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ANALYSIS OF PRIMATE DENTAL MICROWEAR USING IMAGE PROCESSING TECHNIQUES

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Abstract

This paper introduces Fourier transformation as a rapid, replicable means for characterizing and distinguishing patterns of microscopic wear on primate teeth. The two-dimensional power spectra obtained from numerical Fourier transformation are shown to be different between two test patterns, one of which is composed of linear features and the other of randomly-spaced dots. A comparison is made, using Fourier transformation, of dental microwear patterns of small samples of two primate species, Ateles geoffroyi, the spider monkey, and Chiropotes satanas, the bearded saki. Ateles, with a scratch-dominated pattern of microwear, has a Fourier transform resembling that of the linear test pattern. Chiropotes, with a pit-dominated microwear pattern, resembles the transform of the dot pattern. The significance of this is discussed in light of the dietary differences between the two species.

Key words: Image Processing, Diet, Dental wear, Primates, Fourier transforms, mastication, Ateles, Chiropotes, biomechanics, chewing.

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Introduction

The microscopic patterns of wear on the surfaces of the teeth are considered increasingly important as a means to infer the biomechanics of the mammalian, and especially primate, masticatory apparatus (e.g., Hiiemae and Kay, 1973; Gordon, 1982; Rensberger, 1978). Equally, studies of dental wear offer promise for inferring the dietary patterns of extinct primates and other mammals (e.g., Walker et al., 1978; Teaford and Walker,1984). In the latter case, the objective is to characterize the tooth wear patterns of living mammalian species to see whether living animals with differing diets have recognizably different and characteristic patterns of microscopic wear. If so, it is reasoned, the microwear on the teeth of fossils might tell something about their dietary patterns (Grine, 1981; Kay and Covert, 1984; Teaford and Walker 1984).

Early studies of tooth microwear relied on visual impressions for assessing wear differences. Later, the pioneering efforts of Walker, Teaford and Gordon placed microwear analysis on a more objective basis. These workers had some success in atomizing microwear fabrics into individual elements like "pits" and "scratches" and then making counts of feature density, orientation and shape. However, as illustrated by the pattern of scratches and pits seen on Figure 1, it remains difficult to define individual elements and to measure or count them objectively. Moreover, the whole process of measuring and counting features is so extremely time-consuming that it inhibits collection of the large sample sizes required for cross-species statistical assessments. A rapid, replicable means is needed for characterizing and distinguishing various patterns of tooth wear. Analysis of images using optical diffraction or its mathematical analog Fourier analysis offers promise for meeting these needs.

Optical diffraction is becoming increasingly important as a tool for interpretation and enhancement of images (Castleman, 1979). In this approach, a laser beam of coherent light is passed through the film image under study placed on the front focal plane of a curved lense. The light is scattered or diffracted when it passes through this target. The resulting interference pattern is then recorded photographically on the back focal plane of a converging lense receiving the scattered light radiation. The result is the diffraction pattern of the original image (Oxnard, 1973; Taylor, 1978). Alternatively, a digitized version of the negative can be processed mathematically, using a numerical Fourier transformation, and the diffraction pattern image reconstructed (Frank et al., 1981).

In this paper, I introduce numerical Fourier transformation as an analytical tool for characterising tooth wear. Several examples are given of test patterns and two-dimensional power spectra obtained from numerical Fourier transformation. This is followed by a comparison, using Fourier transformation, of dental microwear patterns of small samples of two primate species whose diets differ in the wild.

Materials and Methods

Table 1 describes the specimens used in this study. Two species of Ceboidea were studied, Ateles geoffroyi, the spider monkey, and Chiropotes satanas, the bearded saki. Specimens under study come from the Smithsonian Institution and were wild shot. Also, two test patterns analogous to pits and scratches, one of randomly spaced dots and the other of lines of similar orientation were prepared and analysed.

Casting and SEM

For each dental specimen, dental impressions were made with "Xantopren-Blue" molding compound (United K Corporation, Monrovia, CA). Epoxy casts drawn from the molds were sputter-coated with approximately 200 Angstroms AuPd alloy under a vacuum in a "Film-Vac Inc. Mini-Coater." The specimens were examined on a JEOL-T20 scanning electron microscope (SEM). A micrograph was made, at approximately 160 x, of the worn enamel surface on the lingually-facing slope of the hypoconid cusp of mandibular second molar (wear facet 9 of Kay, 1977). Care was taken to obtain an image perspective as nearly as possible at right angles to the wear plane, although, in practice, the angle of view was 20 to 30 degrees from normal to obtain sufficient contrast.

