Clinical Update

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**Dental Imaging - advances in conventional and digital radiography**

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**Introduction**

Digital dental radiography was introduced in 1987, and many thought this technology would quickly take over as the standard in dental radiology. However, this has not been the case as only 7% to 8% of dental professionals currently use digital imaging systems (1). Many dentists have been resistant to change as the diagnostic quality of digital radiography has been questionable when compared to conventional film. The purpose of this *Clinical Update* is to review the advances made in both conventional and digital dental imaging and discuss the future of this technology in military dentistry.

**Kodak Insight (a new F-speed dental film)**

Technological advancement of conventional dental film is aimed at producing faster films without sacrificing the image quality of radiographs, so that the amount of x-radiation to which patients are exposed is reduced. Eastman Kodak has lead the way with improvements in conventional dental film technology. When Kodak produced its current version of D-speed film (Ultra-speed) in 1955, it became the "gold standard" to which all subsequent films and digital technology has been compared.

In 1981, Kodak introduced Ektaspeed film (E-speed film), which promised to reduce radiation exposure to patients by 50% compared to Ultra-speed film, but gained limited clinical acceptance because of poor image quality. Kodak refined their technology and launched Ektaspeed Plus film to replace Ektaspeed in 1994. Ektaspeed Plus introduced a new T-mat film emulsion, which uses light-sensitive silver halide grains that are flat rather than pebble-shaped and oriented to face the x-ray beam in a perpendicular fashion. T-Mat technology has purportedly not only improved the image resolution but also increased the light-gathering ability, or speed, of Ektaspeed Plus (2).

In April of 2000, Eastman Kodak announced the introduction of InSight, classified as an F-speed intraoral film when processed in roller-transport automatic dental processors. This film builds on the existing emulsion technology used for Ektaspeed Plus film, as the same T-grain emulsion is refined with an optimum amount and size of silver grains, so as not to degrade image sharpness (3). The manufacturer claims that this new film requires 60% less exposure time than Ultra-speed film and 20% less than Ektaspeed Plus.

In 2001, Kodak discontinued the production of Ektaspeed Plus film due to the reported success of Insight, and the film is no longer available for purchase. Kodak's discontinuance of Ektaspeed Plus may signify that the new film has gained quick acceptance, or perhaps is simply a business decision.

**Comparison of Kodak InSight to D and E-speed film**

Initial research reports have demonstrated that Kodak InSight performs well in comparison to D and E-speed dental films. A test of image resolution showed all three film types were able to resolve at least 20 line-pairs per millimeter. InSight film was also shown to provide stable image characteristics in depleted processing solutions (up to 5 days of heavy use), and is more resistant than Ektaspeed Plus to decreases in film speed when processed in used chemicals (4). Clinical investigations revealed that Insight was comparable to Ultra-speed and Ektaspeed Plus films for the detection of caries (3) and endodontic file length (5) measurements. These are promising initial results, but in subjective assessments of image quality, researchers (4,5) have noted Insight appears grainier than the other films. At this point, it is still unclear whether clinicians will choose InSight over D-speed film.

**Technological advances in digital radiography**

There are currently three types of digital radiography systems available for the use in dental imaging: 1) CCD - Charge-Coupled Device (direct system), 2) CMOS – Complementary Metal Oxide Semiconductor (direct system), and 3) PSP - photostimulable phosphor (indirect system). The manufacturers of digital dental imaging are dynamic and continuously changing as the dental profession has been slow to accept this technology.

A few manufacturers have recently utilized CMOS technology in direct digital sensors. The clinical images acquired by CCD and CMOS receptors are not very different. The receptor construction and transfer of the charge detected to the computer, however, is very different. Both direct sensor systems use a scintillator coating, made of silicon, on the surface of the sensor to capture the x-ray photons exiting the patient's tissues. When an x-ray photon strikes the scintillator, it breaks a covalent bond on the silicon, releasing an electron. One electron is released for every x-ray photon striking the silicon. The electron then travels to an area called the electron well (positively charged), which is actually an individual pixel. Here the electrons are stored until the exposure is finished (6). It is at this point where the CCD and CMOS systems differ in the processing of the image.

In a CCD sensor, the charge or electric signal is read by transferring the collected charge in each pixel, in a serial fashion to a readout amplifier. The same photon-generated charge collected at each pixel site is transferred (coupled) pixel by pixel (similar to a *bucket brigade*) in a predesigned sequence that cannot be interrupted. When the pixel charge is transferred to the readout amplifier, it is destroyed. Next, the output from the CCD is digitized. A special hardware converter (analog-to-digital converter [ADC]), separate from the sensor, then takes the voltages generated by the individual elements of the CCD and rounds them off into the number of alternative values to be used to represent the image digitally (7).

