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FEATURE ARTICLE

Integrating digital radiography: From diagnostic input to procedure guidance

**Allan G. Farman, BDS, PhD, DSc, and
Claudio M. Levato, DDS, FACD**

Allan G. Farman, BDS, PhD, DSc

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Dr. Farman lectures internationally, has published more than 300 peer-reviewed scientific articles and proceedings and has coauthored or edited 14 books. His principal research efforts are directed to digital image acquisition, image processing, 3D imaging, image fusion, and interoperability.

Claudio M. Levato, DDS, FACD

Dr. Claudio Levato is a 1976 graduate of the University of Illinois, College of Dentistry. He is in private practice in Bloomington, IL, and has invested heavily in leading-edge technologies over the past 30 years, spanning four computer systems and transitioning different operating systems to create a fully integrated digital patient record.

The decision to invest in digital radiographic procedures should be a simple one for all dental practitioners to make. Even the earliest solid-state digital systems for intraoral radiography, released to the market some 15 years ago, proved to be equal to analog film radiographs. This was shown for detecting such conditions as dental caries and periodontal bone loss and for the operative guidance during endodontology when using size #15 files.¹⁻⁵ These solid-state X-ray devices and their supporting computers were primitive in comparison to the matured state of computer and detector science of the present (Figure 1).

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Although the digital detector has long equaled analog film for most diagnostic tasks, it has many advantages over film radiography. The most important include the following:

- immediacy of image production with solid state devices
- interactive display on a large high-resolution screen with the ability to enhance image features and make direct measurements
- integrated storage with access to images through practice management software systems
- security of ready back-up and off-site archiving
- perfect clone duplicates to accompany referrals
- security mechanisms to identify and differentiate original from altered images
- ability to tag such information as patient identifier, date of exposure, and other relevant details

Every general dental practice as a minimum should have at least 1 or 2 intraoral digital detectors for operative imaging procedures when immediacy is important, both for the health of the patient and the comfort of the practitioner.

Various strategies can be used when deciding to go digital. The decision about which to adopt depends, to a

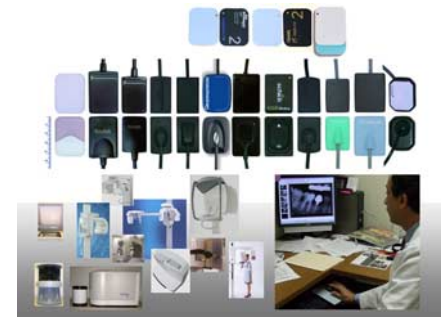


Figure 1. A sample of digital intraoral detectors compared with size #2 analog film (top), a sample of digital panoramic systems (lower left), and an endodontist using digital radiographs for case assessment (lower right).

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large extent, on the state of the imaging equipment in your existing dental office. If cost is a significant factor and you have already invested in a darkroom and processor, you might decide to initially purchase 1 or 2 digital detectors for "operative radiography" and retain film for the initial full-mouth X-ray series, panoramic, or periapicals plus bitewings. Because computer workstations are required for digital radiography, a single workstation in your primary operatory would be a stepwise introduction to implementing this technology with a limited budget. This hybrid approach has

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Figure 2. The latest models of cone-beam computed tomography (CBCT) scanners often appear similar in size and appearance to panoramic dental machines. This appearance is deceptive. CBCT provides three-dimensional imaging with isotropic volume elements, making measurement free from distortion and precise. The system illustrated here is the Imaging Science International iCAT manufactured in Hatfield, PA.

the advantage of letting you adapt to digital radiography incrementally before making a full leap into the modern digital era.^{6,7} Such a hybrid decision, however, makes less sense if you are contemplating a new facility or a major renovation of your dental office.