Image processing

Negatives of each micrograph were scanned on a computer-controlled digital microdensitometer (Perkin-Elmer Corporation). Optical density values are converted into digital form and written on computer tape. The total field sampled on each micrograph was 100 micrometers squared and the total number of density values is 512 squared. This matrix was analysed on a Digital Equipment Corporation (DEC) PDP-11/45 computer using the "SPIDER" software system (Frank et al., 1981). Using SPIDER, the two dimensional power spectrum is obtained by a numerical Fourier transform of the image.

Table 1. Samples used for tooth wear analysis.

Taxon/Specimen number	Locality (Coll. date)
Chiropotes satanas USNM 406430	Amazonas; Venezuela (3/24/67)
USNM 406431	Amazonas; Venezuela (4/14/67)
USNM 406592	Amazonas; Venezuela (7/11/67)
Ateles geoffroyi USNM 292206	Near Palenque; Mexico (3/31/51)
USNM 292207	Near Palenque; Mexico (3/31/51)

Analysis

Each two-dimensional power spectrum was analysed as follows. The integrated optical intensity of each power spectrum was calculated radially from the center to the outer recorded edge of the spectrum. The power spectrum was then rotated five degrees and the integrated optical density again determined. This procedure was repeated through 180 degrees. The summed intensity along any one traverse was expressed as a percentage of the total summed intensities for all traverses. This procedure controls and removes differences in brightness in the recorded images. The results were illustrated as bivariate plots of percentage of total intensity vs. degrees. The maximum optical intensity for any pass was arbitrarily set at 90 degrees.

Results

Figure 2 depicts the two test patterns and their resulting power spectra. The first image (Figure 2a), a series of randomly spaced dots, yields a diffraction pattern (Figure 2b) consisting of a series of concentric rings of light. The second image (Figure 2c) of roughly parallel lines of constant breadth and variable length yields a diffraction pattern (Figure 2d) in which most of the light intensity forms a narrow oval the long axis of which is oriented at right angles to the average orientation of the lines of the target. Information can be obtained about the size and spacing of these dots, or the length and breadth of the lines in the target, but this is not the point of interest here (see Taylor, 1978 for further information). Clearly, the two test patterns and their power spectra are very different, as confirmed by the bivariate plot of radially integrated optical intensity vs. angle in degrees (Figure 3). In the case of the dots, the intensity is nearly equal at all angles radiating from the center of the power spectrum, whereas with the lines, the intensity is much greater in some areas. In general, patterns of dots should always present different diffraction patterns from those of lines unless the lines have no preferred orientation.

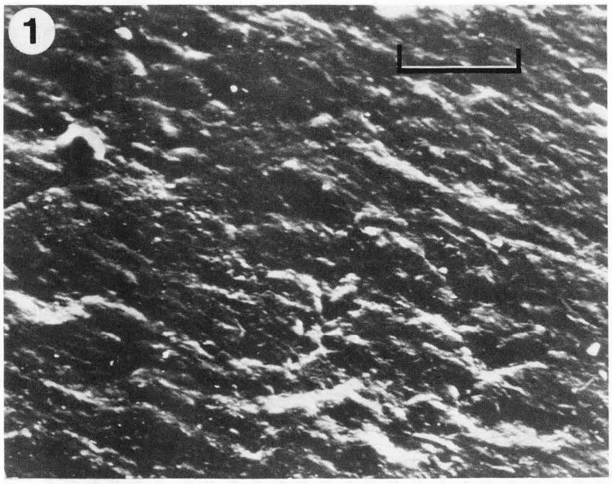

Figure 1. Dental Microwear pattern on the talonid basin of the lower second molar (Wear facet 9, Kay,1977) of Aotus trivirgatus, USNM 443734. This figure illustrates the difficulty of identifying individual elements of tooth wear from the surrounding wear fabric. Bar equals 400 micrometers.

