Digital radiology in dental diagnosis: a critical view

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Medical history is replete with technologies rapidly accepted but quickly disappearing as their lack of benefit becomes evident. The difference between long- and short-lasting technologies depends to a large extent on how critical the scientific community has been whilst in the middle of an exciting development. Many technologies have been developed and slowly gained clinical acceptance as more evidence has been accumulated about their worth. To rapidly implement techniques of indisputable value and to avoid implementation of techniques later to be deemed of less value, evaluation must run parallel to technique development. Implementation must not be allowed to get ahead of evaluation.

Film-based and film-free radiological systems

In the film-based system the film serves to detect, store and display information. In the film-free system these functions are served by three units: a sensor, a computer memory and a monitor. The question is whether this system will bring about sufficient benefit justifying the substitution of the simple film, or is there some truth in the remark that had radiology developed initially as a digital-based discipline and radiologists become accustomed to viewing images on monitors, the invention of film-based systems probably would have been rewarded by a Nobel prize?[1] The use of a hybrid system may also be discussed. In this the conventional film serves as a detector, its information sampled by a scanning device or a TV camera, digitized, stored in computer memory and displayed on a monitor. With both systems image-processing methods can be applied to visually enhance and statistically evaluate information. The latter provides a foundation for automated image analysis.

The film-based system can be described in a model linking its components from exposure to diagnosis. The radiation pattern after passage of the object forms the input to the imaging part of the process, where it is modulated by film properties and film processing. Density variations in the image forms the input to the visual system but may on its way to it be affected by the viewing conditions. The perception of the image is influenced by several factors. Some are integral parts of the image itself, others depend on the image observer. A diagnosis cannot be made unless information, other than from the radiograph, is taken into account, for example, the nosological characteristics of diseases affecting the teeth and jaws. Anamnestic, clinical and epidemiological data are also important non-radiological factors. Other information influencing the diagnosis emanates from previous radiographs.

The model can be adapted to digital imaging. The film and film processing are replaced with an electronic sensor and a computer. The image is displayed on a monitor and can be changed by image-processing techniques. When making the diagnosis earlier radiographs stored in computer memory can be retrieved and compared. A radiographic data base can be accessed and lesions similar to that observed presented with their names and pertinent epidemiological data. If uncertainty still remains about the diagnosis the image can be electronically sent to colleagues to obtain second opinions.

Clinical purposes of radiographic diagnoses

When comparing systems for radiographic imaging of the teeth and their surrounding bone by means of intraoral techniques, a summary of the clinical purposes of a radiographic diagnosis may serve as a background:

- It is used to establish presence and extent of disease in patients suspected of disease from clinical history, signs and symptoms.
- It can be used to screen for possible disease in 'normal' populations.
- It is used to monitor disease and treatment effects.
- It is used to choose the treatment alternative with the best long-term prognosis.

It should also be borne in mind that the radiographic process is a system consisting of: data collection, data presentation, data observation and decision making.

Film-based and film-free systems to achieve the clinical purposes

To establish the presence of disease that is suspected in a patient, it is a matter of changing a probability of disease in the absence of radiographic information to a conditional probability given some radiographic information. The posterior probability is to a great extent dependent on the prior probability of disease. Therefore, relevant selection criteria must be used based on clinical history and examination. Several studies indicate that selection criteria based on patient needs rarely determine the taking of radiographs[2]. If this is the case with the current rather cumbersome system of obtaining radiographs, will a system providing immediately accessible images not increase the risk of taking radiographs just in case?

To determine extent of disease is important in dentistry where efforts are taken toward secondary prevention and postponement of invasive treatment both caries and periodontal disease. This requires projections capable of revealing the actual extent of lesions. The projection is one of the weakest links in current dental radiography, often resulting in disturbing amounts of anatomical noise from structures being projected onto the areas of interest. The film-free techniques offer no solutions to this. On the contrary, the relatively bulky sensors may make projections even more difficult.

To determine extent of disease is indeed important in extensive lesions such as cysts and tumours. The character of the borders of the lesions and their relation to surrounding structures influence both diagnosis and treatment planning. A common reason for diagnostic failures is insufficient coverage of the area of interest, making extensive bone lesions difficult to evaluate and sometimes even to detect. This type of failure is bound to increase with available film-free techniques. A major disadvantage with available film-free systems for dental radiography is the small size of the image area. They therefore require supplementary examinations where current intraoral methods may suffice. Do dentists in the future have to have access both to panoramic radiography and an intraoral electronic sensor to make examinations which in most cases can be performed using current intraoral techniques? In that case it is easy to foresee increasing costs for dental care.