With a CMOS receptor, the electrons still gather in pixel areas, but their strength is amplified at each pixel and the electronics allow each pixel to be addressed or read out individually with no charge–transfer process as in the CCD (6). CMOS sensors also permit the integration of control circuitry, including the analog-to-digital converter (ADC), directly into the sensor. The major advantages of CMOS technology are design integration, low power, manufacturability, and lower cost. The Schick CDR sensor (Schick Technologies, Long Island, NY) is an example of the application of this newer technology (7).

One notable advancement in recent years with direct digital sensor systems has been an increase in image resolution. Direct digital sensors are arranged in a grid or rectangle. The more sensors, or pixels, that are packed into the grid, the better the quality of the image that is captured. The limited number of pixels that can be grouped together in the CCD or CMOS sensor restricts the digital image resolution. As a result, the spatial and gray-scale resolution often do not exceed the accuracy of conventional film-based images. Developments in direct digital systems have overcome this restriction of limited numbers of pixels. Recently, sensors have been introduced with pixel sizes of approximately 20 µm, replacing existing sensors with pixel sizes of 45 to 70 µm (7). For comparison, storage-phosphor plates have a typical pixel size of about 60 to 70 µm (8).

Image resolution is an important concept, especially because it allows for a comparative measure between conventional and digital images. Resolution is typically evaluated by a line-pair test tool, which is expressed in terms of distinguishing line pairs per millimeter (lp/mm).

However, maximum resolution is not only determined by the spatial density of the pixels in the detector, but is also a function of the various optical, electronic, and display properties of the system(9).

With all this discussion about improvements in image resolution, what is the need for higher resolution? Practitioners will not be able to discern 12 lp/mm with the naked eye, and no scientific study has shown that higher spatial resolution is needed for any tasks involving oral and maxillofacial radiology (10). A list of several manufacturers of dental digital imaging systems is provided as a reference to compare the theoretical resolution capabilities of these current systems. Note, conventional dental film produces images with a resolution of >20 lp/mm.

| Manufacturer | Product Name | Sensor Type | Pixel Size (mm)* | Resolution (lp/mm)** |
|---|---|---|---|---|
| Dexis Corporation | DEXIS | CCD | NR | >10 |
| Planmeca | Dixi2 | CCD | 19 | >20 |
| Sirona | Sidexis | CCD | 19.5 | >20 |
| The Trophy Group | RVGui | CCD | 19.5 | >20 |
| Dent-X Corporation | EVA | CMOS | 30 | 16 |
| Schick Technologies | CDR | CMOS | 40 | 12.5 |
| Dentsply Gendex | DenOptix | PSP | 60-70 | 6-8 |
| Soredex | Digora | PSP | 60-70 | 6-8 |

* As reported by the manufacturer
** Theoretical resolution derived from pixel size (resolution = 1 / 2 X pixel size)
NR = not reported by the manufacturer

The quality of digial images has been the focus of much research. Current studies show no significant differences for proximal caries detection between digital systems and conventional film (11). Digital images have also been found to be as accurate as film based images for detection of marginal bone loss in periodontal and implant patients (12). Endodontists, who have embraced this technology, suggest caution should be exercised when determining working length using small endodontic files, however, digital sensors have yielded accurate results for size 15 files and larger (13). Overall, the diagnostic accuracy of direct digital radiography is approaching, or equal to, the accuracy demonstrated by conventional dental radiography.

**Digital imaging in military dentistry**

Digital dental radiography has many attributes which makes it appealing to military dentistry. These advantages include, but are not limited to: 1) Instant image retrieval; 2) Radiation Dose Reduction; 3) Image Enhancement; 4) Teleradiology; 5) No Chemical Waste; and 6) Efficient for use in Forensic Dentistry.

One advantage of digital radiography, especially for military dentistry, is the capability of using digital images as a method for long distant consultation. In an environment where specialists are not located in every dental clinic and patients present urgent needs in remote locations, the ability to consult quickly and effectively may have a significant impact on treatment outcomes. An Air Force study evaluated the Schick CDR system as an alternative for field-use radiography (14). As a result of this successful trail, digital radiography is now being integrated in all expeditionary medical support units for future field deployments.

One disadvantage facing the military is the lack of standardization between companies manufacturing dental digital radiology equipment. Although there is no limitation on how an image can be formatted and stored, the challenge is to develop a format that can universally accommodate all diagnostic imaging data. The Digital Imaging and Communications in Medicine (DICOM) standard defines a set of communications protocols allowing the interchange of information and images from radiology equipment (15). DICOM will enable military dentistry to store/archive and utilize digital images, regardless of the type of system, and as a means of consultation across broad geographic areas.

**Summary**

The following conclusions can be made from this review:

1) Kodak Insight, a new F-speed conventional dental film, has demonstrated similar diagnostic quality to D and E-speed films, with the benefit of reducing patient x-ray exposure.

2) Technological advances in digital sensor technology has focused on improving image resolution, and many companies have produced sensors which theoretically produce images of equal resolution to conventional film; future investigations are needed to validate these claims.

3) Research has demonstrated that the diagnostic accuracy of direct digital systems is approaching, if not equivalent to, the accuracy of conventional dental radiography.

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