B. DENTAL RESEARCH

PRELIMINARY OBSERVATIONS AND PROJECTIONS

Dr. Richard L. Webber
National Institute of Dental Research

Although there was a desire to emphasize clinical applications for the Lixiscope, this report is limited to preliminary observations and projections for two reasons:

1) Objective clinical evaluation requires formal testing, which involves a research protocol. Any protocol involving human subjects at potential risk requires appropriate clearances and reviews, which take substantial amounts of lead time. This is particularly true in an organization as large as the National Institutes of Health (NIH). In the case of the Lixiscope, a prototype has not been in existence long enough to get such a project initiated, much less reviewed.
2) A prototype suitable for clinical application in dentistry has specific requirements and environmental restrictions over and above those associated with the orthopedic applications described by the previous speakers.

The design of the Lixiscope at this stage in its development is not precisely determined. About all that can be said is that it involves three distinct considerations:

1) **a small self-contained source of ionizing radiation,**
2) a high-speed photon detector capable of producing an on-line image derived from a microchannel plate image intensifier, and
3) **a suitable geometric relationship which determines the coupling between these two components.**

These conceptual ingredients are yet to be integrated into a prototype suitable for clinical application in dentistry and thus no device exists which can be tested for the potential applications currently being considered at the National Institute of Dental Research (NIDR). Given that no Lixiscope currently exists which meets the needs of a clinical research protocol yet to be completed, one might conclude that little is known about the potential applicability of the Lixiscope in dentistry. Fortunately this is not entirely true, because the three conceptual ingredients cited above have been independently under investigation by NIDR scientists for some time. Therefore, it is possible to consider conceptual limitations on basic design requirements common to the Lixiscope in the absence of a clinical experience with a suitable prototype. Hence, the remainder of this paper concerns pertinent observations applicable to the Lixiscope considered within this rather loosely defined conceptual framework.

Exposure Geometry

By placing the source of radiation in the mouth and the imaging device outside, it is possible to significantly reduce the amount of radiation dose to the patient as compared with the conventional dental radiographic technique as shown in Figure 1. It should be noted that conventional radiographs are produced from film packets situated inside the mouth. The x-ray source must emit a beam sufficiently larger than the film to assure that a portion of the film is not missed in the process of aiming. As a result, a substantial portion of the head is subjected to radiation extending beyond the film plane, which contributes to patient dose and image degradation due to radiation scatter from deeper structures.

Contrast this geometry with that shown in Figure 2 which corresponds to that made possible by the Lixiscope. The intraoral collimated source is rigidly coupled in such a way, that it is impossible for the beam to miss the detector. Hence, the beam can be made small without risk of "cone-cutting" the image. Unnecessary exposure is further reduced by having the x-rays directed from inside the mouth to the outside, because the only tissues irradiated are those of diagnostic interest plus the soft tissues of the lips or cheek. Figure 3 is a plot of the theoretical dose

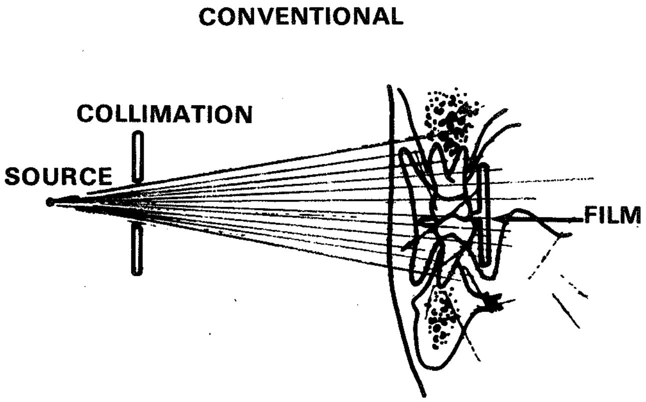

Figure 1. Schematic Diagram of Conventional Dental Radiographic Geometry

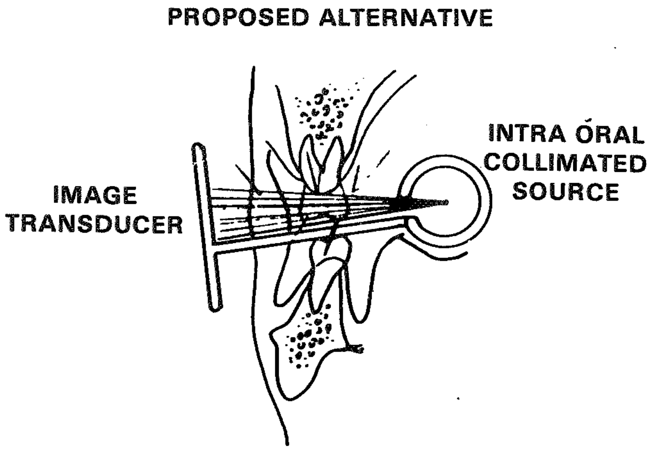

Figure 2. Schematic Diagram of Alternative Geometry Made Possible by an Intraoral Source of Radiation

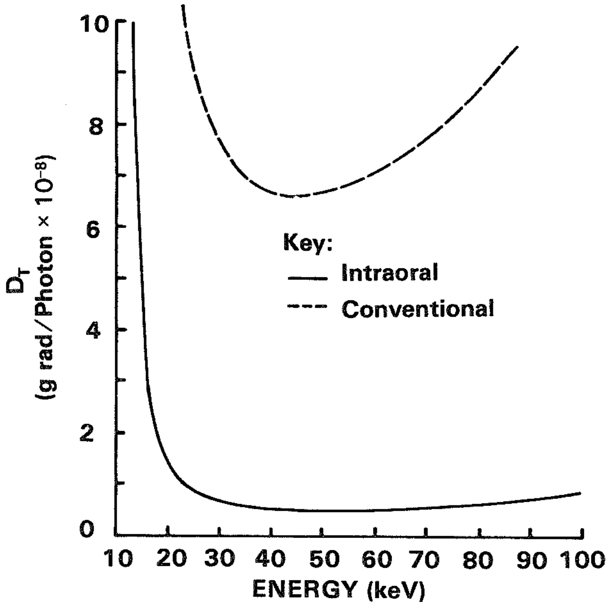

Figure 3. Integral Dose per Photon Reaching the Detector Expressed as a Function of Energy for Conventional and Intraoral Source Models

advantage expressed as a function of x-ray photon energy computed from a water phantom using a simple geometric model designed to compare these two configurations.[1] It can be seen that at no level of energy does the estimated integral dose per photon reaching the film plane for the intraoral source exceed that computed for the conventional source geometry. Even when a liberal allowance is made for the acknowledged limitations of the model, it is intuitively obvious that exposure efficiency is greater when the source is located intraorally, because radiation extending beyond the film plane does not contribute to patient dose.

Another geometrical advantage of the Lixiscope when compared with the *status quo* is the fact that it functions as a true fluoroscopic device. This is to say, that it can be manipulated on-line to permit multiple views to be sequentially observed to yield an integrated three-dimensional conceptualization of the structure being imaged. The dental significance of this multiple-view capability provided by the Lixiscope is illustrated by the effects of a change in source angulations shown in Figures 4 and 5 respectively (reproduced with the permission of Dr. K. Thunthy, Louisiana State University, School of Dentistry). The radiograph shown in Figure 4 indicates interproximal bone between the second bicuspid and first molar extending all the way up to the point where the dental enamel of the crowns joins the cementum

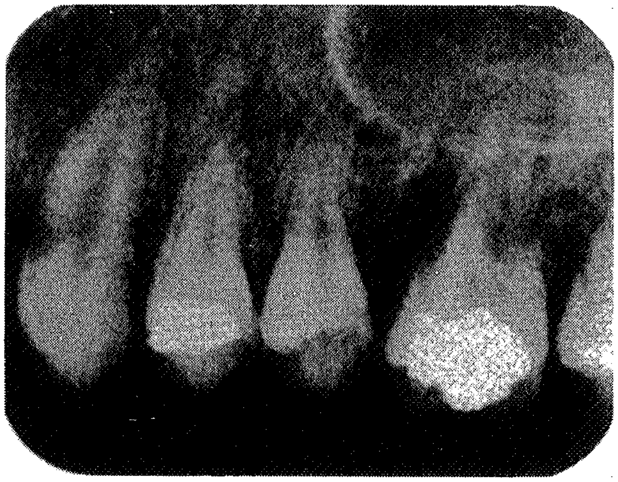

Figure 4. Angled Projection of Periapical Structures Showing Interproximal Bone Between the Bicuspid and Molar

Figure 5. Same Tissues as Shown in Figure 4. Altered Projection Geometry Reveals Large Periodontal Lesion Between the Bicuspid and Molar

covering the surface of the respective roots of these teeth. Figure 5 shows the same teeth projected from a slightly different source position. The bone in the interproximal region of interest is now seen to be missing next to the molar all the way up to the apex of the root. Thus, it is easy to see how this huge periodontal lesion could be missed by limiting consideration to a single x-ray projection as conventionally practiced. The potential diagnostic advantage afforded by the exposure geometry of the Lixiscope under these conditions is self-evident.

Radiation Source

In addition to the obvious advantages of simplicity, self-containment, and small size afforded by the use of an isotope as an x-ray source, the monoenergetic nature of the energy spectra produced by suitable isotopes has interesting implications for fluoroscopic applications. For example, ^{125}I used in the prototype Lixiscope described previously has line spectra narrowly clustered around 29 keV (see Figure 6). Also shown is a typical aluminum-filtered spectrum produced by a conventional dental x-ray machine. The relative maximum spectral output is approximately at the same energy as that produced by ^{125}I, but the conventional source produces a much broader spectrum ranging from zero to 60 kVp or more. This basic difference in energy distribution has a significant effect on the potential maximum amount of information available depending on the nature of the diagnostic task to be accomplished.

The exact nature of this relationship was explored by C. O. Henrikson[2], who used a hydroxyapatite-water phantom to model the caries detection task in teeth having a variety of equivalent thicknesses. By taking into account the linear attenuation characteristics of the tissues he was able to determine the minimum radiation dose as a function of x-ray energy required to reliably detect a one mm^3 lesion assuming an ideal radiation detector.

The results of this exercise are shown in Figure 7. It can be seen that the optimum energy, i.e. the energy requiring the lowest dose for reliable caries detection, depends on the thickness of hydroxyapatite to be penetrated. Of particular interest is the fact that energies around 30 keV appear optimum for the detection of small lesions in the 2 mm hydroxyapatite model. This suggests that for relatively thin calcified tissues ^{125}I has a nearly ideal spectrum. On the other hand, thicker tissues require significantly higher energies to efficiently yield diagnostic information at the same level of reliability. Translated in terms of the Lixiscope, this means that ^{125}I will require significant doses to produce satisfactory images of calcified structure with equivalent hydroxyapatite thickness greater than 3 mm. Of even more importance is the fact that this limitation is of a fundamental nature that cannot be changed by manipulation of other elements in the system. Clearly, efficient use of an isotope such as ^{125}I requires that the Lixiscope be limited to a relatively narrow range of diagnostic applications.

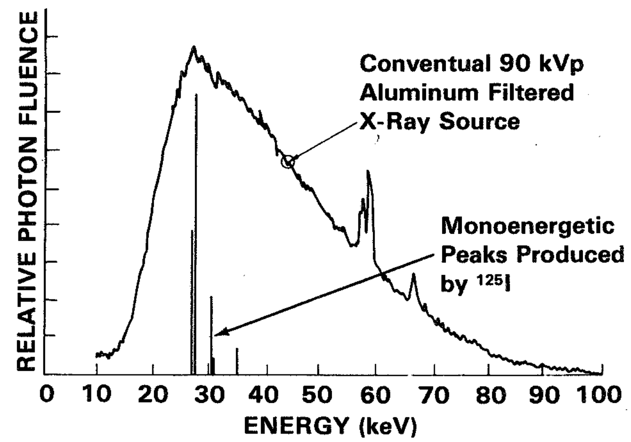

Figure 6. Relative X-ray Energy Spectra of a Conventional Source and ^{125}I

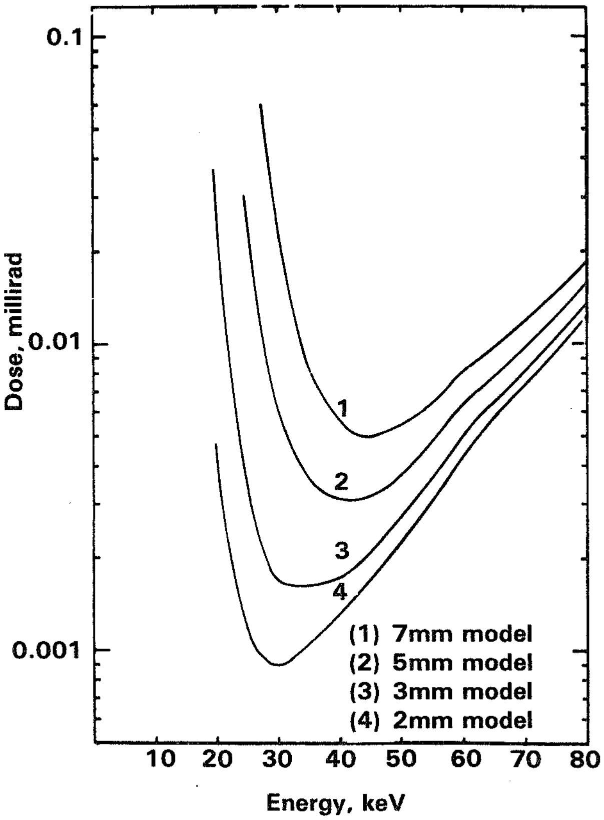

Figure 7. Dose as a Function of Energy for Various Hydroxyapatite Models (Courtesy of C. O. Henrikson)