The two test patterns illustrate what might be expected in a comparison of two fabrics of tooth wear one of which is dominated by long linear "scratches" and the other by irregular or rounded "pits". According to Teaford and Walker (1984) a major distinction between the microwear of various primate species is between the relative numbers of "pits" and "scratches" which they operationally defined in terms of the ratio of lengths to breadths. Teaford and Walker (1984) defined a scratch as a feature with ten times greater length than breadth and a pit as having less than ten times greater length than breadth. Using optical diffraction, if tooth wear fabrics are

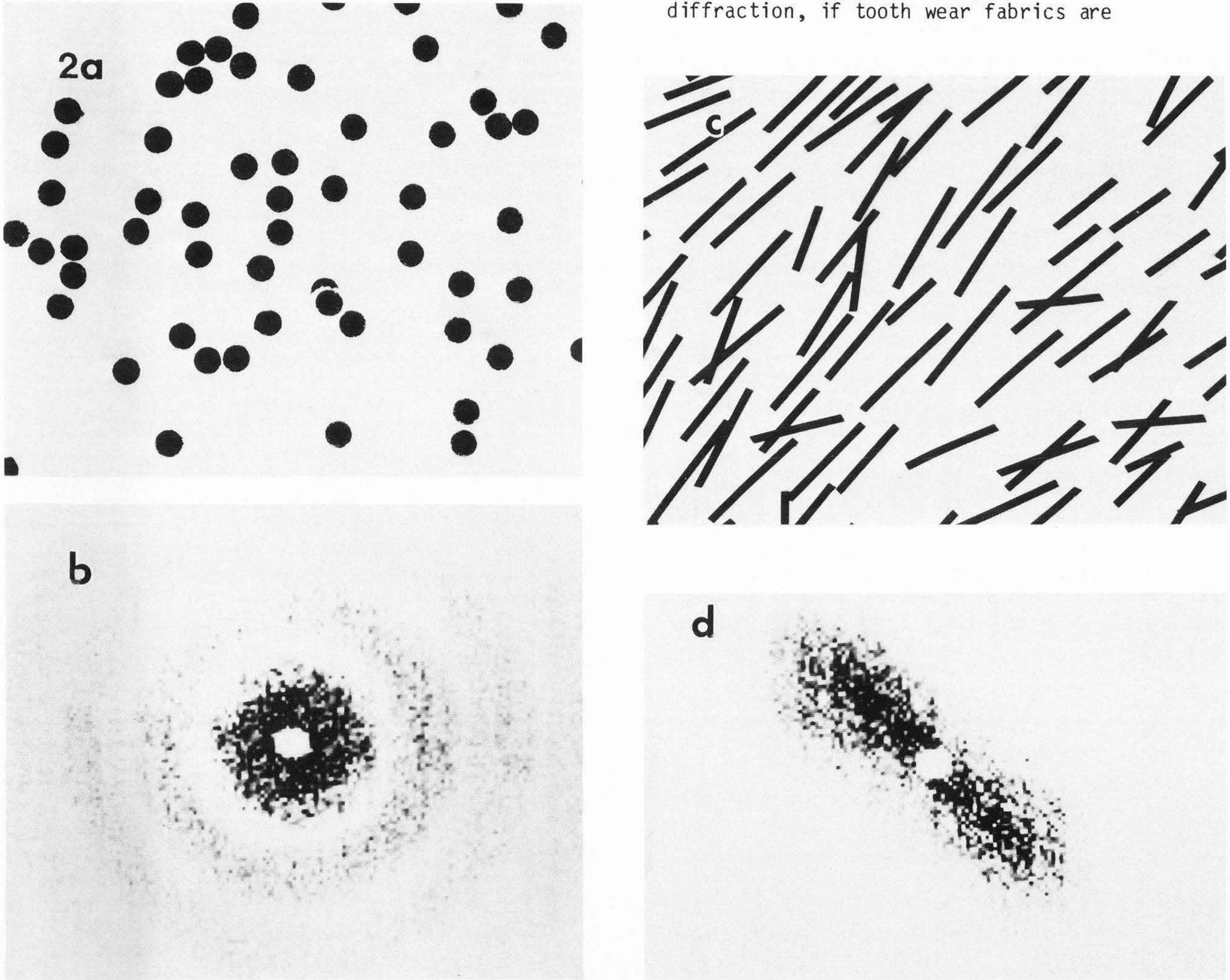

Figure 2. Test patterns and the corresponding two-dimensional power spectra obtained by numerical Fourier transformations. a, a pattern of randomly spaced dots; b, two-dimensional power spectrum of a; c, a pattern of lines arranged roughly parallel to one another; d, two-dimensional power spectrum of c.

