

Factors to consider in the transition to digital radiological imaging

Abstract: The dentist considering adopting digital radiological technology should consider more than the type of detector with which to capture the image. He/she should also consider the mode of display, image enhancement, radiation dose reduction, how the image can be stored long term, and infection control.

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Introduction

The high profile developments in oral and maxillofacial radiology (OMFR) are: digital conventional radiography (digital equivalents of existing analogue intra- and extra-oral techniques); and, cone-beam computed tomography (CBCT). These are accompanied by the more mundane, but nevertheless essential, developments in data storage and image display. For the dentist, particularly the family practitioner, it is digital radiography, particularly solid-state detectors, that is of most interest, because they produce an almost instantaneous image on the monitor, which facilitates ergonomics and time management. Digital radiology can be integrated into a digital patient record. It also dispenses with hazardous and noxious chemicals. Since Dr Mouyen introduced RadioVisioGraphy in 1987,¹ the developments in the image quality and ease of use of dental radiography have been phenomenal, so that now digital radiography has many advantages over dental film. However, dental film was first used within months of the discovery of x-ray by Roentgen in 1892 and is a very robust technology, which, when properly used, will produce a record that for all practical purposes is permanent. Nevertheless, as seen from the already almost complete eclipse of film photography by digital photography, radiographic film, although still used by the overwhelming proportion of dentists worldwide, is likely to suffer a similar fate eventually. The delay in its eventual demise reflects the fact that digital dental radiography, although the subject of much

research, is still very much a work in progress. The focus of much of this research is on the quality of the captured image, but little research has been carried out on the image display or on long-term storage of the entire data set.

There is a general view in the dental profession worldwide that digital dental radiography is largely film-based technology replaced by digital images, and that the main problem is: "What particular product is best for my practice and my patients?" This question, frequently the first question asked of the author, should actually be the last following an exploration of the whole digital issue. Many dentists are still surprised to learn that the solid-state detectors are inflexible and relatively more difficult to place in the mouth, because they are encased in a bulky plastic case. Furthermore, the area available to capture the image is much smaller than that for film. Altogether these result in more retakes, certainly initially, and more images. The solid-state detectors' cables have to be cared for to prevent damage, which can occur if they are bitten. In addition to their high retail cost (Parks² has recently reviewed their costs, which is a complex process), most solid-state detectors are very susceptible to serious damage, which in turn invites costly replacement. The phosphor plate detectors, although individually cheaper, need an expensive scanner to realise their latent images. Furthermore, phosphor plates, having no protective surface, are extraordinarily easy to damage during routine use. In addition to these technical challenges, there are

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FIGURE 1: Prescribing dental radiographs (adapted from the FDA guidelines)