X-Ray Detector

Perhaps the most novel aspect of the prototype Lixiscope involves the use of a high-gain microchannel plate image intensifier as an x-ray detector. Figure 8 shows schematically the basic elements of this device. x-ray photons containing information of diagnostic interest cause a fluorescent screen to emit luminous energy which in turn activates a proximity-coupled photocathode. The resulting electrons are accelerated at high potential through a coherent array of hollow glass tubes fused into a disc-shaped structure called a microchannel plate (MCP). Each tube acts like a miniature photomultiplier, so that each electron entering the plate creates an avalanche of electrons, which are detected at the output by a proximity-coupled phosphor screen to create a visible image.

Rational selection of MCP specifications demands an assessment of clinical requirements. Quantum-limited photomultiplying devices are intrinsically noisy, so that there is a definite need to determine how much information is necessary to perform tasks of diagnostic interest. The research in this area is only beginning to yield answers which confirm the task-dependent nature of image quality. The over-all efficiency of information transfer is also influenced by the choice of detector. This effect is illustrated by comparing the information capacity per dose produced by two typical x-ray imaging-systems as shown in Table 1. It can be seen that there is slightly more than a three-to-one ratio in information capacity between screen and no-screen systems, whereas the ratio between respective doses is more than an order of magnitude. This means that the higher speed system is more than five times as efficient in transfering information. The use of high-speed screens with the Lixiscope makes possible a substantial increase in efficiency for a variety of potential applications in dentistry. The anticipated compromise in image quality is illustrated in Figure 9 (courtesy of Dr. J. Gibbs, Department of Radiology, Vanderbilt University). The only difference between the dental radiographs shown is that the one at the top was produced conventionally, whereas the bottom radiograph was produced with an intensifying screen inside the intraoral film packet.

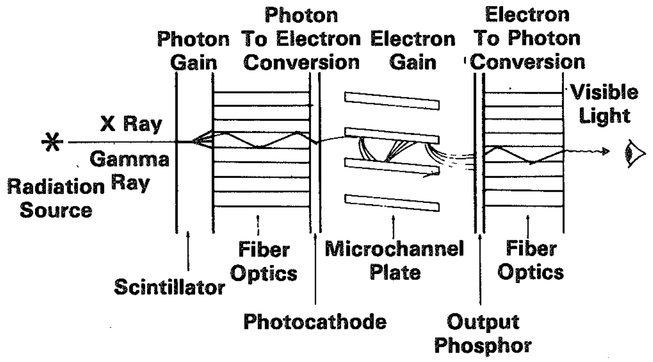

Figure 8. Schematic Diagram of MCP Image Intensifier Used in the Lixiscope

Table 1. Relationship Between Information Capacity and Dose

	PA	PA c̄ Screens
Information Capacity (Bits)	168,000	52,000
Dose (mR)	50	3
Capacity/Dose (Bits/mR)	3,360	17,200

For many routine diagnostic tasks in dentistry, it appears obvious that the image quality of the bottom radiograph would be adequate. This conclusion is substantiated by the observation that a reduction in computed signal-to-noise power ratio of approximately 30 percent failed to significantly influence the detectability of incipient interproximal lesions from bite-wing radiographs when tested parametrically with 140 degrees of freedom.[3] In this case, image degradation was produced by prefogging