Screening radiography may be questionable in dentistry but often used for the diagnosis of approximal caries. To date reliable indicators to identify patients in need of radiography do not seem to have been developed. Radiographic screening for caries may therefore continue especially to detect lesions which may be arrested by means other than restorations. In addition, the presence of approximal caries seems to be one of the best predictors for new caries. Radiographs from one point in time can be used to determine the timing of subsequent radiography based on individual patients' needs.[3]. A technique requiring less dose, as offered by the film-free systems, would be of value in caries management.

To monitor disease and treatment when changes over time are small puts high demands on reproducibility of projections, density and contrast. It is easier to standardize density and contrast using a digital system[4], but devices to secure standardized projections must be developed. Even though mathematical reconstructions may aid in making serial radiographs geometrically comparable, this should more easily be achieved from images which are not so different that features in one are completely overshadowed by anatomical noise in the other.

An important role of radiograph is to help in choosing treatment alternatives. A new radiological system should then either improve the possibilities of choosing the treatment alternative with the best prognosis or have other advantages, e.g. lower cost, less radiation, much simpler to use. To decrease costs requires a system that does not merely supplement an existing one.

Evaluation of diagnostic imaging systems

In 1983 Fryback published a paper[5] with an important message to everybody concerned with the development of new radiological methods. He proposed four premises shaping the design and purpose of studies to evaluate diagnostic imaging. These are summarized below with some modifications to adapt them to dental radiography.

Premise 1. The purpose of a diagnostic system is to help ensure a favourable net outcome to the patient. On average, the patient should gain and not lose by his encounter with the diagnostic system. This establishes a goal for diagnostic imaging – to improve the state of the patient.

Premise 2. The imaging process is a system with three interacting parts: the imaging device, the interpreter and the clinical user of the image information. Benefit to the patient cannot occur except as a joint action of these parts. Since they can be seen as stages of an information-conveying channel, some degradation of the information transmitted is likely to occur at each successive stage.

Premise 3. The diagnostic imaging system is not the sole source of information about the patient. The fact that one has decided to take radiographs in some particular areas of the jaws is evidence that the search is narrowed down based on some other information. One must be aware that more information is not necessarily more efficacious than a little. If a clinical examination has made it likely that the patient suffers from a periapical osteitis and even a less good radiograph indeed shows a periapical radiolucency, this may suffice to increase the diagnostic certainty sufficiently to choose correct treatment. More information may increase the diagnostic certainty even more but well above that needed. A less expensive, albeit less diagnostically precise, technique may suffice.

Premise 4. Therapeutic treatment is not a smooth function of diagnostic probabilities. Usually there are a few courses of action available. The function describing the correspondence between diagnostic probabilities and actions is non-continuous, it is a step function. All changes in diagnostic probabilities will therefore not cause a change in the therapeutic course.

It follows from the premises that a diagnostic imaging method can be evaluated at different levels starting with the image and continuing in a logical order to its societal effects.

At level 1 the image itself is evaluated, e.g. with respect to spatial and grey-scale resolution. Cost-effectiveness, for example, can be measured as the monetary cost per line pair per mm or mSv per examination.

At level 2 system performance is measured just distal to the observer and can be expressed in terms of diagnostic accuracy and different ROC-curve parameters.

Levels 3 and 4 concern steps instrumental in transforming output at levels 1 and 2 into an output at level 5, improvement in patient outcome. To demonstrate that a particular imaging technique on average leads to a better or a similar outcome requires prospective randomized clinical trials. While it may be ethically difficult to conduct such studies on well-established technologies, they should be easier to perform during a period when a new technology is introduced and an old one is still in use.

As a proxy for randomized clinical trials at level 5 studies can be performed at level 4, because a diagnostic procedure cannot be more efficacious in changing patient outcome unless it leads to different therapeutic choices than when using the method with which it is compared. However, demonstration of an effect at level 4 does not ensure an effect at level 5 because different therapeutic choices may not necessarily change patient outcome.

At level 6 the issue is whether resources spent on a new imaging modality are best utilized there or in some other approach to improving dental health. One needs to know not only that diagnostic accuracy is improved by a certain proportion or that health is improved in a certain number of cases, but also if any additional costs associated with the new technology would not have resulted in better results if spent elsewhere. Evaluation at level 6 is important if the cost for a new technology is appreciably greater than for existing ones and if it is used to supplement rather than to replace them.

