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## Digital Radiography for the Quantification of Alveolar Bone Loss in Studies of Periodontal Disease Variation

CHARLES F. HILDEBOLT, THAD Q. BARTLETT, AND MICHAEL K. SHROUT

*Washington University School of Medicine, Mallinckrodt Institute of Radiology, 510 S. Kingshighway Blvd., St. Louis, MO 63110 (C.F.H.); Department of Anthropology, Washington University, St. Louis, MO 63130 (C.F.H., T.Q.B.); Medical College of Georgia, School of Dentistry, Augusta, GA 30912-1241. U.S.A. (M.K.S.)*

It has been hypothesized that differing human groups show varying patterns of periodontal disease. To test this hypothesis, accurate and reproducible measures of periodontal disease must be used. One method for achieving this end is through the use of digital radiography. Once the distribution of periodontal disease is known, it will be possible to make suggestions concerning possible etiologic agents. In this paper, we present a short review of periodontal disease epidemiology and our experience with digital radiographic methods for the quantification of periodontal disease.

The largest and most comprehensive dental survey ever undertaken was recently conducted by the National Institute of Dental Research (The National Survey of Oral Health of U.S. Employed Adults and Seniors: 1985-1986). In this study, 20,000 adults representing 104 million people were examined. This survey was a repeat of one conducted in 1979-1980. Although periodontal health had improved since the earlier time period, 42% of those over the age of 65 were toothless. Those who retained teeth had more severe and advanced periodontal diseases than did younger adults. It was concluded that "periodontal diseases remain widespread in America" (Broadening the scope: Long-range research plan for the nineties: National Institute of Dental Research, NIDR).

The actual cause or causes of periodontal disease are not well understood. Bacteria in dental plaque are generally thought to be major contributors, but whether a genetic or environmental component contributes to increased host susceptibility or whether particularly virulent strains of bacteria cause rapid disease progression is unknown. Findings that the rate of periodontal disease differs among individuals has led to the suggestion that periodontal bone loss does not occur at equal rates throughout the population and that the highest prevalences of loss may occur in specific ethnic, geographic, and socio-economic groups (Bailit and Manning, 1988; Baelum et al., 1988; Albandar, 1990). The identification of these groups highlights an important area for future research; however, the identification of putative high-risk groups requires a suitable method that can be used to quantify periodontal disease. The development of such a method has proven to be a challenging problem (Hildebolt and Molnar, 1991).

### CLINICAL METHODS FOR STUDYING PERIODONTAL DISEASE

Clinical evaluations of periodontal disease are based predominantly on probing depths, a soft tissue measurement that is made with a hand-held periodontal probe. For example, the presence of a periodontal pocket is considered to be pathognomonic of past adult periodontal disease activity and indicates cumulative damage to the junctional and sulcular epithelium, with concomitant apical migration of the junctional

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epithelium and destruction of the periodontal ligament and alveolar bone (Barrington and Nevins, 1990; Greenstein and Caton, 1990). A more time-consuming measurement is gingival attachment level (AL). The measurement of AL (usually made from the cemento-enamel junction) is the most commonly used measurement of past disease activity in clinical trials (Caton, 1989; Greenstein and Caton, 1990; Lang and Bragger, 1991). It is important that such trials be conducted over an extended period of time to assure that measurements represent true changes in attachment level and not merely changes due to localized gingivitis (Greenstein and Caton, 1990). The inherent problems associated with making such evaluations with a standard manual probe (for instance measurement accuracy and repeatability) are well known (Jeffcoat, 1991; Hildebolt and Molnar, 1991).

Another commonly used method for measurement of periodontal disease is the quantification of alveolar bone with dental radiographs. The ultimate sequela of periodontal disease is advanced alveolar bone resorption and related tooth loss. Digital radiography has the potential to identify bone resorption before it is clinically detectable and thus aid diagnosis and treatment. In the past, however, the quantification of alveolar bone loss from dental radiographs was cumbersome, and therefore radiographic methods were not widely used. Recent advances in digital imaging technology have provided new possibilities for improving the diagnostic capabilities of dental radiology.