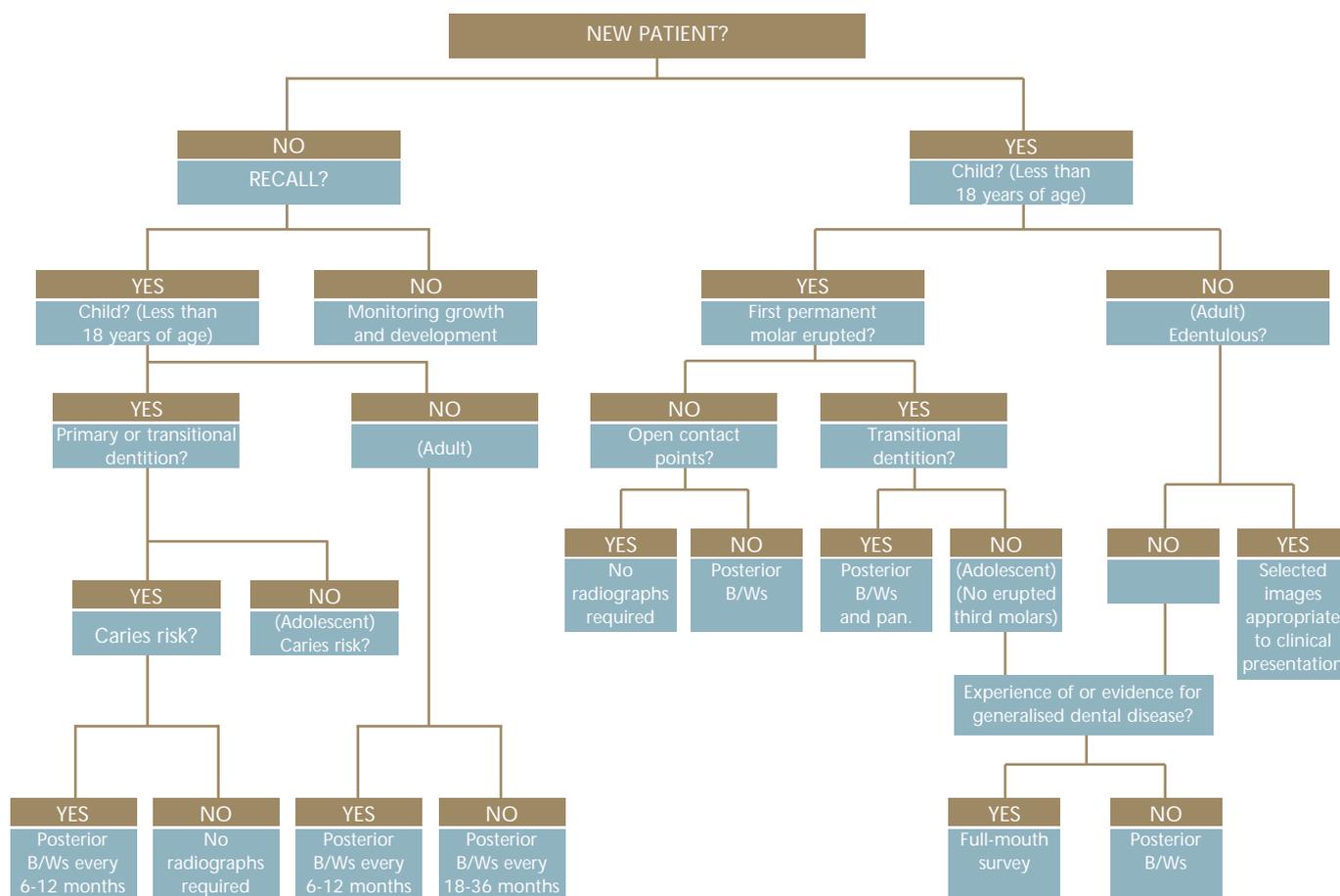


FIGURE 1: This decision tree has been adapted from the United States' Food and Drug Administration's guidelines for prescribing dental radiographs. Abbreviations: B/W: bitewings; pan: panoramic radiograph; post: posterior.

infection control issues unique to digital radiography, which have not been met when using film. Therefore, the necessity for the dentist to acquire a deeper understanding of these emerging technologies prior to going digital is pressing. This paper attempts to encompass all of the important aspects of digital dental radiology and associated developments.

Changes to Irish law as it applies to radiation protection

As our profession necessarily intrudes upon the persons and well-being of our patients, the law must equally intrude upon our practice, particularly where there is a real risk of harm. Medical radiology contributes 13.7% of the radiation burden on the Irish population, over 90% of this from diagnostic radiology.³ Although dentistry only accounts for a fraction of this, dentists radiograph a larger proportion of the population. Therefore, the dentist is required to justify or demonstrate that there is a clear clinical reason for making the exposure (justification). The United States' Food and Drug Administration has published a comprehensive set of guidelines;⁴ Figure 1 displays a flowchart based on these. The dentist will then

need to optimise the quality of image acquisition (optimisation). Justification and optimisation are two of the three principles of radiation protection; the third is the application of dose limits.⁵ This last is represented in Irish law by the diagnostic reference level (DRL).⁶ "DRL is a benchmark against which practice in relation to medical exposure is evaluated",⁷ and "should not be exceeded for a standard procedure when good and normal practice regarding diagnostic and technical performance is applied".⁸ This has already been discussed by Fanning recently in this journal.¹

The dental practitioner, unlike his/her medical colleagues, is frequently the prescriber, the practitioner and the radiographer for almost all exposures he/she prescribes.¹⁰ In these three roles, he/she will determine that an exposure is clinically indicated, will clinically direct the selection of the most appropriate techniques and then make the exposure. According to the provisions of SI 478 of 2002, this process needs to be audited. "The primary rationale for audit is to determine that the dental radiographic practice under review meets a reasonable standard."¹⁰ Such an audit should at least consider selection criteria, technique selection, x-ray equipment, patient dose,