Current literature on digital dental radiography

A search of the literature on digital dental radiography, excluding panoramic imaging, showed around 50 papers which could be classified as dealing with technical development of either the direct digital imaging or the hybrid technique. Forty-two of the papers were about subtraction radiography. In about 50 of the total number of studies some form of evaluation had been performed. Again, the majority of those papers dealt with subtraction. *In vitro* experiments accounted for about 70% of the evaluation studies. Fourteen papers described clinical studies where a digital technique had been used to evaluate treatment. In 13 subtraction radiography was employed. Evaluation procedures were sometimes found in articles also classified as dealing with technical development. Some papers describe both *in vitro* and *in vivo* studies.

In the studies classified as concerned with evaluation, ROC-curve parameters had been used in 13, sensitivity and specificity in eight, number of correct diagnoses, positive and negative, in seven and correlation coefficients in 13. The latter were articles concerned with, for example, area measurements, marginal bone level assessments and measurements of the extent of caries. In most studies external validation procedures had been used. The presence or absence of lesions was determined from, for example, histology, measurement on dry skulls or by creating artifical lesions. The latter method may be disputed because of the artifical nature of the lesions. However, when a new technique is compafled with an established procedure such lesions may be acceptable proxies. A new method which does not give rise to expected results during favourable *in vitro* conditions stands a poor chance of being successful *in vivo*.

In most evaluation studies the results from digital images were compared with those from conventional radiographs. It may be argued that a diagnostic technique should not be compared with others but evaluated against some preset specifications of diagnostic performance. However, when a new technique may replace an established radiographic technique the quality of images produced with standard X-ray film is the standard to which other systems must be compared. New systems must be able to deliver a diagnostic quality at least equal to that of existing systems. Unless a new system cannot do this more rapidly and less expensively, there is a risk that its interest will be limited to research applications.

Evaluation of direct digital techniques

With respect to digital imaging techniques as represented by the RVG, the Sens-A-Ray or the Visualix systems, the only studies found through a literature search deal with the RVG. Most evaluated image efficacy in terms of resolution, contrast, noise, distortion and exposure dose. Only three concerned image-observer efficacy. One of these[6] compared two types of conventional intraoral films with the RVG system for the detection of holes, 2 mm in diameter, drilled to various depth in a piece of aluminium exposed with different exposure times. On average, ten observers detected more holes with the RVG images than with any of the film systems at low exposure levels.

Another study[7] compared the percentage of root canal length visible in extracted teeth in E-speed films, RVG images and contrast-enhanced RVG images. No significant differences were found between the results from RVG images, enhanced or unenhanced, and those from conventional films.

In the third study[8] four observers diagnosed caries in non-cavitated occlusal surfaces in 81 extracted third molars in E-speed radiographs, in digitized conventional radiographs after contrast enhancement and high pass filtering and in RVG images, first using a contrast manipulating facility and a second time using a density saturation facility. Histological sections of the teeth were used to establish the presence and extent of caries. For each of the methods sensitivity, specificity, positive and negative predictive values and ratios between true and false positive rates were calculated. Although contrast-enhanced digitized images and contrast-enhanced RVG images resulted in similar or slightly higher likelihood ratios than the conventional radiographs, statistically significant differences were not demonstrated.

From this review of the current literature on digital dental radiography it is evident that evaluation of its value has been made mainly at levels 1 and 2 of

Fryback's models. This can be explained by the relatively recent introduction of digital dental radiography, but serves as a reminder that it is still in its infancy.

A preferred course of action

What would be preferred in the development of a new technology is a gradual transition from basic research and development via preclinical and clinical research and finally into the clinic if justified by sound evaluation procedures. These should run in parallel with the development and continue during the clinical implementation phase to make sure not only that a new method *can* work, but also that it *does* work under normal clinical conditions.

While the film-free and the direct digital systems have much in common as regards evaluation demands, a film-free system also has to be evaluated regarding its clinical feasibility in terms of possibilities of achieving correct projections, coverage of sufficient object area, patient acceptance, need for supplementary radiography, etc. Other areas to be evaluated are image memories, image retrieval possibilities and image display facilities. In this connection it will be interesting to see how film-free the film-free systems will actually become. How often will dentists prefer to view their images on a monitor as opposed to when copied on film or paper?

Potential advantages of digital dental radiography

An advantage of a film-free system is the elimination of the time-consuming darkroom procedure which often fail to produce high quality radiographs. Undoubtedly, a major reason for the low quality often found in current dental radiography is faulty darkroom procedure. However, for a fraction of the cost of a digital system an automatic processor, properly maintained, contributes to high quality radiographs. They are not ready for immediate viewing, but how often in dentistry is time really an issue?

The dose reduction with a digital system is another of its advantages. However, to make full use of this the beam area has to be restricted to correspond to the size of the sensor. One also has to take into account that to examine a jaw area for which two intraoral films of size 2 are sufficient, up to five exposures are needed with available film-free systems. Only to compare the amount of radiation required to expose an intraoral film with that for one exposure with a film-free system can be misleading.