It is our considered opinion that most dental offices should be contemplating the integration at least of intraoral digital detectors and a digital panoramic system. These are an important backbone irrespective of your specialty. For orthodontists and maxillofacial surgeons, there is a need for images of the entire head. For them the decision involves a straight traditional replacement providing two-dimensional images compared with the three-dimensional capabilities of the growing number of

cone-beam computed tomography (CBCT) X-ray systems (Figures 2 and 3).^{F3} The latter technology is rapidly becoming the state of the art, if not yet standard of care, for such procedures as dental implantology.⁸⁻¹⁰ This does not displace the basic intraoral and panoramic systems for most dental diagnosis and treatment planning; however, referral of appropriate patients for CBCT can vastly expand the horizons of any dental practice.

This article aims to provide a pragmatic approach to modern digital imaging in current dental practice. It is based on insights gained by both authors over a period that stretches back to the pioneer devices in the early 1990s and extends forward to the latest generation of digital X-ray devices.

DIVERSITY IN DENTAL PRACTICE By practice type

All dental practices require image management, not all require the same images. The backbone for radiographic images in general dentistry is predominately intraoral with many practices also using panoramic images. If one were to look at the most extreme differences for radiographic use in dental practice, at the most narrow extreme are the endodontic practices. Endodontists have the most limited requirements, involving only intraoral images of single teeth, meaning that a single size sensor com-

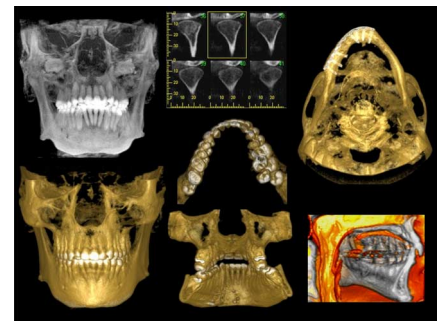


Figure 3. Representative three-dimensional cone-beam computed tomography (CBCT) reconstructions, each possible from a single low-dose 20-second imaging sequence. Multiple different reconstructions are possible with one exposure.

parable to a #1 film would suffice. The other end of the spectrum is the oral and maxillofacial radiologist whose specialty encompasses all the different mediums from intraoral to CBCT and hospital-based medical imaging systems. Oral surgeons and periodontists need both intraoral and extraoral capabilities and, with their focus on implantology, will probably be forging into the world of CBCT. Orthodontists rarely require intraoral X-rays but need both panoramic and cephalometric images; this specialty will also benefit from CBCT for evaluation of patients on occasion,

By dentist generation outlook, preference, and training

Individual bias will always be a factor in equipment selection and market segmentation. Early adaptors in dentistry have an affinity for purchasing new applications and will manage to figure out a way to implement them into their practice.^{11,12} Radiology training for most dentists has been limited, but, with the advent of digital radiology, interest seems to be renewed in the field. Because so much information and misinformation is available about this topic, it appears that the marketplace is looking for stronger and more reliable sources for digital information.

Sunk costs versus new startup

Every dental practice has already made some investment in radiographic applications. The primary motivation for most dentists is to be able to use whatever they currently own in the migration toward digital solutions. X-ray generators are usually universally adaptable, providing they have an electronic timer, and rarely are replaced unless a new facility is planned. The dilemma is the incorporation of computer workstations in the operator. The temptation to cut costs and to use a laptop and a detector to begin your journey into digital radiology, in our opinion, should be considered an interim solution at best. However, if you are an itinerant endodontist who works in multiple general practices or if you are working in remote areas that require multiple locations,

this could be your most efficient option. For the general dentist or specialist that functions in one location and has a busy ongoing practice, this would likely be an inefficient use of this technology in the long run.

The single most important benefit of digital radiology is TIME, and no matter how you calculate your practice worth, time equals money. The most efficient use of time will allow you to see more patients or do more procedures, and anything that can be delegated to properly trained staff members will leverage your ability for increased production. This single tool will dramatically change the dynamics of patient flow. For example, if you perform endodontic procedures, you can take an image as you work without leaving the patient, thus allowing you to finish the entire procedure in one seating if you prefer. You will also discover that you will probably be taking more needed radiographs in a timely manner because of the simplified process.

