer processing, and display of the visible image on a computer screen.
Digital images are numeric and discrete in two ways:

- In terms of the spatial distribution of the picture elements (pixels) and
- In terms of different shades of gray of its pixels.
At each pixel of an electronic detector, the absorption of X-rays generates a small voltage.

More x-rays generate higher voltage and vice versa.

At each pixel, the voltage can fluctuate between a minimum and maximum value and is therefore an analog signal.
Analog to digital conversion (ADC).

- ADC consists of two steps: sampling and quantization.

- **Sampling** means that small ranges of voltage values are grouped together as a single value. Once sampled, the signal is quantized, which means that every sampled signal is assigned a value.
These values are stored in the computer and represent the image. In order for the clinician to see the image, the computer organizes the pixels in their proper locations and gives them a shade of gray that corresponds to the number that was assigned during the quantization step.
FIG. 12-1 The digital image is made up of a large number of discrete picture elements (pixels). Their size is so small that the image appears smooth at normal magnification. The location of each pixel is determined by a coordinate system.
Three Methods to Obtain a Digital Image Currently Exist

- **Direct Digital Imaging**: Here a sensor is placed in the patient's mouth and exposed to radiation. The sensor captures the radiographic image and then transmits the image to a computer monitor, and within seconds the image appears on the computer screen.
Digital system

Diagram showing a digital system with components such as an X-ray machine, sensor, film processor, computer, laser scanner, storage, and printout.
- **Indirect Digital Imaging:** X-ray film is digitized using a CCD camera, and then displays it on the computer monitor.

- **Storage Phosphor Imaging:**
  - records diagnostic data on the plates following exposure to the X-ray source
  - and uses a high speed scanner to convert the information to electronic files which can be displayed on the computer screen.
Fig. 30.4 After X-ray exposure, a storage phosphor plate is placed in a laser scanning device, where the plate is scanned line by line by a thin laser beam. This procedure results in light emission from those crystals, that had been excited by X-radiation energy. The light is captured by a ccd camera, the signal amplified and transferred to the computer.
SENSORS

1. Charged couple device - CCD
2. Complementary metal oxide semiconductor - CMOS
3. Charge injector device - CID
4. Storage phosphor plate - SPP or Photostimulable phosphor plate - PPP/PSP
FILM & SENSORS
Fig. 30.2 Two solid-state ccd-receptors on the left side versus a storage phosphor plate on the right. All receptors represent typical intraoral detector sizes.
Digital Detectors

CHARGE-COUPLED DEVICE (CCD)

- The charge-coupled device (CCD) was the first direct digital image receptor to be adapted for intraoral imaging and was introduced to dentistry in 1987.
- Uses a thin wafer of silicon as the basis for image recording.
There are two types of digital sensor array designs.

- **Area arrays** - are used in intraoral radiography (Sizes-0,1,2)
  - **Fiberoptically coupled sensors** - Gadolinium oxybromide and cesium iodide
  - **Direct sensors**

- **Linear arrays** - are used in extraoral radiography (panoramic and cephalometric imaging)
Basic structure of the CCD
When exposed to radiation, the covalent bonds between silicon atoms are broken, producing electron-hole pairs.

The number of electron-hole pairs that are formed is proportional to the amount of exposure that an area receives.
FIG. 12-5  A, Outer shells of the silicon atom showing an energy difference between the valence band and the conduction band. B, X-ray or light photons impart energy to valence electrons, releasing them into the conduction band. This generates an “electron-hole” charge pair.
Region of maximum potential
The image is read by transferring each row of pixel charges from one pixel to the next in a "bucket brigade" fashion.

As a charge reaches the end of its row, it is transferred to a readout amplifier and transmitted as a voltage to the analog-to-digital converter located within or connected to the computer.

Voltages from each pixel are sampled and assigned a numerical value representing a gray level. The silicon matrix and its associated readout and amplifying electronics are enclosed within a plastic housing to protect them from the oral environment.
Fig. 17.1: Scheme of direct digital image acquisition using two types of CCD-based systems.
Most detectors incorporate an electronic cable to transfer data to the ADC.

One manufacturer has produced a system that replaces the cable connection with a microwave transmitter. This frees the detector from a direct tether to the computer, but it necessitates some additional electronic components, thus increasing the overall bulk of the sensor.
These detectors are silicon-based semiconductors but are fundamentally different from CCDs in the way that pixel charges are read.

Each pixel is isolated from its neighboring pixels and is directly connected to a transistor. Like the CCD, electron hole pairs are generated within the pixel in proportion to the amount of x-ray energy that is absorbed.
This charge is transferred to the transistor as a small voltage. The voltage in each transistor can be addressed separately, read by the frame grabber, and then stored and displayed as a digital gray value.
**Charge Injection Device (CID):**

- *Charge Injection Device (CID):* is another sensor technology, structurally it is very much like the CCD, but in this case no computer is required to process the images.

- This system consists of a CID X-ray sensor, cord and plug that can be inserted into the light source on the camera platform, digital images are seen on the system monitor within seconds.

