Abstract:

Diagnostic performance obtainable from existing dental radiographic systems tends to be limited largely by arbitrary, two-dimensional sampling of dynamic processes manifest in three spatial dimensions plus time. Improvement requires a more rational sampling strategy. Depending on the particular diagnostic task involved, this usually can be facilitated through an increase in the range and number of x-ray projections produced. In order to minimize necessary exposure risks, temporal ambiguity, and patient discomfort, this should be accomplished as fast as practical with a concomitant reduction in radiation dose per projection.

Keywords: Dental Radiography, Imaging, Diagnosis, Technological Limits

Background:

Dental radiology is big business. The National Center for Health Care Technology estimated the cost of dental radiographic examinations to be more than $730 million in 1978 [1]. Current national expenditures for dental radiographic services may exceed $2.5 billion per year. It follows that the usefulness of these exams should reflect this substantial investment, yet few unbiased data support their assumed utility. Indeed, many published studies compare performance between dental x-ray modalities without any independent clinical control whatever. [2-5] Other studies involve opinions based on consensus agreement from data obtained using multiple radiological sources,[6,7] or from selected clinical interpreters to establish conceptual ground truth from a single radiographic modality. [8-10]

These intrinsic limitations may be problems when the likelihood of necessary diagnostic information being contained in the particular radiographic projections selected for interpretation is low.

Indeed, this situation has been shown to limit diagnostic performance in certain representative routine diagnostic tasks such as the detection of interproximal caries [11] and skull fractures [12]. Results from the latter study suggest that diagnostic accuracies as low as 62% may be found under conditions when guessing alone could be expected to produce an accuracy of 50%.

While these comments apply to all types of diagnostic tasks encountered in dental radiography, they are particularly relevant for diagnosis of changes in calcified tissues. This is true because such changes are characteristic of the two disease processes of primary concern to dentists: caries and the periodontal diseases. These diseases have three features in common:

1) the processes are insidious and relatively slowly progressing;
2) in early stages, they tend to be asymptomatic;
3) the problems lead largely to irreversible changes unless recognized and treated early.

In addition, both caries and periodontal disease are characterized by multiple sites of activity that can evolve relatively independently. Because of these attributes, a dental radiographic system should perform the following tasks particularly well:

1) early detection of small incremental changes in the status of the dentition and related oral structures;
2) unequivocal location and estimation of the size and shape of specific sites of disease activity or developmental change;
3) identification of common anatomic variants that can be confused with disease processes or influence the management of related disorders.
Conventional dental radiography may be considered a static imaging technique for showing all or a selected region of the orofacial tissues in a single projection. Such projections usually result in two-dimensional images of one or more teeth and related dental tissues. Most of these images are produced individually and independently on x-ray film either through simple transmission or panoramically. The latter involves scanning the patient with a longitudinally directed fan-shaped x-ray beam which rotates around the patient's head. This produces a panoramic image of the structures lying in a curved plane which usually is positioned in register with the dental arch. The newest available systems differ significantly from this description only through replacement of the x-ray film with a solid-state detector derived from charge coupled device (CCD) technology. Subsequent analog to digital conversion mediated by a frame grabber permits instantaneous display of the projections on video monitors or CRT-based computer displays.

Factors limiting the application of these technologies to the tasks cited above can be prioritized easily when considered within the context of a simple model. [13] Consider the diagnostic process as a closed system by which information extracted from a patient is considered the input and a specific diagnosis is the output. (Fig.1)

Under these conditions it is convenient to divide the diagnostic process into five sequential steps:

1) the delineation of the particular diagnostic question to be answered;
2) the formulation and use of an appropriate method for acquiring information pertinent to that question;
3) the acquisition of data from a sample large enough to permit the drawing of statistically valid conclusions, (but small enough to minimize the necessary disturbance created by any sampling procedure);
4) the processing of these (and pertinent internal) data as required to make the information interpretable to the diagnostic decision maker;
5) the rendering of a diagnostic decision.

Factors influencing the transfer of essential diagnostic information from one step to the next in this process depend on those preceding in this hierarchy. Hence, factors pertinent to all but the last step may be considered as nested elements which can limit accuracy as schematized in Fig.1.