### DIGITAL IMAGING OF DENTAL RADIOGRAPHS

Digital imaging of dental radiographs requires a computer and a digitizing system (Fig. 1). In the last few years competition in the market place has reduced the price of both digitizers and computers, making digital radiography available to an increasing number of researchers. These methods are practical and have a high degree of accuracy and reproducibility. Since 1986 our laboratories have focused on the use of digital radiography to quantify alveolar bone and other dental features in living and extinct, human and nonhuman primate populations.

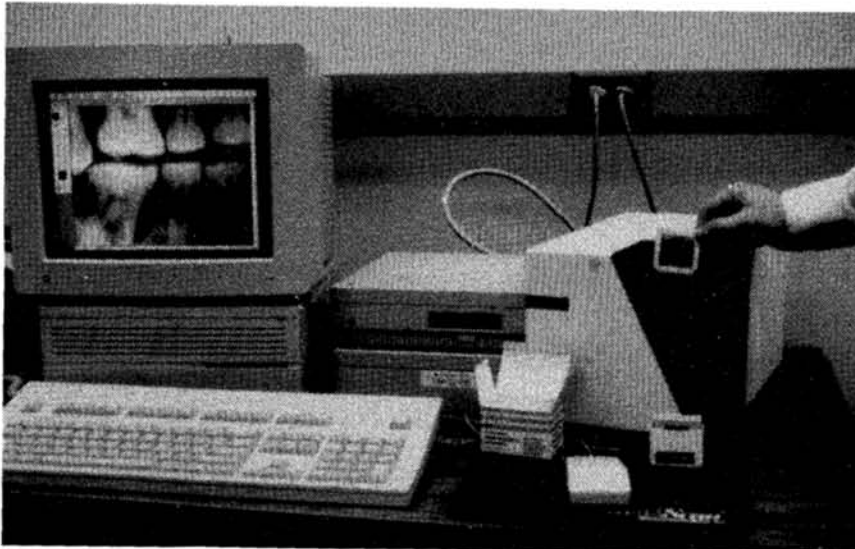


Fig. 1 Macintosh™ personal computer, disk drive, and Barneyscan™ slide scanner used for digital image processing.

In our studies, we have had the most experience with the Apple Macintosh™ (an adequate LC starts at about \$1,500). Therefore, most of our comments concerning image processing (working with the digital image) apply to this computer, although similar comments would undoubtedly apply to IBM PC (and compatibles) 486/25 (or faster) machines.

The digitization process involves converting an analogue radiographic image to a discrete (digital) form. This is done by dividing the image into individual pieces of information called pixels (picture elements). Each pixel contains information on its location within the image and its shade of gray (running from black to white). There are two fundamental techniques used to convert

radiographs to digital images: video systems and scanner systems.

Most quantitative periodontal disease data can be obtained using digitizers with a price tag of \$20,000 or less (that is, little additional data can be obtained with more expensive digitizers). Moreover, because of the fortuitous circumstance that dental radiographs are nearly the same size as 35-mm slide film, dental radiographs can readily be digitized with 35-mm slide scanners, for which there has been considerable competition among manufacturers. We have had experience with two slide scanners: the Barneyscan (Barneyscan Corporation, Berkeley, CA, \$3,500) and the Nikon (Nikon Electronic Imaging, Melville, NY, \$8,700). Both have proven adequate for dental radiographic imaging, although it is our experience that the

Nikon is better able to record brightness variations on dental radiographs. For high resolution (12-bit, see next paragraph) radiometric measurements we are currently using the Molecular Dynamics Personal Densitometer (Sunnyvale, CA, \$20,000).

Digital image quality is directly affected by two factors, contrast resolution and spatial resolution. Contrast resolution is determined by the number of gray scale values into which an image is divided. Most dental investigators use 256 (8-bit) levels of gray. Spatial resolution can be thought of as the number of pixels into which the radiographic image is divided. The most commonly used spatial resolution for dental imaging is 512 x 512. We are currently evaluating 12-bit resolution (4096 gray levels) and spatial resolution requirements for periodontal disease imaging (Hildebolt, Brundsen et al., 1993).