- The CID sensor uses the same docking platform as the intraoral camera. The image can be printed with a color video printer and saved as a computer file or onto a video desk recorder.
Photostimulable Phosphor Plates (PSP)

- The photostimulator phosphor used for radiographic imaging is Europium doped, barium fluorohalide. Barium in combination with iodine, chlorine, or bromine forms a crystal lattice.
These absorb and store energy from X-rays and then release this energy as light (phosphorescence) when stimulated by other light of appropriate wavelength.
When exposed to radiation, valence electrons in Europium can absorb energy and move into the conduction band.

These electrons migrate to nearby halogen vacancies in the fluorohalide lattice and may become trapped there in a metastable state.
While in this state the number of trapped electrons is proportional to X-ray exposure and represents a latent image.
When stimulated by red light of around 600 nm, the barium fluorohalide releases trapped electrons to the conduction band.

When an electron returns to the Europium ion, energy is released in the green spectrum between 300 and 500 nm.
Fiberoptics conduct light from PSP plate to a photomultiplier tube, which converts light into electrical energy.

A red filter at the photomultiplier tube selectively removes the stimulating light, and the remaining green light is detected and converted to a varying voltage.
The variation in the voltage output from the photomultiplier tube corresponds to variations in stimulated light intensity from the latent image.

The voltage signal is quantified by an analog-to-digital converter and stored and displayed as a digital image.

PSP plates are made in sizes similar to intraoral films, and sizes commonly used for panoramic and cephalometric imaging.
Before PSP is used the plates must be erased to eliminate 'ghost images' from prior exposures.

Following exposure, plates should be processed as soon as possible, as the trapped electrons are spontaneously released over a period of time.

The latent image can be read by:
- Stationary plate scans
- Rotating plate scans
The active (tube side) surface of the plate (left) and plate placed in the infection control pouch (right). The plate is oriented with the tube side against the black (opaque) side of the pouch to limit exposure of the active side of the plate to ambient light.
Storage phosphor sensors
The drum on which storage phosphor plates are clipped. The drum is inserted into the scanner and the lid is closed before scanning.
Storage phosphor plates are inserted at the top of the scanner (top arrow) and ejected (bottom arrow) after scanning is complete.
Flat Panel Detectors

- These provide a relatively large matrix areas with pixel sizes less than 100 microns.

- This allows direct digital imaging of larger areas of the body, including the head. These are of two types: Indirect detectors that are sensitive to visible light, and an intensifying screen is used to convert X-ray photons to light.

- Direct detectors which used a photoconductor material (selenium) with properties similar to silicon and a higher atomic number that permits more efficient absorption of X-rays.
Digital detector characteristics

- Contrast resolution
- Spatial resolution
- Detector latitude
- Detector sensitivity
- **Contrast resolution** - is ability to distinguish different densities in radiographic image.

- **Spatial resolution** - is for distinguishing fine detail. The theoretical limit of resolution is function of picture element (pixel) size for digital imaging system. Currently, the highest resolution CCD detector for dentistry have pixel sizes of approx 20 microns. Current digital systems are capable of providing more than 71p/mm of resolution.
- **Detector latitude** - The ability of a detector to capture a range of x-ray exposure is termed latitude. The latitude of CCD and CMOS detectors is similar to film. PSP have larger latitude.

- **Detector sensitivity** - is its ability to respond to small amount of radiation. It depends upon detector efficiency, pixel size, system noise.
Current PSP systems for intraoral imaging allow dose reductions of about 50% in comparison with F-speed film. High resolution CCD and CMOS systems achieve less dose reduction than lower resolution PSP systems.

CCD and PSP systems for extra-oral imaging require exposures similar to those needed for 200-speed screen-film systems.
Digital Image Display

- Cathode Ray Tube (CRT) which are used in conventional computer monitors.

- Thin Film Transistor (TFT) is used in laptop and flat panel computer displays.
The image may be:

- i. Stored permanently in the computer.
- ii. Printed on a hard copy for patient record.
  a. Film printer.
  b. Paper printer.
- iii. Transmitted electronically to insurance companies or referring dental specialists.
Display & print out of image
The computer offers Split screen technology: which allows the operator to view and compare multiple images on the same screen. This helps in the comparison and evaluation of disease progression and treatment results.
Digital image processing operations can be grouped into five fundamental classes:

- Restoration
- Image enhancement
- Analysis
- Compression
- synthesis.
i. **Image restoration**: defects in the raw data received are corrected before the image becomes visible on screen.
ii. Image enhancement:

Most image enhancement operations are applied to make the image visually more appealing. This is done by adjusting the:

a. **Brightness and contrast**;

   - Digital radiographs do not always effectively utilize the full range of available gray values. They can be relatively dark or light, and they can show too much contrast in certain areas or not enough.

   - This can be modified by changing the display of the image without changing the image.
b) Sharpening and smoothing.