LEVELS OF INTEGRATION

The level of integration will depend on the desire and capability of the individual practitioner. There are four distinct choices about digital X-ray imaging integration.

1. None, staying with analog with silver halide film. The advantage is no immediate outlay of capital. The disadvantage is that you have none of the benefits of this technology.
2. Hybrid, combining the strengths of digital systems and analog film. The advantages is a decreased immediate investment. The disadvantages are decreased benefits of technology and continued costs of the analog system.
3. Fully filmless, going with digital imaging *only*. The advantages are greater ability to manage the radiographic component of the practice and the benefits of digital radiology applications. The disadvantages are the lack of a completely digital practice record, the capital costs, and the ongoing maintenance costs.
4. Fully digital, going with integrated digital practice. The advantage is an efficient and productive management of the practice.

The disadvantages are the capital costs and the ongoing maintenance costs.

LEVELS OF COMPLEXITY

It is recognized that levels of complexity are not entirely synonymous with the modality applied; however, the degree of complexity can be considered to represent the number of modalities applied and the variety of systems selected for each of these modalities. Digital imaging modalities available for dental practice currently include, but are not restricted to, the following:

- intraoral radiography
- photography
- panoramic radiography
- cephalometric radiography
- cone-beam computed tomography
- In most parts of the country, the first four modalities listed are primarily acquired by the individual or group practitioner; however, in California, where imaging laboratories are numerous, patients can be outsourced for baseline diagnostic imaging using any of these modalities. CBCT provides the third dimension that is valuable for image-guided procedures and is often provided in referral centers.

LEVELS OF SOPHISTICATION

Traditionally, with the exception of endodontology, radiographs used in dentistry are primarily diagnostic. With the increasing number of dentists placing implants, image-guidance is becoming more important. Standardized image data sets (Digital Imaging and Communications in Medicine [DICOM]) can be transmitted to specific sites for construction of implant placement guides, surgical models, and fabrication of surgical prostheses.

APPROACH TO INTEGRATION

Regardless of how one decides to approach technology integration, a plan is needed.^{13,14} For an existing practice, it is acceptable to use a gradual approach, perhaps simply starting with one detector attached to a solitary computer. This can be used for operative procedures by the dentist. This approach permits a relatively inexpensive trial of the technology and takes care of the learning curve of new technology while stimulating the



attention of the rest of the dental team. Likely, the dental team will soon demand the opportunity to follow the dentist into the new technologic era and will help plan for full-scale integration. For a new facility or an office that is to undergo complete renovation, immediate total networking is advocated. For a beginning general practice, you might consider replacing the traditional full-mouth series with a digital panoramic image plus bitewings and selected periapicals. As with any new technology, a learning period is expected when the practitioner trained with film changes to a digital system. However, in our experience, students trained using both analog film and digital X-ray systems find the latter to be the easier of the two modalities to learn.

BEFORE YOU BUY

Digital radiography is expensive. You should view the new purchase like buying a fine new automobile. Hence, you should “test drive” several systems to find which detector and software fulfill your particular needs and style of practice. The appropriate place to test drive such systems is in your own office where you can compare products in a standardized manner with images that are genuine and not preselected. It is also important to work in your own office environment to determine whether your existing X-ray generators are acceptable or should be replaced. Further, only in your own office environment can you examine ergonomics of use and plan integration.

But, let’s go back to the automobile purchase analogy. Before you even visit the dealership, you would expect to make initial inquiries. You should do the same for digital radiography purchases. First, ask your colleagues (we emphasize the plural, that is, more than one practice) their opinions based on their experiences in the local market area. It is preferable to look at practices that are similar in size and focus so that their experiences would reflect your own needs. Second, view the vendor websites and also visit dentist blogs. Un-

fortunately, most peer-reviewed scientific journals take too long to publish and are not current with the latest products. Another tip is to check the technology assistance hotline for the companies whose system you are considering purchasing to determine whether a real person (who is employed by the vendor rather than an answering service) is ready to take your call.

At this stage you are ready to progress to detailed hardware and software considerations.

HARDWARE CONSIDERATIONS

Detector type

The scientific literature shows very little difference in terms of physical image properties comparing the charge-couple device (CCD) with the complementary metal oxide semiconductor (CMOS) chips for solid-state imaging. The CMOS chip, however, requires less energy, so it is possible to connect directly to the computer by a USB connection rather than needing an additional external box. Further, CMOS technology has permitted the development of wireless detectors. However, the latter can involve the additional running cost of disposable batteries. Solid-state detectors range in cost from US\$5000 to US\$8000 each, with wireless sensors costing up to 50% more. Solid-state X-ray detectors, on exposure, provide a close to immediate radiographic image.

An alternative to solid-state technology is the photostimulable phosphor plate (PSP). The advantage of this technology is that the sizes can closely replicate those of traditional film radiographs. The disadvantages include a propensity of intraoral detectors to degrade because of scratching, the time needed to prepare and package the plates, and the time needed to laser scan the exposed plates to process the latent image. PSP is not immediate. The cost of PSP detectors varies from tens to hundreds of dollars depending on size.

Number of detectors

The number of intraoral solid-state detectors purchased should factor in the need for cold disinfection between pa-

tients, the flow of patients through your office, and the various sizes and shapes required for your patient base. You need not buy all of the detectors from a single vendor so long as the systems conform with DICOM and the images produced are interoperable.¹⁵ For PSP devices, you should factor at least twice the number of plates as your practice would use on patients in a given time slot at your practice plus additions for replacements should some be damaged during use.

Detector specifications

Beware of manufacturer’s specifications. First, make sure that any measurement is achievable rather than theoretical. Second, make sure that the specification has relevance to your practice needs. Most, if not all, current systems are adequate in terms of contrast resolution. Spatial resolution using lead resolution grids can be questioned, because no patient has a lead resolution grid in his or her mouth, and the limiting factor might be tissue contrast. Spatial resolution of high-contrast objects is perhaps only important in intraoral dentistry for depiction of fine endodontic instruments. The quality of the image is also conditioned by the signal-to-noise ratio. Very thin solid-state detectors often do not have a fiber optic to block direct impact of X-rays and so tend to be noisier than those that do have a fiber optic. The bottom line, however, is that no single measurement is likely to describe all elements of diagnostic utility. Although detective quantum efficiency has been found to be useful in judging observer performance in endodontic measurement,¹⁶ data on the detective quantum efficiency of current digital dental X-ray detectors are largely unavailable. When it comes to diagnostic quality, you might be best to trust your own eyes.

One factor that is important is exposure latitude because this has an effect on the control you have over exposure and also on the dose applied to the patient.¹⁷ Usually, PSP and CMOS detectors provide a wider latitude than do CCDs. The latter are restricted by pixel-

blooming artifact from overexposure. In most cases the narrower latitude of CCD detectors is acceptable, and the wider latitude of other detectors can simply mean that you can overexpose a patient's X-ray film and still get a diagnostic image. Do not be put off by high sensitivity. You can reduce the intensity of the X-ray beam emitted from your X-ray generator by simply adding filtration.

Detector physical connection to computer

You have a choice between wired and wireless both for solid-state technology (CMOS using radiofrequency transmission) and for PSP.^{18,19} Where a wire is used to attach the detector to the computer, ensure that the length of the wire is workable in your practice environment, but also make sure that the permitted range of a wireless radiofrequency or Bluetooth system is adequate for your purposes. If there is a wire, look at where it is attached because this can have implications for the types of exposure you can make. If you want the instant image feature of a solid-state intraoral detector and also want to make vertical bitewings, the wire should be attached at the back, otherwise attachment of the wire at one end of the detector is acceptable.