Because of the rapidity with which this technology is evolving, it is important that care be taken to ensure that the digitizer one purchases is appropriate for the questions being asked. For example, some digitizers do not have a linear response to variations in radiodensities (radiographic brightness). This may present problems if radiodensity measures are of interest in analyses. There are a number of easily performed tests that can be used to evaluate digitizer performance (Hildebolt et al., 1990a). The tests require only readily available test patterns and a hand held digital densitometer (which is available in most radiology departments or can be purchased for about \$700). As a bare minimum, one should digitize several radiographs, representing a spectrum of exposures from light to dark. As a rule of thumb, if the digitized image does not look the same as the original radiograph, it is likely that it will not lend itself well to quantitative measurement.

### DATA COLLECTION

For making measurements, we use the Image software package written by Wayne Rasband (Research Services Branch, National Institute of Mental Health, Bethesda, MD). Image is a public domain program that can be freely copied and is available through numerous user groups and Internet (ALW.NIH.GOV) or can be purchased for \$100 from the National Technical Information Service (NTIS, telephone: 703-487-4650). We evaluated Image and three other image analysis programs and found Image to be the most comprehensive for the quantitative measurement of alveolar bone loss (Hildebolt, Vannier et al., 1992).

Two types of data can be collected from digital images of dental x-rays: geometric and radiometric. To document bone loss, linear measures are typically made from the cemento-enamel junction to the alveolar crest. There is general agreement among researchers that this measure represents alveolar bone loss and that differences in geometric measures through time are due to changes in the profile of the alveolar ridge (for a different opinion see Clarke and Hirsch, 1991).

### ADVANTAGES OF DIGITAL IMAGES

Geometric measures are well suited for cross sectional studies in which average bone loss for two groups is being contrasted. These measures have been shown to have a high degree of accuracy and repeatability with both dry skulls and patients (Hildebolt, Vannier, Shrout, Province et al., 1990; Hildebolt, Vannier, Shrout, and Province, 1990). To detect a difference in bone loss of 0.4 mm (a difference that we feel is biologically meaningful) between two age matched groups, statistical significance can be achieved with a sample size as small as 25 individuals (Hildebolt, Vannier, and Shrout, 1993). Such sample sizes are readily available in patient groups and osteological collections.

Another advantage of digital radiography for making geometric measures, is that it is not necessary to make bone loss measurements of all teeth to obtain a good estimate of bone loss patterns. Our research indicates that bone loss measurements for the mandibular second premolars accounts for 84% of full-mouth variation, and 87 to 92% can be accounted for if an additional posterior tooth (excluding 3rd molars) is included (Shrout et al., 1990). Thus, two vertical bitewing radiographs (one for each side of the mouth) would be adequate for most surveys. Moreover, instead of a traditional 16-film full radiographic series, a 7-film vertical bitewing survey allows measurement of bone loss patterns to be made of all teeth, with a concomitant reduction in exposure to ionizing radiation (Shrout, 1991).

Radiometric measures of digitized dental x-rays provide a representation of alveolar bone density. It seems likely that changes in the density of the alveolar bone occur before there are actually changes in bony profile of the ridges. Radiometric measures are, therefore, ideal for longitudinal studies. Before performing such measures, however, variations in exposures among films should be corrected (Ruttimann et al., 1986).



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There is evidence that radiometric data can be used to semiautomatically classify the health of alveolar bone (Hildebolt, Zerbolio et al., 1992). Radiometric methods have also recently been used to show that there may be an interrelationship between bone mineral content in the alveolar processes and in the postcranial skeleton of some postmenopausal osteoporotic women (Hildebolt, Rupich et al., 1993).

Digital subtraction radiography has also been applied to the measurement of alveolar bone loss (Braegger, 1988). With these methods, one image is subtracted from another to determine bone changes. We do not, however, recommend this method, as both images have to be exactly superimposed to obtain quantifiable results. Digital radiographic techniques also have considerable potential for collecting data on other aspects of dental morphology. For example dental features such as dentine and enamel thickness can be assessed noninvasively in both living and fossil subjects. Recently we have applied these methods to the quantification of Neanderthal dental morphology (Molnar et al., 1993). This appears to be an important growth area for dental anthropology.