- The purpose of sharpening and smoothing filters is to improve image quality by removing blur or noise.

- Noise is often categorized as high-frequency noise (speckling) or low-frequency noise (gradual intensity changes).

- Filters that smooth an image are sometimes called *despeckling filters* because they remove high-frequency noise.

- Filters that sharpen an image either remove low-frequency noise or enhance boundaries between regions with different intensities (edge enhancement).
### c. Color-

- Most digital systems currently on the market provide opportunities for color conversion of gray scale images, also called *pseudo-color*.
d) Digital Subtraction Radiography (DSR):

- This is a specialized digital technique in which two digital radiographic images (with an interval) of the same region made by standardized method are made & then the two images are superimposed.

- Special software is used to subtract the regions that are unchanged and thereby highlighting those regions where there is a difference.

- With conventional radiography it is impossible to detect an 0.85 mm changed in cortical bone thickness but DSR is so sensitive it can detect 0.12 mm change.

- DSR can be used in periodontal and carious lesions. For evaluation of small changes in mandibular condyle position and integrity of the articular surface and for assessment of osseous remodeling around granular hydroxyapatite implants.
Digital Subtraction Radiography (DSR):

The subtraction of Figures 1a and b reveals areas of bone loss in black (black arrow) and bone deposition in white (white arrows).

After extraction

1 month later

subtraction of Figures 1a and b reveals areas of bone loss in black (black arrow) and bone deposition in white (white arrows).
iii. Image analysis:

These operations are designed to extract nonpictorial information from image that is diagnostically relevant.

- **Magnification**, this allows better viewing and linear and angular measurements can also be obtained, e.g. for measuring root length.
Magnification
FIG. 12-15  Example of a measurement tool to determine the length of the crown and mesiobuccal root of the first molar. The measurement has been calibrated for a magnification factor of 1.05x. The digital measurement tool is more versatile than the analog ruler; however, for both types of measurement tools, the apparent length remains dependent on the projection geometry.
iv. **Image Compression:**

Here the image is compressed by reducing the number of digital image files for storage or transmission.

- **Lossless methods** do not discard any image data, and an exact copy of the image is reproduced after decompression.

- **Lossy compression** methods achieve higher levels of compression by discarding image data.
Version 3.0 of the DICOM (Digital Imaging and Communications in Medicine) standard adopted JPEG (Joint Photographic Experts Group) as the compression method, which provides a range of compression levels.
v. Image Synthesis:

- Synthesizing new images based upon image data acquired from multiple projections.

- The purpose of these modalities is to access information about the object of interest in three dimensions.

- CT, MRI and Positron Emission Tomography Scanners are amongst the most well known and sophisticated image synthesizers for maxillofacial imaging.
Digital imaging is used in several techniques:

- Intraoral radiography
- Panoramic radiography
- Cephalometry
- C.T.
- MRI
Other Clinical Applications besides Radiographic Imaging

1. *Microscopic Imaging*

Medical grade single frame digital cameras are available which may be attached to dental microscopes, and produce high quality images.

2. *Intraoral Cameras*

- These are dental cameras that can photograph a single tooth, a group of teeth or a patient's full face.
Intraoral Cameras
3. Fiberoptic Imaging

- Fiberoptic endoscopes specifically for use in the oral cavity, to view the root canals. This consists of a 0.7 mm and 11.8 mm diameter light fiberoptic probe, the former can be inserted into the root canal for internal viewing.

4. Digital Photography

- Inexpensive and records the images with a high degree of accuracy. These have a better resolution, accurate color values and no occurrence of ghosting or distortion.
Advantages

- Reduced exposure to X-radiation—may be reduced by 50-90% per intraoral exposure.

- Increased speed or faster image acquisition

- Enhancement of diagnostic image

- Image reconstruction—Digital images may be reconstructed to provide insight into the anatomy of internal structures, display cross-sectional views, and produce multi-dimensional views.
- Image storage-Paperless file
- Effective patient education tool
- Environmental friendly
- Teleradiography
Disadvantages

- Initial set-up is costly.
- Image quality
- Fragility of sensors
- Wire attached to sensor
- Sensor size-these are thicker and rigid than intraoral films and therefore not patient compliant.
- Infection control, the sensor has to be covered adequately in a disposable plastic wrapper.

- Legal issues, because the original digital image can be manipulated, it is debatable whether digital radiographs can be used as evidence in lawsuits.
Conclusion

- DR is an excellent alternative to film-based radiography and continues to grow in popularity.

- Images can be taken, immediately examined, deleted, corrected, and subsequently sent to a network of computers.

- The benefits from digital radiology are enormous. It can make the facility filmless.

- The referring physician can view the requested image on a desktop personal computer, often with the report, just minutes after the examination was performed.
The images are no longer held in a single location; they can be seen simultaneously by physicians who are kilometres apart.

In addition, the patient can have all his or her X rays on a compact disk to take to another physician or hospital.

Thus digital radiography will soon become a standard in dentistry as well as in medical radiology.
References


THANK-YOU