Detector sizes

Check that the range of detector sizes is acceptable during your test drive in your office with typical patients. From our experience, size #2 and #1 detectors are useful, whereas size #0 detectors are of limited use, even when used on child patients. For small mouths, cropped detector corners can be useful; however, in most patients this is not needed and does decrease the area of coverage. About the width of intraoral detectors, we find that slightly thicker solid-state detectors are easiest to place because they do not "cut" into the patient's tissues when displacing them.

Detector-positioning devices

This can be checked during your test drive. No reason exists why the positioners should be different from those

you previously used with intraoral film radiography.

Minimum and preferred computer requirements

In general, if your computer is more than a year old, it is probably worth upgrading your computer system when you invest in digital imaging. The cost of computers is so reasonable these days that you should not try to make savings on RAM, ROM, or speed. As a rule of thumb, 2 to 4 GB of RAM is optimal; unfortunately most systems are configured with less than 1 GB. CPU processor speed should be at least 3 GHz. A terabyte of storage is not excessive for your server, and mirror storage drives are desirable. In a networked environment with a dedicated server, workstations really do not need much storage capacity, so a hard drive of 100 GB is more than adequate. Make certain that the system is installed and working before you pay in full. Extra slots and USB connections are never wasted.

Storage and redundancy options

Storage need not be expensive. You can purchase a terabyte of storage for less than US\$1000. All data should be backed up both locally (mirror drives) and at a secure remote site at least 6 miles from your practice, but preferably further. You can buy services or provide the backup yourself. A simple means of backup is a removable drive that can be copied to the secure remote system on a daily basis. In a real sense, your practice is your patient data, not your physical equipment such as dental handpieces and X-ray detectors. Physical equipment can be readily replaced, but unique data need to be carefully protected.

Display selection

The physical specifications and applied settings of the display will ultimately determine the appearance of any digital image and also the image of your practice to your patients. Flat panels look modern, CRTs look antique. Flat panels are economical on space, CRTs are space inefficient. You should pur-

chase a high-resolution monitor with a wide grayscale contrast capability. Usually an upper-end non-medical-grade monitor is sufficient for administrative or nonclinical locations. In the operatory we recommend that you use medical-grade flat-plane monitors that have sealed nonglare glass fronts. This will be more consistent with your infection control protocol because they can be disinfected along with the rest of the operatory between patients.

Printer

It is not essential to have a printer as long as the practitioners and other third parties to whom you transmit the images are capable of handling digital images provided as DICOM files or in secure pdf files. The printed image is usually of lower diagnostic quality than the originally displayed image. A diagnostically acceptable low-end printer can be purchased for less than US\$400, whereas a medical-grade printer will cost ten times that amount. Less-expensive printers usually are accepted for administrative purposes such as insurance claims; however, they should not be considered diagnostic in output.

Networking

For an integrated practice a hard-wired network is preferable to a wireless network. Depending on your space requirements and accessibility, you can use a combination of both, but bear in mind that wireless applications are more susceptible to interference and are less secure. Network systems require network cards, hubs, cable, and routers if you are incorporating wireless components.

The quality of the diagnostic image ultimately depends on the weakest link in the imaging chain. This should be considered when deciding whether to upgrade the X-ray source. Units older than 10 years should be replaced, but newer units should also be replaced if the timer is incapable of making reproducible short exposure times or if image quality is considered to be suboptimal.



SOFTWARE CONSIDERATIONS

Operating system

The operating system must be compatible with the digital imaging system and also with other software to be used on the same computer or network. You need to be assured that the system will be updated to be compatible with modifications to the operating system.