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Table 1: A comparison between the imaging technologies available to dentists.

| | IMAGING TECHNOLOGIES | | | |
|--|--|---|--|--|
| | Film | SOLID STATE | | Phosphor plate |
| | | CCD | CMOS | |
| Brief description partly provided by Parks (2008) | Silver bromide developed to silver, the density of which provides the greyscale image | X-rays cause emitted electrons to collect in electron wells converted to greyscale image | Array of field effect transmitters with a polysilicon gate | Scanned by red light laser and emit blue light |
| Vulnerability to damage? | No – unless poorly stored – heat fogs it | Yes – by dropping and autoclaving | Yes – by dropping and autoclaving | Yes – frequently unusable after 50 uses |
| Basic costs of detectors – not including operating systems or software | Cheapest – note the film is completely consumed in a single use These costs were derived and converted into Euros from the following URL – http://www.cliniciansreport.org/page/additional-studies-archive , also discussed by Parks (2008) | On average €10,000-20,000 | On average €10,000-20,000 | Although €40-50 each, they last for 50 uses and the scanners are expensive – €10,000 |
| Immediate Image? | No – chemical development of latent image | Yes | Yes | No – needs to be scanned into the patient record |
| Likelihood of image degradation if delayed? | No – unless re-exposed before developed | N/A | N/A | Yes – deteriorates with delay before scanned |
| Special room required? | Yes (dark room) | No | No | Yes (dim room) |
| Noxious chemicals? | Yes | No | No | No |
| Whole surface available for image capture? | Yes | No | No | Yes |
| Spatial resolution (detail) in line pairs per millimetre? | Kodak InSight 20lp/mm | Kodak RVG-ui 20lp/mm | Kodak RVG 6000 20lp/mm | Planmeca Dixi 16lp/mm |
| | ALL from the 2005 report by Farman, A.G., and Farman, T. They compared 18 detectors. | | | |
| Dynamic range? | Narrow | Narrow | Narrow | Wide |
| Shorter exposure time? | Yes – if E and F speed | Same as E and F speed | Same as E and F speed | Yes – potential to be shorter |
| More exposures required for full-mouth survey? | No – optimum | Yes – smaller area available for image capture | Yes – smaller area available for image capture | No – same area available for image capture as film |
| Retakes more likely? | No | Yes | Yes | No – scanned image is automatically inserted into the patient record |
| Patient comfort? | Yes | No – bulky and inflexible | No – bulky and inflexible | Yes – same as film |
| Permit taking of vertical bitewings? | Yes | No – bulky and inflexible | No – bulky and inflexible | Yes – same as film |
| Occlusal size available? | Yes | No | No | Yes |
| Panoramic radiograph? | Yes | Yes | Not yet available | Yes |
| Lateral cephalogram? | Yes | Yes | Not yet available | Yes |
| Infection control challenges? | No – disposal after single use | Yes | Yes | Yes |
| Integration with an electronic patient record (EPR)? | No – also scanned image contains a fraction of the information | Yes | Yes | Yes |
| Image display | Bright – light viewing box | ALL three digital technologies under high brightness medical diagnostic grade greyscale monitor | | |
| Optimal viewing conditions? | ALL under reduced ambient lighting | | | |
| Ease of image enhancement? | No – brightness only | Yes | Yes | Yes |
| Integrity of original image (vulnerability to fraud)? | No | No – almost all modern systems preserved original image – any subsequent amendments are preserved as date-stamped editions | | |
| Long-term storage? | Yes – if properly developed | Unknown | Unknown | Unknown |
| Vulnerability of data in the image to loss? | Not if properly developed and stored, but will be destroyed if surgery is destroyed | Can be vulnerable to computer viruses. If the data is backed-up to a remote facility it can survive destruction of the surgery | | |
| Telemedicine? | No | Yes | Yes | Yes |

processing, image quality, image interpretation, records and training."¹⁰ In addition, the final report of the Health Service Executive's task force recently "recommended that the Dental Council make it mandatory for dental practitioners to attend appropriate training courses on an ongoing basis in relation to dental radiology."¹¹ Therefore, the audit process is not confined to the dental practitioner's practice, but includes the dental practitioner him/herself. Furthermore, in order to set up the audit process properly, the dental practitioner may require the services of a medical physicist and/or radiation protection advisor.¹⁰