dominated by parallel or nearly parallel scratches, the power spectrum should resemble that for the linear test pattern but if pits dominate the resemblance should be to the power spectrum of the dot pattern. This expectation is supported by a comparison of the wear fabrics of two species, the spider monkey and the bearded saki, one of which has a scratch-dominated pattern of microwear and the other a pit-dominated pattern. Figures 4a-d illustrate the wear fabrics and their corresponding diffraction patterns on the lower second molars of *Ateles* and *Chiropotes*. *Ateles* wear is dominated by scratch features and its power spectrum (Figure 5a) shows an intense band of light concentrated at right angles to the long axis of the scratches. *Chiropotes* surfaces are dominated by pits and the power spectrum is more diffuse. Bivariate plots of radially integrated optical intensity vs. degrees show the same tendencies (Figure 5b).

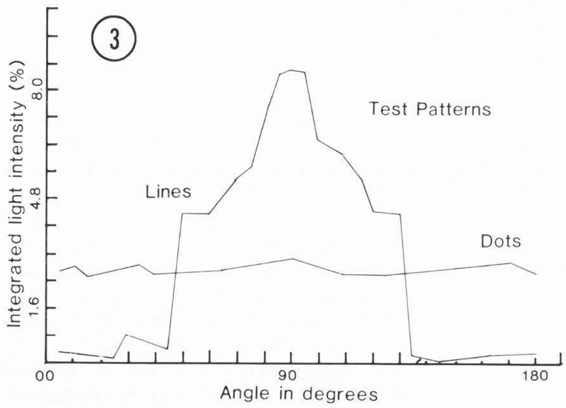

Figure 3. Bivariate plot of integrated light intensity measured radially from the center of the two-dimensional power spectra vs. angle of the measurement in degrees. Spectra are of the test patterns shown in Figure 2b and 2d. Lines are connected between 5 degree intervals.