Assuming the three essential diagnostic tasks in dentistry to be defined unequivocally as listed above, consideration can be extended directly to the second element in the nested chain comprising the model. This element deals with the strategy used to sample the signal. In the case of the existing dental radiographic technologies described above, sampling means choosing a particular projection or sequence of projections which optimally demonstrate the extent of lesions to be detected. The main problem here is that an appropriate projection usually depends on where the lesions are located, which necessarily is unknown and hence determinable with assurance (if at all) only after the fact. That this uncertainty of location is of real concern is easily demonstrated with interproximal caries where even a small change in horizontal angulation of the primary x-ray beam can result in significant overlap in the images of associated proximal surfaces. For conventional film-based dental radiography, it is well known that this overlap can irreversibly mask evidence of incipient decalcification in this region. It can be shown that comparable obscuration of poorly localized lesions, such as are common in periodontal diseases, likewise results from inappropriate projection geometry. However, in this case the inadequacy of the projection usually is much less obvious. Hence, to the extent that this simple nested model is valid and traditional radiographic

![Fig. 1](image-url)
projections undersample available data, no amount of improvement in signal-to-noise ratio or mode of display (system elements 3 and 4, respectively) is likely to improve resulting diagnostic performance very much.

 Conversely, significant improvement in diagnostic performance of these essential tasks probably will require more uniform sampling of dental radiographic images in three spatial dimensions (3-D) plus time. This in turn requires new technology capable of recording 3-D information reliably and reproducibly from projection angles limited by available access to the associated oral tissues.

That technology designed with these constraints in mind is capable of yielding improved diagnostic performance in such applications has been demonstrated using computer simulations and a variety of in vitro models. In the most basic terms this amounts to a discrete implementation of circular tomography. However tomosynthesis has a unique advantage over its long-established tomographic counterpart in that it permits any desired slice to be synthesized from available projection radiographs after the fact. This characteristic is particularly useful in applications wherein the diagnostic task requires a search strategy. As mentioned previously, a common dental example involves the need to detect changes in periodontal status when the location of the site of tissue destruction is previously unknown.

Another common variation of the tasks listed above, which cannot be implemented with existing technology for the same reason involves the desire to make assessments of tissue changes derived from comparisons of current images with uncontrolled conventional radiographic images produced months or even years earlier. Preliminary work involving applications of robust contrast-correction algorithms, projective geometry, and reconstruction of arbitrary 2-D projections from an existing series of constrained tomosynthetic projections provides theoretical grist for more elegant solutions to such problems. A particularly troublesome obstacle is the need for an efficient means of mapping clinically unchanged elements of one image into another when they are generated using different and unknown projection geometries, and when they manifest uncontrolled, nonlinear contrast differences.

Technology Constraints and Specifications:

Because the process of signal sampling precedes consideration of signal strength in the nested model shown in Fig. 1, it stands to reason that radiographs characterized by high information capacity may not be essential for satisfactory performance of tasks limited primarily by inappropriate sampling. That this is true for dental diagnostic tasks of the type listed above has been demonstrated from objective measurements of diagnostic performance obtained from images differing only in signal-to-noise ratio.

Conversely, significant improvement in diagnostic performance of these tasks can be realized through redirection of the sampling strategy rather than through increases in the total amount of information (data) obtained. Accordingly, the total exposure to x-rays required to perform the task should be determined by the associated cost/benefit ratio.

Preliminary findings based on the application of digital subtraction radiography suggest that image displays having pixel capacities of 512 x 512, dynamic ranges of no more than six bits, and simulated x-ray fluences as low as 20 photons per pixel are adequate to permit significant improvement in the performance of a representative diagnostic task of the type cited above. Such specifications lay well within the capabilities of economically reasonable x-ray sources and graphic-display products which are commercially available even today. Conversely, the lack of apparent quantum mottle in conventional nonscreen dental radiographs likewise suggests that noisier and more quantum-efficient transducers could be tolerated in many other dental applications notwithstanding the reluctance on the part of many dentists to give up such "pretty" images.

To the extent that existing technology is to be used to gather multiple images during a single examination to facilitate the acquisition of three-dimensional data, the time required to perform this operation becomes an important constraint. Not only does patient stress increase with prolonged data acquisition times; the longer the procedure, the more likely inadvertent movement of the x-ray system relative to the patient. Depending on the design of the system, this movement can destroy the geometric basis for reconstruction of the three-dimensional image.

Contemporary dentistry provides a particularly challenging target for technological innovation of the type suggested because its market base is
distributed largely among many relatively small independent entrepreneurial clinical practices. For the most part, these individual practices lack sufficient financial resources to support the cost of even modest technical developments of the sort routinely established in large medical clinics and hospitals. For this reason, engineering of improved dental diagnostic systems must include consideration of innovative means for marketing and distributing investment resources consistent with a reasonable economic return. This consideration implies either individual one-time investments limited to a few thousands of dollars or some sort of networking scheme to facilitate cost sharing among multiple practices.

Contact:
Richard L. Webber, D.D.S., Ph.D.
Professor, Departments of Dentistry and Radiology
The Bowman Gray School of Medicine
Medical Center Boulevard
Winston-Salem, NC 27157-1093
Telephone: (919) 748-4707
Telefax: (919) 748-4204
Electronic Mail: webber@mrips.bgsm.wfu.edu

References:


