PREFACE

Dr. Reidar Sognnaes died on 21 Sept. 1984 of a heart attack at the age of 73. Several months following his death, Dr. Gratt was asked by his widow to explore the possibility of completing this manuscript from Dr. Sognnaes' notes. This manuscript is published posthumously and, in so doing, honors the memory of Professor and Dean Emeritus, Reidar Sognnaes.

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Biomedical Image Processing for Age Measurements of Intact Teeth

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ABSTRACT: With increasing age the roots of teeth undergo sclerosis. The degree of dental root sclerosis can be demonstrated visually if light is transmitted through the specimen. However, this resultant image is only a two-dimensional (2-D) visualization which misrepresents what in truth is a three-dimensional (3-D) characteristic. We have described an image acquisition and computer processing system for imaging intact teeth, with special reference to the root transparency, which tends to progress from the root apex towards the neck of the teeth as a function of age. The components of our system involve: (1) an energy source with light transmission through table-mounted dental specimens; (2) an image processor with a digitizer; (3) a step motor with a holder to rotate the tooth specimen; and (4) a software package to computerize and reconstruct the sectional digital images. After rotating the position of the specimen, while at each rotation obtaining a 2-D image of the sample, we then can reconstruct the true 3-D cross-sectional or longitudinal morphology or both from these 2-D images. With this new approach, the reconstructed dental images represent segments from different angles of the tooth specimen. Picture element values in each image, quantitatively indicate the optical density, expressing the age dependent pattern of the 3-D anatomy in toto.

KEYWORDS: odontology, dentition, computers

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In 1980 the American Association for the Advancement of Science organized a symposium on aging, later published as a monograph in Washington, DC [*1*]. For this symposium Dr. Sognnaes served as organizer, moderator, and coauthor of a multi-authored chapter on oral aspects of aging. This chapter covered various approaches to studies ranging from anthropology to pathology. Of particular interest to Dr. Sognnaes was the various age changes observed in sectioned human teeth from individuals of different ages. These investigations compared, among other things, the several criteria which Gustav Gustavson [2] had proposed years earlier for the aging of teeth, ranging from attrition and secondary dentine to periodontal attachments, cementum deposition, root resorption, and, in addition, root transparency. It is the latter condition, root transparency, which Dr. Sognnaes pursued further employing biomedical image processing.

Root Sclerosis and Transparency on Human Teeth

A cooperative study was undertaken by Dr. Sognnaes and his former Harvard students (Drs. Nalvention and Gonzales). They examined, in detail and employing time magnification, the nature of the secondary mineralization of the dentinal tubules that result in dental root transparency. Evidence was obtained by several methods (including high resolution microradiography, optical transparency, transmission electron microscopy, and electron diffraction) which compared normal young dentine with that of older sclerosed dentine. It became apparent that this transparency phenomenon is less likely to be influenced by secondary habits (or pathology), as would be true in the case with attrition (wear and tear on the outside of the teeth), secondary dentine deposition, the height of the epithelial attachment (as periodontal recession takes place with age), and secondary cementum deposition and resorption (as influenced by occlusal changes and pathology). The investigators were able to confirm Dr. Gustavson's general conclusions regarding the total of age changes seen in teeth and arriving at similar age distributions. These studies emphasized the particular significance of the root transparency for the aging of teeth.

Others who had an opportunity to observe and study their results came to similar conclusions [*3-6*]. One Visiting Fellow from the University of Bergen, Dr. Gisel Bang, returned to Norway and in collaboration with Dr. Ramm studied age determination from optical studies of the root dentine transparency published in Scandinavia in 1970 [*7*]. Actually, with adequate lighting, the apical root transparency can be measured, to some extent, when applied to whole, intact teeth. As a matter of fact, this was one of the methods Dr. Sognnaes used in age determination from dental examination of the skull excavated in Berlin and attributed to Hitler's right-hand man, Martin Bohrman [*8*].