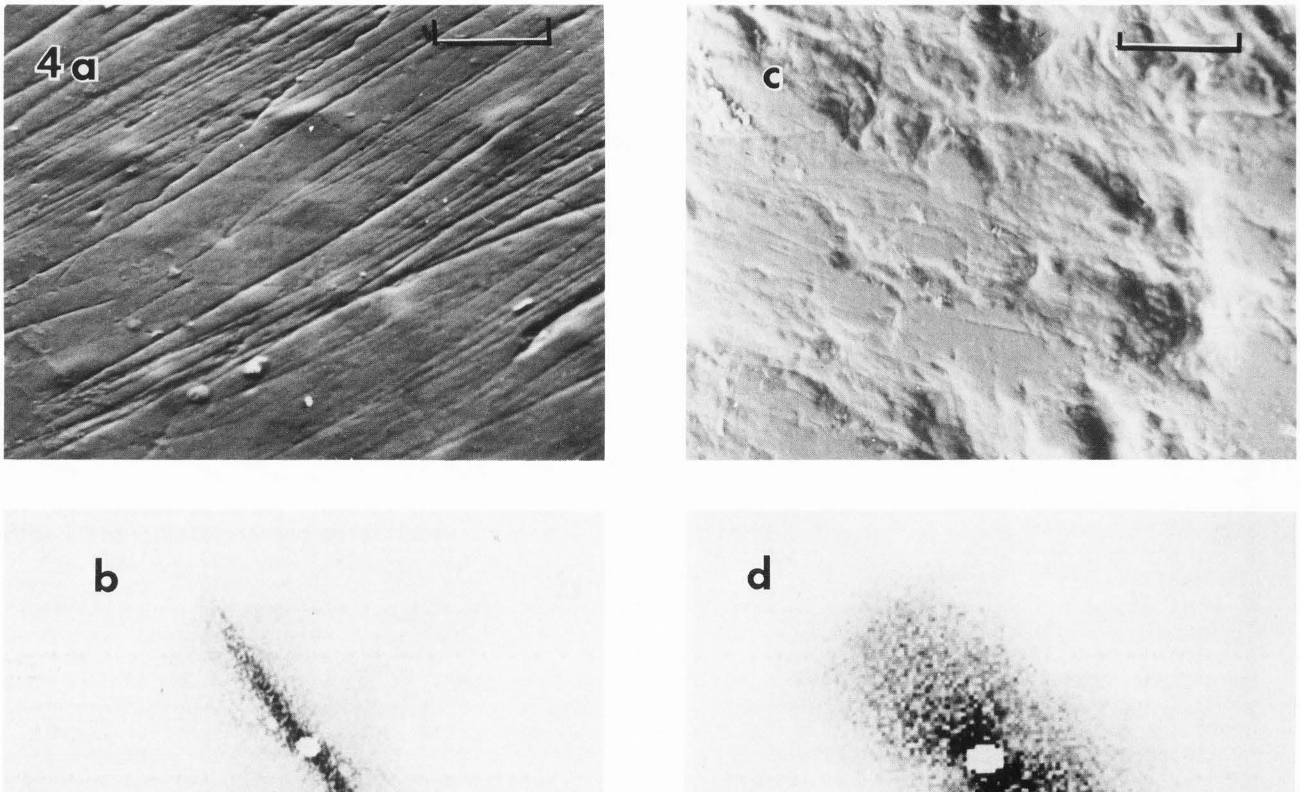

Figure 4. Dental microwear patterns and their corresponding two dimensional power spectra. The surfaces are from wear facet 9 on the talonid basin of lower second molars. Bar equals 200 micrometers. a, *Ateles geoffroyi* (USNM 292206); b, power spectrum of USNM 292206; c, *Chiropotes satanas* (USNM 406431); d, power spectrum of USNM 406431.

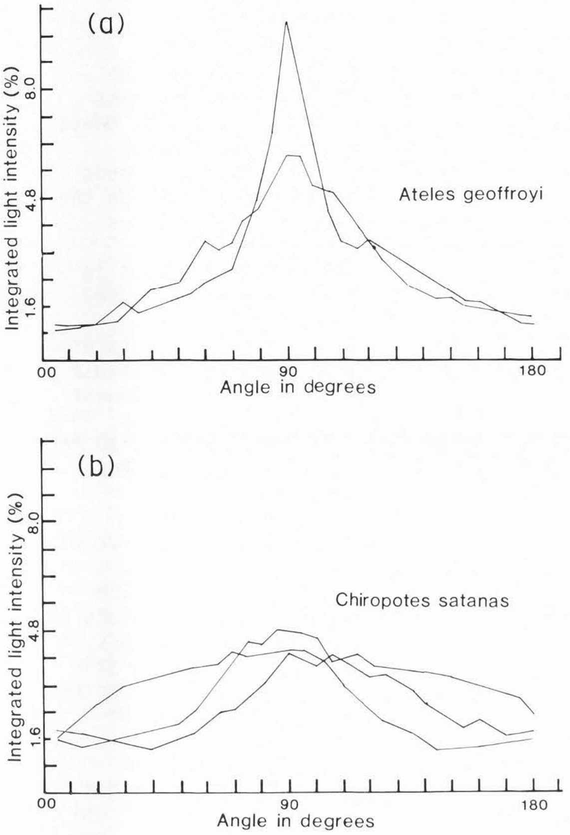

Figure 5. Bivariate plots of integrated light intensity measured radially from the center of the power spectra vs. angle of the measurement in degrees. Lines are drawn between 5 degree intervals. a, two specimens of *Ateles geoffroyi*; b, three specimens of *Chiropotes satanas*.

Discussion

This short study demonstrates one way in which optical diffraction (or if preferred Fourier transformation) can be employed for pattern recognition in the study of dental wear. Once the data from the power spectra are reduced to bivariate arrays, it should be possible to utilize several statistical tests to demonstrate the distinctiveness of curves although I have not done so here because of the small size of the samples.