Regardless of the technology used, The European Commission's Guidelines on Radiation Protection in Dental Radiology state that "all radiographs must be evaluated by the dentist and an appropriate report on the radiological findings made."¹² The dentist should review the images, not only for the presenting complaint and/or the clinical findings that prompted the radiograph's prescription, but also for hitherto undetected and as yet asymptomatic disease, which may have significant repercussions for the patient. Two such lesions, which are particularly important in the elder patient, are atherosclerosis and osteoporosis. Although calcified carotid arteries are indicative of atherosclerosis, a recent systematic review has suggested that this is not conclusive.¹³ Furthermore, some radiopacities in the vicinity of the carotid arteries on a panoramic radiograph are normal anatomy, such as the larynx cartilago triticea.¹⁴ In addition, mineralisation of the stylohyoid complex frequently presents as isolated radiopacities in this area.¹⁵ Those with osteoporosis tend to have a low OSIRIS score (a higher risk for osteoporosis) and a thinned cortical mandibular border as determined on a panoramic radiograph.¹⁶ Therefore, dentists serving the community at large now have a definite role in the detection of patients at high risk of osteoporosis. The reader should clearly understand that the author is not advocating 'screening' of patients for these diseases, but instead is advocating fuller use of all radiographs, in the making of which the patient has already incurred the burden of increased risk of radiation-induced damage and neoplasia. It naturally follows that all images should be properly dated, identified, orientated and archived (the storage of images will be discussed later).

Image capture

In spite of the considerable pace of digitisation, dental film remains the 'gold standard' with regard to image quality, when it has been properly exposed and developed, and viewed on a standard illuminated viewer under reduced ambient light. Furthermore, the much vaunted claim of digital imaging's substantial reduction in radiation dose as a reason for converting to digital technology, will only be fulfilled if the clinician is abandoning the slower D speed film (still used in about 60% of North American dental practices) rather than the faster E and F speed film. Also, the wide latitude of the phosphor plates may permit overexposure of patients by inappropriately high exposure times without incurring any degradation of the image, which would be readily apparent on film or solid-state detectors, indicating a need to reduce the exposure time.¹⁷ Integration into a digital patient record system and easier image

management (enhancement for clinical purposes, storage and teleradiology) are other advantages of digital imaging. Integrating digital radiology with a digitised oral health record offers clear advantages: it streamlines office processes; enhances efficiency; and, minimises errors, reducing the risk of legal liability. The devices used to capture the primary x-ray beam that emerges from the patient's jaw are variously known as a detector, a sensor or a receptor. In this report, only the term 'detector' will be used throughout. Comparison between film and the digital technologies is set out in Table 1.

Digital dental intra-oral radiography

There are two entirely different digital technologies: solid-state and phosphor plate (photostimulable phosphor [PSP]).^{2,17,18} As the term PSP is widely used, it will be used from now on instead of phosphor plate and the other acronyms (SPS and PIP). The solid-state technology is still largely represented by the charge-coupled device (CCD), but has now been joined by the complementary metal oxide semiconductor (CMOS). Both CCD and CMOS offer the clinician an image immediately after exposure. This differs from the PSP system, which requires scanning of the detector before the captured latent image can be displayed. The scanning of the PSPs should be performed as soon as possible after the detector has been exposed and should take place in a dim room in order to minimise degradation of the latent image.¹⁹ Therefore, a separate room, the dim room, akin to the darkroom, is still required. PSP detectors should be considered semi-disposable to ensure that an adequate standard of image quality is maintained. Bedard and co-authors²⁰ determined that PSP detectors were so damaged after 50 uses that they should be replaced.