More recently, Dr. Sognnaes worked with colleagues within the UCLA Center for the Health Sciences studying root tip transparency of intact teeth by means of the newer tools of image acquisition and computer processing. The components of this system consist of: (1) an energy source with light transmission through table mounted specimens; (2) an image processor with a digitizer; (3) a step motor with a holder to rotate the specimens; and (4) a software package to compute and reconstruct the sectional digital images.

Image Acquisition

The imaging acquisition chain (Fig. 1) consists of placing the tooth sample with the intact root along the axis of the stepping motor shaft. The black-and-white video camera (Spatial Data VidiCon) is then placed in front of the sample (Fig. 2). Since portions of the tooth root are semitranslucent one can see the interior structures with backlight supplied by the light table.

The image from the camera is constructed into a digital matrix of 512 by 512 elements. Each element, called a pixel, is assigned a discrete gray level value of 0 (black) to 255 (white). This process called digitization is performed by the Gould IP8500 image processor.

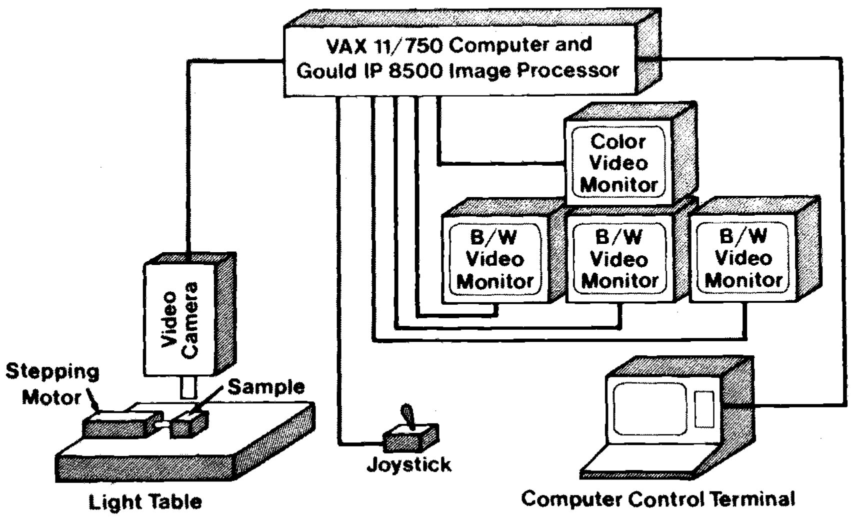

FIG. 1—*Overview of imaging system where* (a) *tooth is placed in sample holder.* (b) *Light table provides a backlight for transillumination of tooth which is then scanned by standard black-and-white video camera.* (c) *Stepping motor is used to rotate tooth to obtain the ideal profile.* (d) *Signal from the camera is sent to the VAX Computer and Image Processor. Once stored in the computer the images can be displayed on the bank of video monitors. More than one image can be displayed simultaneously for comparative purposes.* (e) *System control comes from the computer terminal along with the joy stick control for image processing and isolation of special regions of interest.*

While viewing the image on a video monitor, the operator can control the stepping motor to rotate the sample at increments of 0.9° steps to obtain the profile of interest which is then stored into image memory. Control of the image acquisition is supplied by the VAX 11/750 VMS minicomputer interfaced to the control terminal and the image processor.

The operator can now perform various image processing routines for analysis of the images (Fig. 3).

Image Processing and Analysis

The image processor can manipulate and perform processing of up to twelve images (Fig. 4). Additional external image storage can be supplied by computer disk storage and magnetic tape archiving.

Image processing programs include outlining areas of interest and gathering quantitative measurements that can be related to qualitative image analysis for diagnostic purposes. Manual contour drawing of specific areas of interest on the image can be drawn by the operator with the joystick (Fig. 5). After the area is drawn quanitative information can be calculated. This includes a gray level histogram which summarizes the gray level content of an image. The gray level histogram is a function showing, for each gray level, the number of pixels in the image (or area of interest) that have that gray level. Other statistical information can be read off the monitor including range of gray levels, mean gray level, standard deviation, median gray level, and relative or absolute area size (Fig. 6).