### SUMMARY

In sum, practical and affordable digital radiographic methods exist for making accurate and reproducible quantitative measures of alveolar bone loss in comparative studies of periodontal disease variation. We have even used these methods in a demanding field environment to study the periodontal health of baboons (Hildebolt, Phillips-Conroy et al., 1993). These methods offer a means of establishing the distributions of periodontal disease. Once this is accomplished, potential etiologic agents can be suggested.

### AUTHORS' NOTE

In the last issue of DAN [Clarke N (1993) Periodontitis in dry skulls. 7 (2):1-4], it was stated that "since the mid-eighties it has become evident that at the present time periodontitis is neither an all-embracing disease nor an important cause of tooth loss." In this article, we present a different but more widely held view. Additional research is required to resolve this issue.

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### *Book Review*

RECENT CONTRIBUTIONS TO THE STUDY OF ENAMEL DEVELOPMENTAL DEFECTS. Edited by Alan H. Goodman and Luigi L. Capasso. Chieti (Italy): Journal of Paleopathology, Monographic Publication 2. 1992. 400 pp. 150,000 lira (approximately \$95.00) (paper).

The study of enamel hypoplasia (EH) and other enamel defects has been, and continues to be, a common method for estimating environmental stress within prehistoric and recent populations in both physical anthropological and dental clinical fields. *Recent Contributions to the Study of Enamel Developmental Defects* will be of interest to workers in both fields. The volume contains 29 articles (plus introduction) divided among three broad categories: (1) Fundamental Issues and Methodological Contributions, (2) Application to Studying Past Human Populations, and (3) Reviews and Applications to Studying Contemporary Human Populations. With 55 contributors from the US, Canada, Mexico, Europe, India, Hong Kong, Japan, Australia, and New Zealand, this book truly represents a broad-ranging international contribution to the study.

Section 1 contains nine articles. Berti and Mahaney attempt to determine confidence intervals in the estimation of the age at which hypoplastic defects occur; and they discuss different methods of age determination. Sciulli presents a new method for aging EH defects in deciduous mandibular teeth, noting that older methods may not be reliable. Skinner discusses the neonatal line and its formation; he relates that it occurs nearer to the occlusal surface in pre-term infants. Danforth and Giliberti present an assessment of inter- and intraobserver concordance—an aspect of enamel developmental defect study which has seldom been evaluated. Condon and Rose find some differences in EH defects within and between tooth types, but overall observe a great deal of similarity. They note that linear defects between teeth can be matched in the same manner as dendrochronology, allowing a record of stress throughout childhood. Marks reports similar findings utilizing SEM analysis. Capasso and Di Tota discuss the possibility that the lower molar buccal pit is actually an enamel developmental defect as opposed to a morphological variant. Eckhardt et al. describe vertical EH, a rare enamel defect, in Liberian chimpanzees. And, Goodman et al. state that surface and histological defects in the permanent canines of prehistoric Black Mesa, Arizona individuals suggest chronic stress.

Section 2 contains 10 articles. Mack and Coppa look at EH in 5000 year-old Arabian Peninsula hunter/gatherers; over 98% of the individuals exhibited at least one hypoplasia. Mittler et al. find a positive association between EH and cribra orbitalia in a study of Medieval Nubian sub-adult mortality. Larsen and Hutchinson find a decrease in hypoplasia from prehistoric through European Mission period times in Florida Native Americans, an apparent contradictory finding compared to several other stress indicator studies. Storey discusses enamel opacities and other better known enamel defects in deciduous teeth, whereas Whittington studies chronic and acute EH in permanent teeth from a Classic Maya sample. Ubelaker records EH in 15 samples, spanning 8000 years in coastal and highland Ecuador. He describes evidence for maternal stress in more recent samples based on defects in deciduous teeth. Marcsik and Kocsis observe a variety of enamel defects in prehistoric and historic samples from Hungary, and relate that the overall incidence of EH is low. Yamamoto notes variation in hypoplastic defects from Jomon through modern times in Japan. Kuhl looks at six cremated Bronze and pre-Roman Iron Age children, and records EH, Harris