Many clinicians may find that CCD/CMOS and PSP technologies complement each other. The CCD/CMOS technology's instant image is invaluable for endodontic or other chairside procedures, which need almost real-time imaging. The more flexible PSP detector (as flexible as film) can be used in situations in which the bulkier CCD/CMOS detector is difficult to use, such as limited opening and shallow palates. PSPs are also better for vertical bitewings. Detectors for occlusal projections are generally only available as PSPs, as an occlusal-sized solid-state detector would be extremely expensive. Therefore, the dentist who is considering 'going digital', rather than attempting to choose between solid-state and PSP detectors, may consider both depending upon the nature of his/her practice. Farman and Farman last objectively reviewed a range of detectors in 2005.²¹ The spatial resolution of the 18 detectors they reviewed varied widely, from five to over 20 line pairs per millimetre (lp/mm). The reader is alerted to the fact that some manufacturers quoted a theoretical resolution for their spatial resolution, based simply on the pixel size, which was unlikely to be achieved in practice.²¹

Extra-oral digital radiography

Panoramic radiography has also been substantially affected by digitisation. This has been achieved by simply replacing the film with a similar sized sheet of PSP, which is scanned and displayed on the monitor. Other panoramic units use solid-state detectors, which display the image instantly upon exposure. As a full-sized sheet of

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CCD or CMOS similar to that used for film or PSPs would be prohibitively expensive, such detectors are reduced to a vertical bar, whose solid-state elements are continuously exposed during the entire exposure.

Lateral cephalometry has been similarly served by digital technology. Yu and co-authors²² revealed that digital lateral cephalometry might display certain features better, though not significantly so, than film lateral cephalometry.

Image display

The European Commission's Guidelines on Radiation Protection in Dental Radiology emphasise the importance of the quality of the monitor.¹² Although Krupinski and co-authors found no difference between the performance of radiologists using monitors of differing luminance, the dwell-time (time spent reviewing the image prior to diagnosis) was significantly longer.²³ The two factors affecting display are the quality of the monitors and the ambient lighting at the time of reviewing the displayed image.

Monitors

In medicine, diagnostic images are read by radiologists on medical-grade diagnostic greyscale (monochromatic) monitors under reduced ambient lighting. The main advantage of these monitors is their high luminance, which makes it easier to see the entire greyscale from black to white. They produce a report, which accompanies the images. The referring clinician, using a 'point-of-care' monitor (which can have a colour display) has the radiologist's report to guide him/her. Therefore, it follows that dentists, who are their own radiologists, should also use similar facilities to 'read' their images. The best medical greyscale monitors, although more expensive than commercial monitors, cost the same or are cheaper than a single No. 2 size CCD detector (about the same size as a standard periapical film). The NDS's E3 (3-megapixel; formerly made by Planar Systems) is ideal for panoramic and high spatial resolution intra-oral images and costs around €6,000. The 2-megapixel E2 costs around €4,500, but will no longer be made in the near future. At the time of writing, this monitor was the smallest to offer all the following features: an optimal spatial resolution (image detail, measured in line-pairs per millimetre [lp/mm]); contrast resolution (discerning the difference between two adjacent densities and commonly expressed in bit-depth or grey levels); high brightness; and, self-calibration.

The displayed image should fully represent all the data captured by the detector. Ideally, the display of each pixel of the image captured by the detector should be represented by a corresponding pixel on the monitor display in order to optimise the detector's spatial resolution (1:1 display). Therefore, information contained within the captured image may not be displayed on the monitor if the display is not 1:1. Haak and co-authors²⁴ reported that ratios of 1:1 and 2:1 were significantly better for detection of approximal caries than a ratio of 7:1. In their comparison of a standard desktop with a dedicated medical monitor, Gutierrez and co-authors²⁵ found that the standard desktop display was clearly inadequate for diagnostic radiology. These medical-grade, diagnostic or primary-read monitors are

technologically complex. For example, the greyscale standard-display function (GSDF) is based on a phenomenon called human-contrast sensitivity (HCS), which takes the human eye's non-linear perception into account. The human eye more easily sees relatively small changes in brighter areas than in darker areas. The GSDF adjusts the brightness so that all areas have the same level of perceptibility.²⁶

Although the monitors employed for medical diagnosis use 12-bit-depth technology, if they are operating within an operating system (OS) such as Windows, they will only resolve to 8-bit-depth (or 256 grey-level used by ordinary monitors). Despite this, medical monitors do require the 12-bit-depth (4096 grey-levels) technology for accurate self-calibration, which is performed to digital imaging and communications in medicine (DICOM) standards.

Seto and co-authors' results "indicate that medical display systems must be carefully.... calibrated to ensure adequate image quality".²⁷ Self-calibration of the monitor's brightness (luminance) ensures that every time the dentist, in his/her essential role as radiologist, reviews an image, it is of optimal quality. Medical grade monitors are exceptionally bright, optimally about 500 candela (candles) per square metre (cd/m²). As all monitors fade with time, this self-calibration ensures optimal and standardised brightness, until the backlight brightness falls below the threshold and needs to be replaced.