To make film-free dental radiography become not only a tool to be used in dental research, where many advantages can be found, but a clinically useful method, image areas have to be increased. One may then have to look for other detector technologies than the CCD technique. This may require that real-time imaging has to be sacrificed.

For many purposes digital images would be ideal. It would be easy to create radiological databases to be used for educational purposes and not least as image-based decision support systems. However, this would require that all types of images taken in a radiology department were digital. This means, at least for quite some time, that some film-based images have to be digitized. The application of digital techniques should make it possible to improve dental radiology education worldwide.

In what direction and for whom should digital systems be developed?

The future development of digital dental radiology direction chosen. Should it be directed toward the totally film-free dental radiology? Should it be directed towards a mixture of film-free and a hybrid system, or rather towards only a hybrid system with development of techniques for quick and easy image digitization and storage? Another important question is for whom a digital system is intended. Is it for the general practitioner, the radiology specialist or both? Will both categories be interested and knowledgeable enough to take full advantage of it, including image processing possibilities? Will it be possible to sufficiently educate dental students in digital radiography when, judged from several studies, it has not been possible to educate them sufficiently to use current simple technology to its full advantage? How interested are dental practitioners in sophisticated technology when many do not seem able to perform high quality film processing or interested enough to use high speed films? Or should film-free systems should be advocated for exactly these reasons?

Properly performed intraoral radiography yields a great deal of clinically important information. Judging from the present literature on attempts at extracting more information through different image processing techniques, only marginal achievements have been made. There are some exceptions though. One is the digital subtraction technique[9], although it can be questioned whether it will become a more generally applied technique and not just used in clinical research where may be important enough. Another promising technique is tomosynthesis[10], which again may be a technique more easily applicable in research-oriented institutions than in general practice. Interesting possibilities have also been demonstrated to digitally enhance visually underexposed conventional radiographs so as to obtain as much diagnostic information as from those properly exposed but at a fraction of the dose[11].

Final comments

Digital dental radiography is in its infancy. During its further development it should be critically scrutinized by members of the dental radiology community. A problem is that few institutions can devote sufficient time and manpower. Maybe the time has come for a special section for digital radiography within our international society in which individual institutions and persons interested in various research areas are connected through a computer network. In this way we would be able to join forces, which should make it easier to receive necessary support from international and national research foundations as well as industry.

References

1. Vizy KN. The roles of film in an increasingly computerized world. *Invest Radiol* 1989; **24:** 503–5.

2. Matteson SR, Morrison WS, Stanek EJ III, Phillps C. A survey of radiographs obtained at the initial dental examination and patient selection criteria for bitewings at recall. *J Am Dent Assoc* 1983; **107:** 586–90.
3. Lith A, Gröndahl H-G. Predicting development of approximal dentin lesions by means of past caries experience. *Community Dent Oral Epidemiol* 1992; **20:** 25–9.
4. Ruttimann UE, Webber RL, Schmidt E. A robust digital method for film contrast correction in subtraction radiography. *J Periodont Res* 1986; **21:** 486–95.
5. Fryback G. A conceptual model for output measures in cost-effectiveness evaluation of diagnostic imaging. *J Neuroradiol* 1983; **10:** 94–6.
6. Benz C, Mouyen F. Evaluation of the new RadioVisioGraphy system image quality. *Oral Surg Oral Med Oral Pathol* 1991; **72:** 627–31.
7. Shearer AC, Horner K, Wilson NHF. Radiovisiography for imaging root canals: an *in vitro* comparison with conventional radiography. *Quintessence Int* 1990; **21:** 789–94.
8. Wenzel A, Hintze H, Mikkelsen L, Mouyen F. Radiographic detection of occlusal caries in noncavitated teeth. A comparison of conventional film radiographs, digitized film radiographs, and RadioVisioGraphy. *Oral Surg Oral Med Oral Pathol* 1991; **72:** 621–6.
9. Brägger U. Die Entwicklung der Digitalen Subtraktionsradiographie in der Zahnmedizin – Eine Übersicht. *Schweiz Mon Zahnmed* 1988; **98:** 1200–7.
10. van der Stelt PF, Webber RL, Ruttimann UE, Groenhuis RAJ. A procedure for reconstruction and enhancement of tomosynthetic images. *Dentomaxillofac Radiol* 1986; **15:** 11–18.
11. Wenzel A. Effect of image enhancement for detectability of bone lesions in digitized intraoral radiographs. *Scand J Dent Res* 1988; **96:** 149–60.

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