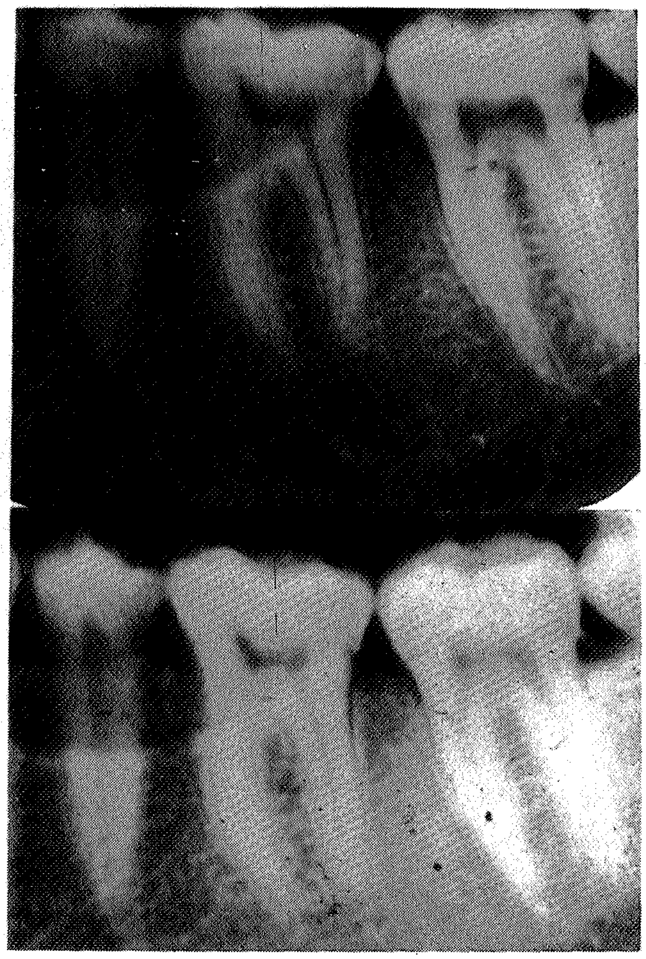

Figure 9. Comparison of Conventional (Top) and Screen-Film System (Bottom)

no-screen film with unmodulated x-ray exposure as exemplified in Figure 10. Of course factors other than source geometry, spectral characteristics, and detector speed influence image quality obtainable from Lixiscope, and these too must be considered in order to characterize unequivocally its diagnostic potential in dentistry. At least some of these have been addressed by Dr. Yin in a recent paper presented under the auspices of the Society of Photo Optical Instrumentation Engineers.[4]

Figure 11 is an actual example of a dental image produced from a skull phantom with a prototype Lixiscope. It clearly shows the root canals in maxillary teeth including the relative position of an endodontic file. It should be noted that the image was photographed with a Polaroid camera optically coupled to the output screen of this Lixiscope. The result is a photographic "positive" rather than the conventional radiographic "negative." Hence, radiopaque structures are imaged dark rather than light.

Figure 10. Effect of Unmodulated Radiation on Posterior Bitewing Radiograph. Darker Region on Right has 30% Reduction in Estimated Signal-to-Noise Power Ratio

While the image appears to be an encourgaging example of what has already been accomplished with the Lixiscope, its future in dentistry will undoubtedly depend on how well it performs in actual clinical situations, particularly when used as a fluoroscope. Hopefully the interest generated by its development and expressed in this conference will be sufficiently sustained to adequately test its potential in the clinical practice of dentistry.

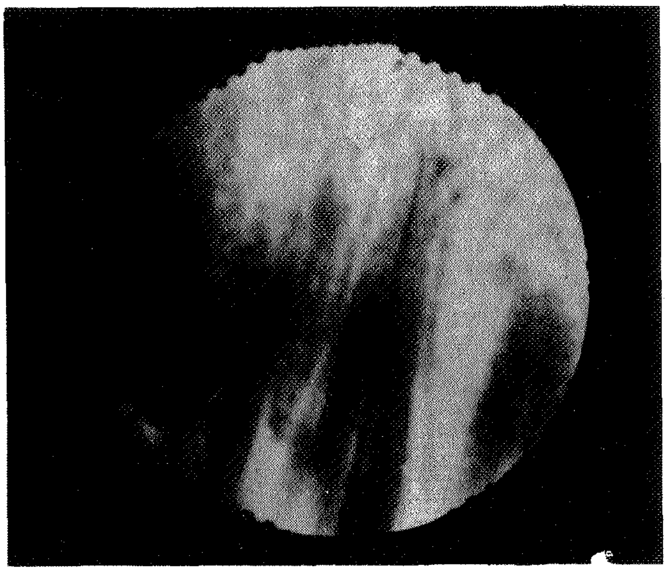

Figure 11. Photograph from Lixiscope Image of Maxillary Teeth Showing Root-Canal File

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2. Henrikson, C. O., Acta Radiologica Suppl. *269*, 1, (1967).
3. Webber, R. L and L Stark, Investigative Radiol. 7, 6, (1972).
4. Yin, L., J. Trombka, S. Seltzer, R. L Webber, M. Farr, and J. Rennie, NASA Technical Memorandum 79634.