Ambient lighting (illuminance)

Reduced ambient lighting (illuminance) essentially goes in tandem with monitor brightness. Recommendations for reduced ambient lighting in diagnostic reading stations for conventional analogue (and digital) radiographs are 2-10lx (illuminance is commonly expressed in lux or more simply lx), in comparison with 200-250lx in clinical viewing stations in hospitals.¹⁸ The evidence for the need for reduced ambient lighting for dentistry is provided by Haak and co-authors.²⁹ They found that differences in monochromatic intensity were detected significantly earlier if the ambient lighting was reduced (70lx versus the 1,000lx recommended for the dental operator). More recently, Hellén-Halme and co-authors demonstrated that when the reduced ambient lighting is less than 50lx there is a significant increase in the accuracy of diagnosing approximal caries.³⁰ Although both monitors used by Haak and co-authors²⁹ did not reach the National Electrical Manufacturers Association's (NEMA) standards for DICOM,²⁶ Haak and co-authors²⁹ found that the flat screen monitor performed better than the cathode ray tube (CRT) in the dental operator, probably because the flat screen monitor was brighter. Note that both CRT and LCD monitors function equally well provided they comply with DICOM standards.²⁶

Image enhancement

Enhancement of the captured image is clearly an advantage that the digital technologies have over film. Parks² recently displayed and discussed several enhancements: 'density' (brightness); 'contrast'; 'measurement'; 'image inversion'; 'magnification'; 'flashlight'; and, 'pseudocolour'. Although altering the brightness can lighten over-exposed images, under-exposed images should be retaken. Therefore,

the need to optimally expose a solid-state detector is just as important as it is for film.² As indicated earlier, images should be reviewed at a 1:1 ratio. But this may not be always possible, particularly for detectors with very high spatial resolutions or large images such as panoramic radiographs. In such cases a 1:1 ratio will magnify ('magnification') the image, requiring the clinician to scroll through the image. Haak and co-authors²⁴ demonstrated that review of radiographic images at higher magnification improves accuracy. Perhaps one of the most desired features of digital radiology is measurement; nevertheless, Kal and co-workers³¹ found that all processing algorithms provided significantly shorter measurements of the endodontic file lengths than their true length.

Koob and co-authors³² compared the effect of different image processing modes or filters on the reproducibility and accuracy of the assessment of approximal caries viewed in CCDs. Although they found that there were no significant differences in reproducibility, the exposure time influences the overall accuracy of the central depth measurement of the approximal carious lesion. Haiter-Neto and co-authors³³ found that the accuracy for the detection of non-cavitated approximal caries among seven solid-state detectors was not significant.

Storage and compression of images

Adopting digital technology does not alleviate the problem of long-term storage of all existing films (analogue images). Fundamentally, the storage of electronic dental records must accurately preserve the original content of the record (e.g., text, image or chart).³⁴ The record must include complete information about the creation of any modification (author, date, time and exact source of the record, such as work station). The format must be 'read only' and protected from unauthorised alteration, loss, damage or any other event that might make the patient information it contains inaccessible. Many jurisdictions require that digital clinical data be backed up to a remote server. The advantage of this is that this data is preserved if the surgery has been destroyed by fire or natural catastrophe. The advantage to both the dentist and his/her patients is that this data can be retrieved and treatment quickly recommenced at an alternative venue. This is particularly important, as the value of a practice is still based in part on the 'good will' represented by active patient records. This back-up of patient data is stated in the European Commission's Guidelines on Radiation Protection in Dental Radiology.¹²

The Dental Council of Ireland recommends retention of dental records for at least 10 years. The dentist considering adopting digital radiography needs to consider this, as it is likely that during that period, at least for some of his/her patients, he/she may need to convert to a different system at least once. It is a common experience that information technology (IT) changes rapidly with time, with a risk that different generations may become incompatible. Therefore, in order to ensure that data survives transfer from one system to another, the dentist must ensure that not only are the systems DICOM compatible, but also that all digital images are transferred into the new record system without a loss of data. So far there does not appear to be a report to confirm that this can actually be achieved in dentistry.