Other programs include:

(1) pseudocolor mapping of gray level steps (Fig. 4*b*),
(2) image enhancement, and
(3) image comparison routines.

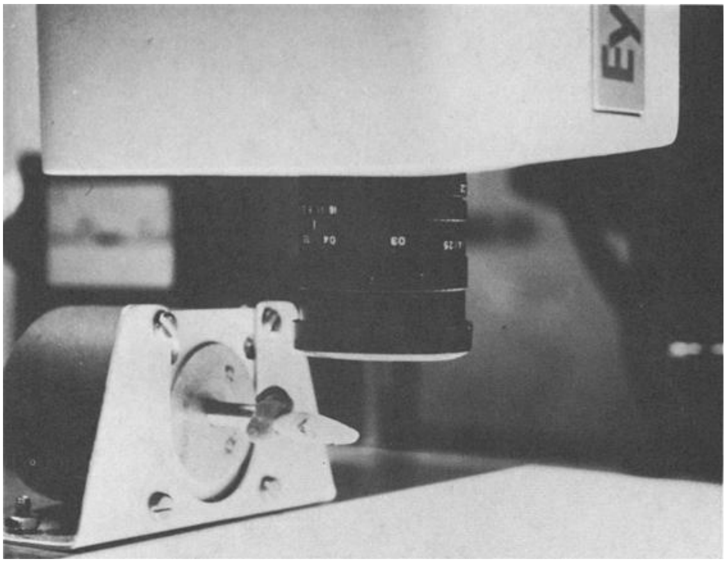

FIG. 2—*Tooth sample held by stepping motor device with light table as a source of illumination. Note the position of the Eye Com video camera (black lens) to the root end of the tooth (sample).*

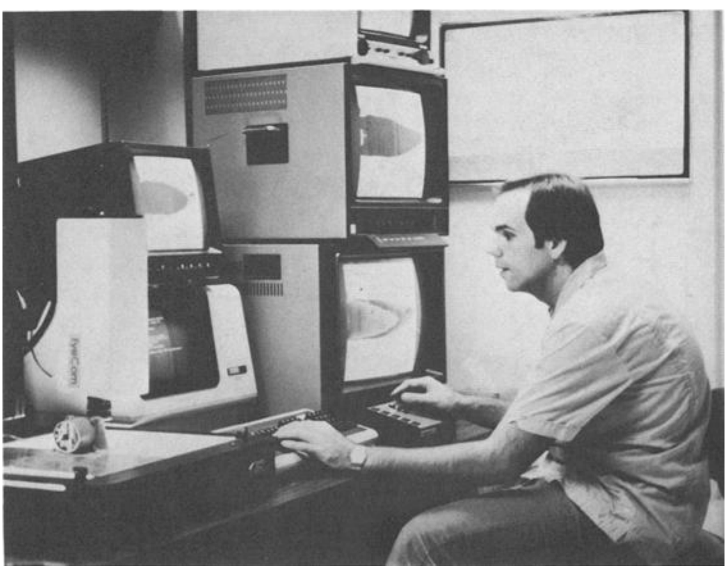

FIG. 3—*Photograph of research operator using the image processing system.*

Discussion

Some 50 years ago it was observed that dyes penetrated dentine in teeth of younger individuals whereas teeth of older persons contained areas that were partially or totally resistant to the penetration of the stains [*9–10*]. This difference was probably caused by impregnation of the dentinal tubular spaces with secondary matters. At first, it seemed logical that this was

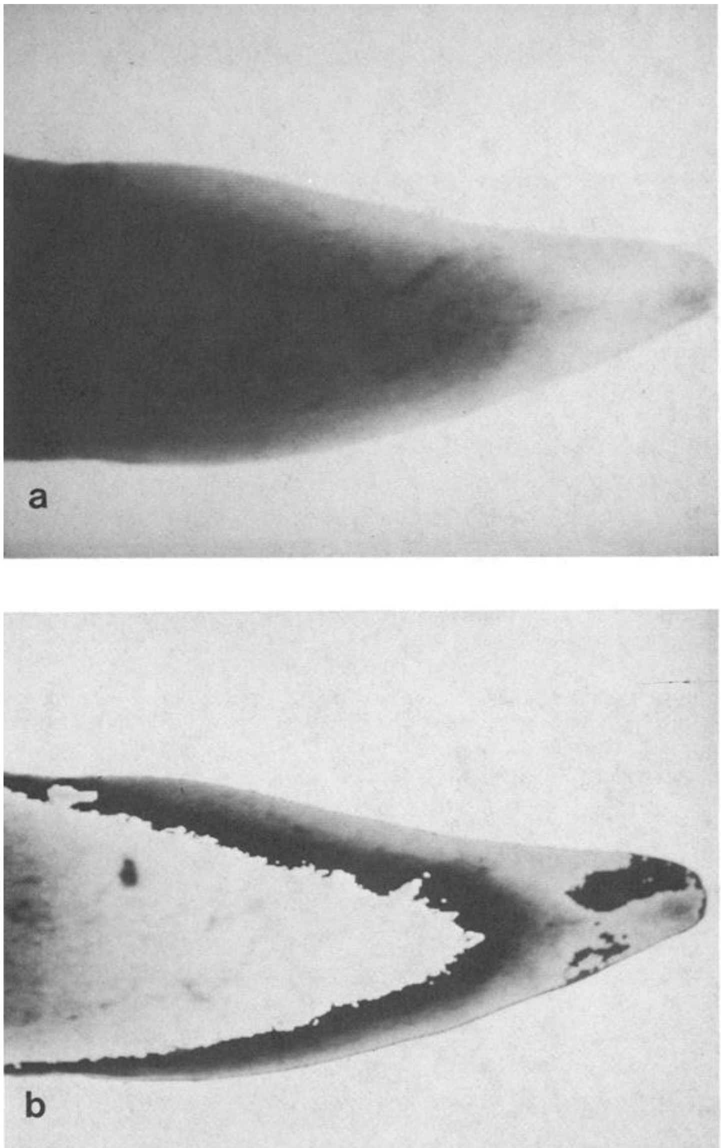

FIG. 4—(a) *Digital image of the tooth seen on video monitor from the image processor. Note the translucency at the root end of the sample.* (b) *Same tooth and image with a computer conversion from gray levels to pseudocolor imaging.*

caused by a condition that could lead to a higher calcium content of the areas so affected. Subjective tests, however, proved relatively noninformative and Dr. Sognnaes concluded that this was largely a result of the fact that studies were based on gravimetric measurements. That is to say, if an area of dentine not affected by sclerosis was weighed, one would simply, in order to obtain comparable weights from a sclerotic area, deal with a smaller portion of the substance rather than a difference in weight. It is what Dr. Sognnaes referred to as the Swiss and American cheese comparison. By weight, there is about an equal calcium content, but by volume, the

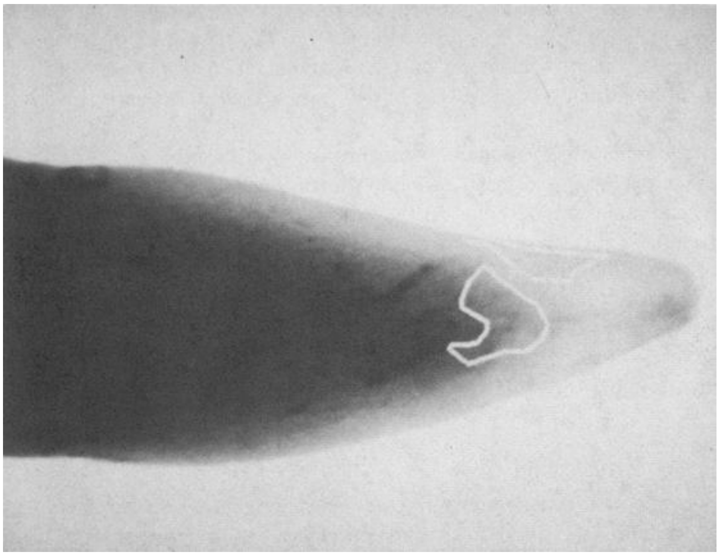

FIG. 5—*Digital image of tooth (same image) indicating areas of interest drawn by operator using the computer joy stick. Note white lines on the digitized root image.*

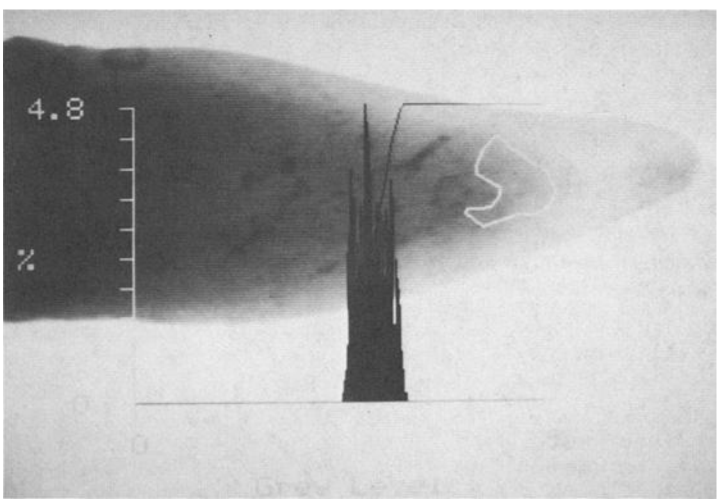

FIG. 6—*Demonstrates histogram superimposed over digitized tooth image. A quantitative assessment of density is being made in indicated areas.*

slice of Swiss cheese, would, of course, be considerably larger, if the study had been made on a volumetric basis. It was Dr. Sognnaes' conclusion, therefore, that future studies of this nature regarding the mineral content in ordinary and sclerosed dentine must be based on gravimetric analysis.

Methods for separation of the various fractions of dentines by gravimetric means were developed in the 1980s by Dr. Hutch and Manly at the University of Rochester. A second and more direct approach is to obtain micropore samples of the dentine from the roots of teeth of various ages and set up a battery of fluids of different gravimetric density as did Hutch and Manly and then determine the specific gravity of the samples involved. It would, of course, take a very elegant, small core drill with diamond dust to obtain such small samples on human teeth, whereas it would be probably readily done initially on elephant tusks with a much larger core drill.

Previously, the main observations in assessing root translucency had been related to the method of image processing in terms of a two-dimensional observation of intact teeth as in medical X-ray computed tomography. In the future we will be investigating the feasibility of using the system described to reconstruct actual two-dimensional tomographic sections from the profiles of the tooth samples rotated around 180°. In addition, other light energy sources and light detectors are under evaluation. This, of course, would have a greater practical value for prompt determination of the probable age of the potential victims of crime. In addition, the computer application presents very prompt diagrams and statistical information that can be stored for future comparisons [*11*].

Conclusion

In conclusion, the new developments in image processing have been applied to an exploratory study of its potential use in age measurements of root transparency of intact human teeth. It is suggested that this phenomenon of secondary mineralization and sclerosis of the root dentine is perhaps the most reliable physiological age change of human teeth less affected by secondary pathology and habits. The method has the advantage that it would not require the destruction of the specimens involved by sectioning. In addition, with a computer imaging system, the method permits an immediate graphic illustration of the observed differences in transparency in various areas of the root and statistical information for storage of the quanitative data for any future use.

Acknowledgment

As a final note, Dr. Sognnaes wished to not only add his appreciation to his colleagues in the various departments at UCLA, but inject the general comment that such cooperation within the university framework would probably be of great benefit to advances in forensic odontology, which is no longer as readily conducted from the private dental office as it was with simpler methods in the past.

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