File format

The American Dental Association has resolved that interoperability should be through the DICOM standard and associated means.²⁰ DICOM is an ISO Referenced Standard. Check to ensure that the system you purchase does have DICOM conformance and permits export and import of DICOM files. You would not purchase a fax machine that could only send faxes to machines from one vendor. File interoperability protects the diagnostic information of your patients and also protects your investment in digital technology. It means that you cannot be held hostage by the proprietary file formats of an individual vendor.

Ergonomics of data entry and retrieval

The system should require the minimum number of keystrokes and preliminary screens. Make sure that you and your staff members have no problems interacting with the software.

Integration with practice management software

It is preferable that your images are accessible through your practice management software. Leading practice management software systems do provide for the import of images in the DICOM format. Further, the DICOM image file tags can actually populate new patient information, saving staff time and making errors less likely to occur.

MAINTENANCE

Warranty

Digital imaging systems do represent a fairly high-cost investment. The warranty is important. Carefully read the small print to ensure that your investment will be adequately protected.

Hardware service contract

A hardware service contract is advisable. For intraoral solid-state detectors this should provide for overnight replacement. In our experience, hardware failure is unusual; however, when it does occur, immediate replacement is needed.

Software service and update contract

A software service contract, including future upgrades, is also needed and should include support when the computer operating system or your practice management software is upgraded.

As mentioned earlier, it is essential that the toll-free number for technical service is answered when you try it before purchase. Continued technical support should be part of the warranty and maintenance contract.

Established reputation is something to be considered. Several companies have been in the business of dental digital radiography for more than a decade. For companies to survive for such a time suggests that their customers are satisfied. Beware of new start-ups, excessive cost cuts for detectors, and excessively long warranties from unestablished concerns. You have to look at the company behind the sensor and will they be there for you in 5 years, 10 years, or longer. "Past performance is no guarantee of future results" is a disclaimer we have all seen in financial instruments, but it is certainly a factor in determining which company to work with.

COSTS

To access the total costs of going digital, you need to add all of the following costs:

- capital costs of hardware and software
- running costs of disposables (eg, plastic wraps for detectors, printer supplies, computer storage)
- costs of secure data backup
- maintenance costs
- initial and ongoing training costs
- You should also factor the costs that would apply if you were not to go digital. These costs can include film, processing solutions, processor maintenance, dark-room space, film mounts, and storage of

film radiographs, as well as TIME, practice prestige, and workflow ergonomics.

THE BUSINESS DECISION (DOLLARS AND COMMON SENSE)

Even at the level of diagnosis, where digital detectors simply replace traditional film, the decision to go digital makes dollars and common sense. It has been reported that digital imaging is "more than a fad, less than a revolution." This is correct only when comparing digital X-ray images against perfectly exposed and processed film radiographs in tasks in which analog film has succeeded for more than a century of use. However, such a conclusion does not take into consideration (1) that most film radiographs made in dental practice are suboptimal in exposure and processing; (2) that film processing takes time, whereas digital images can be almost instant and thereby guide treatment; and (3) that enhancements made to digital images could make possible tasks previously inadequate or impractical with film.^{21,22}

Some practitioners want to wait until the cost of detectors comes down; however, this is an unrealistic expectation. In 1990 the real cost then of a single intraoral solid-state digital dental X-ray system was approximately US\$25,000. The present cost ranges from US\$5000 to US\$8000 for a much improved detector and has stayed at that level since around 1993. Competition and decreased component costs did bring the price down initially; however, the components are quite expensive, and the dental market is much more limited in size than the general consumer market. It is unlikely that costs will decline substantially in the immediate future.

Other practitioners indicate that they will wait for three-dimensional imaging availability at an affordable price. They could wait quite a long time. Moreover, they miss the point that three-dimensional imaging is complimentary to rather than competitive with two-dimensional imaging. For other than specialists or practitioners who are extensively involved in implantology,

CBCT is probably going to remain prohibitive for purchase for the immediate future. This does not mean that you should not take part in the revolution of image guidance. It simply means that for most practitioners, referral of your patients to an imaging center is probably the wisest way to get started.

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