Although not much of an issue for a single practitioner, the storage of images may present a much greater challenge for a large group practice that uses CBCT data for implants and orthodontic cephalometry. Intra-oral images account for only hundreds of bytes of storage and panoramic radiographs for only a few thousands. The very large image files required for CBCT data quickly exhaust even a very generous storage capacity, measured in picabytes.

Compression of image files is an alternative to increasing storage. Two systems are used for compression, lossless and lossy. The files of the iCAT (a CBCT unit) are automatically losslessly compressed, without loss of data. Lossy compression, however, involves an irrevocable loss of data. Although Eraso and co-authors³⁵ reported that loss of image quality is not a factor unless the file size is reduced to 4% or less, Fidler and co-authors,³⁶ who systematically reviewed the literature on lossy compression, reported that the amount of information lost is difficult to express and standardise. Therefore, until lossy compression has been definitively tested, all data contained in a clinical image file must be preserved. Furthermore, the format of the image at the time of creation remains the original.³⁷ Therefore, scanning a film, even on a medical grade scanner, only creates a copy; the film is the original image and must be preserved. Furthermore, those images created digitally remain the original images, although they may have been printed on to the appropriate quality of paper or transparencies by medical grade printers. These printouts are just copies. It also follows that any modification of the original image can only ever be an edition of the original, which must remain unaltered. The later edition should be automatically date-stamped with the date of its later creation.

Before we leave this section, the dentist must understand that the image he/she views on his/her monitor is not the original image captured by the detector. This captured image is itself still not the raw image captured by the detector, but instead is the image that has been automatically 'pre-processed' so as to compensate for defects such as non-functioning pixels. The programs that perform this pre-processing cannot be accessed and modified by the dentist. It is this 'pre-processed' or 'presented' image that constitutes the 'original' image from a legal perspective.

Infection control

Infection control necessarily lies at the very heart of dentistry. Infection control for film is relatively straightforward; the contaminated film wrapping is discarded and the film developed. Therefore the entire film packet is completely consumed in a single use, whereas in digital imaging the detectors are used many times. As any instrument that comes into contact with the mucosa should be sterilised, the detectors, which are readily destroyed by autoclaving, pose a particular problem. Ethyl oxide sterilisation can be applied in a large dental facility, but is potentially hazardous to use in dental practice. An alternative practice of sealing the detectors in watertight bags (which are later discarded) prior to insertion in the mouth is widely used. Although a single report showed that bagging of detectors was unreliable as it failed in half of cases,³⁸ a pilot study on PSPs in the author's institution has revealed that this need not be the case if a rigorously practised infection control protocol is followed. As infection

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control is infrequently raised at trade shows and demonstrations, the dentist should understand how he/she would be able to achieve infection control in his/her practice when choosing between systems. Infection control bags and wraps have to be included as a recurring cost in the overall cost of 'going digital'.¹⁸

Conveying electronic information between clinicians

The application of teleradiology has been accelerated by picture archiving and communication system (PACS) and DICOM, eliminating the physical transport of hard copy as printed transparencies, or soft copy as DVDs or CDs. Teleradiology should be defined as the formal transmission of images within a secure local area network (LAN) and not as transmission by ordinary email. Email transmissions are not secure, nor are the attached images diagnostic, particularly if they were lossy compressed. Teleradiology currently lacks standards for an interoperable, manufacturer-independent protocol for secure teleradiology.³⁹ Therefore, in the absence of formal teleradiology, downloading the data onto a DVD or CD is preferred for medico-legal reasons because it contains all the original data generated during the investigation (conventional digital radiology, CT or MRI [magnetic resonance imaging]), rather than selected and manipulated images printed on transparencies. The data on the DVD/CD can be downloaded by the patient's dentist (or the clinician the dentist has referred the patient to) to be reconstructed according to the clinician's needs. However, this may require the appropriate software, for example Simplant for implants, to be fully effective.

Other developments

CBCT, virtually unknown to the dental profession only five years ago, is today perhaps the most widely discussed and exciting development in OMFR. Although CBCT is a topic that would be better addressed in a separate article, some comments can be made here. There are already over 12 different models available in the global market. They vary widely, both in technical specifications and in the radiation dose they deliver, the lowest perhaps being the Newtom 3G, the original CBCT and the most widely studied. Like any other CT technology, CBCT is subject to spray artefacts arising from metal restorations (including implants), which, although they can be reduced by metal artefact reduction (MAR) software, cannot be entirely eliminated. Therefore, such artefacts will appear on any reconstruction, including a panoramic reconstruction. Although the latter is more dimensionally stable and is free of secondary artefacts in comparison to those produced by the conventional panoramic radiography units, the dentist considering referring his/her patient for CBCT imaging should first reflect upon the implications of spray artefacts and the radiation dose of the particular CBCT upon which the referred patient will be imaged. Although guidelines for CBCT and other advanced imaging modalities are not yet available, most referrals for CBCT are for preosseointegrated implant assessment. Although the European Academy of Osseointegration (EAO) published guidelines for the use of diagnostic imaging in implant dentistry in 2002 (based on a workshop held at Trinity College in Dublin in 2000),⁴⁰ these need to be revised as they occurred prior to the advent of CBCT. Other

referrals are clinically indicated for investigation of unerupted third molars and non-locally invasive benign neoplasms and cysts. Although such latter referrals are entirely appropriate, they are not for those lesions that may be malignant or are locally invasive, such as ameloblastomas, odontogenic myxomas and keratocystic odontogenic tumours (formerly known as odontogenic keratocysts).⁴¹ These lesions need to be investigated by spiral CT and MRI, usually with contrast, to determine invasion of the adjacent soft tissues. CBCT is unsuitable for their investigation for two reasons. CBCT's bit-depth is only between 12 and 14 and cannot display soft-tissue detail, whereas spiral CT has a bit-depth of between 16 and 24. With the exception of the Newtom 3D, all CBCTs investigate the patient while vertical and are thus unsuitable for delivery of intravenous contrast, mainly because it can provoke an adverse reaction, which is best managed when the patient is supine. Fortunately, when such lesions are considered for such advanced imaging they are already in the hands of oral and maxillofacial surgeons, and are no longer an issue for the dentist serving the community at large.

The advent of CBCT has raised a number of issues. Although the radiation dose imparted by CBCT is lower than that for spiral CT, because it is infrequently prescribed by a radiologist there is the real risk that for many exposures CBCT may not be the appropriate imaging modality, and the patient may be needlessly exposed. Even if it is clinically indicated, the prescribing clinician will still be required to make two important decisions: he/she will have to determine whether the field of view (FOV) is the appropriate size; and, whether a radiologist should report the resultant images. The FOV should be adequate to cover the area of clinical interest, but should not be excessively large. An excessively large FOV would impart a needlessly high radiation dose to the patient, particularly if a high spatial resolution is chosen. This spatial resolution can be as high as 0.01mm voxel size, which translates into 5lp/mm and approaches the spatial resolution the unaided human eye experiences when viewing a conventional panoramic radiograph. Once acquired, CBCT images should be read and reported like any other image. If the FOV has only encompassed the jaws, then the images could be read safely by dentists who have undertaken the appropriate training in operating and interpreting the entire CBCT data set. If extragnathic areas were included, particularly when a large FOV has been selected, the data set would be better referred to a radiologist.⁴²

Concluding remarks

The experiences of dentists providing general dental services to certain European and North American communities will now be briefly reviewed in order to give the Irish dentist an insight into 'going digital'. Although film was preferred for its pre-exposure user-friendliness, digital was preferred for its post-exposure user-friendliness.⁴³ Nevertheless, dentists were more likely to take more images when using digital rather than conventional radiography; this could arise because the solid-state detectors have smaller surfaces to receive the image than film, thus necessitating more images. This cannot be the complete explanation, because the same report⁴⁴ revealed a smaller increase in the number of PSP images, which have

a similar sized radiosensitive area as film, and like film, do not have the advantage of the solid-state detectors, which produce an immediate image automatically after exposure. One American study reported that although cost is a major issue for most dentists, they considered it to be a worthwhile investment;⁴⁵ an American⁴⁶ and a Norwegian⁴⁷ report found digital radiology most frequently in group practices. Two Scandinavian reports^{48,49} stated that equipment failure and problems were common. This would suggest that the vendor's and manufacturer's after-sales service should be fully explored prior to completing the purchase. Furthermore, this major investment should be protected by acquiring contracts for servicing the hardware and software, and for software updates.¹⁸

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