The demonstration of the great difference in the wear patterns of *Ateles* and *Chiropotes* begs the question of what dietary difference, or difference in jaw movement, between these two species, could produce such a great disparity in the wear patterns. Field studies of both these species demonstrated that both are extremely frugivorous in the wild: *Ateles geoffroyi* ingests 80% fruits by weight (Hladik and Hladik, 1969) and *Chiropotes satanas* spends more than 90% of foraging time eating fruits (Van Roosmalen,1984). However, Van Roosmalen has suggested that categorizing *Ateles* and *Chiropotes* simply as frugivorous hides a fundamental difference in their dietary patterns (Van Roosmalen's comments concern *Ateles paniscus*, not *A. geoffroyi*, but the dental structure of the two is so similar that his observations apply). He finds that although both are frugivorous and eat the same plant species, they differ in several critical ways. *Chiropotes* predominantly eats young seeds found in fruits that are still encased within a tough shell, sometimes in combination with hairs and spines. It uses its tusk-like canines for cracking hard-shelled fruits and its procumbent incisors for scraping seeds out of the broken food parts. According to Van Roosmalen, the cheek teeth are not *Chiropotes*' chief tool for cracking or splitting these fruits, but are used for breaking up and masticating the smaller pieces once ingested. *Ateles paniscus* in contrast chiefly feeds on mature fleshy fruits and swallows both pulp and seeds without much effort at mastication. Thus, differences in the toughness or hardness of the ingested food are correlated with the observed wear patterns.

This pilot study demonstrates the power of optical/Fourier techniques for analysing dental wear patterns but clearly much more can be done to extract biologically significant information from tooth-wear images. For example, information can be gained about the size, spacing and orientation of wear features (Oxnard, 1973; Taylor, 1978). This, and appropriate statistical analysis of larger samples should yield important new insights about dental microwear and masticatory behavior.

Acknowledgments

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References

Castleman KR (1979). Digital Image Processing. Prentice Hall, Inc., Englewood NJ. Pp. 1-428.

Frank J, Shimkin B, and Dowse H (1981). SPIDER-a modular software system for electron image processing. Ultramicroscopy, 6:343-358.

Gordon KD (1982). A study of microwear on chimpanzee molars: implications for dental microwear analysis. Am. Jour. Phys. Anthrop., 59:195-215.

Grine FE (1981). Trophic differences between "gracile" and "robust" australopithecines: a scanning electron microscope analysis of occlusal events. South African Jour. Sci., 77:203-230.

Hiiemae KM, Kay RF (1973). Evolutionary trends in the dynamics of primate mastication. In MR Zingeser, (ed). Symp. IVth Int. Congress of Primatol., Vol. 3, Craniofacial Biology of Primates. Karger, Basel. Pp. 28-64.

Hladik A, Hladik CM (1969). Rapports trophiques entre végétation et primates dans la forêt de Barro-Colorado (Panama). Terre Vie, 23:25-117.

Kay RF (1977). The evolution of molar occlusion in Cercopithecidae and early catarrhines. Am. Jour. Phys. Anthrop., 46:327-352.

Kay RF, Covert HH (1984). Anatomy and behaviour of extinct primates. In DJ Chivers, BA Wood, A Bilsborough, (eds). Food Acquisition and Processing in Primates. Plenum Press, New York. Pp. 467-508.

Oxnard C (1973). Form and Pattern in Human Evolution. University of Chicago Press, Chicago. Pp. 1-218.

Rensberger JM (1978). Scanning electron microscopy of wear and occlusal events in some small herbivores. In PM Butler, K Joysey (eds). Development, Function and Evolution of Teeth. Academic Press, New York/London Pp. 425-438.

Taylor CA (1978). Images. Wykeham Publications, London. Pp.1-205.

Teaford M, Walker AC (1984). Quantitative differences in dental microwear between primate species with different diets and a comment on the presumed diet of Sivapithecus. Am. Jour. Phys. Anthrop., 64:191-200.

Van Roosmalen MGM (1984). Subcategorizing foods in primates. In DJ Chivers, BA Wood, A Bilsborough, (eds). Food Acquisition and Processing in Primates. Plenum Press, New York. Pp. 167-176.

Walker AC, Hoeck HN, Perez L (1978). Microwear of mammalian teeth as an indicator of diet. Science, 201:908-910.

Discussion with Reviewers

G.H. Albrecht: It seems clear that the approach taken in this pilot study has the potential to mechanize, objectify, and make practical the quantitative assessment of dental wear patterns. I have several questions. (1) What are some of the statistical methods for comparing the information contained in the plots of integrated light intensity versus angle? (2) Is it possible to obtain information about the "sizes" of elements in the microwear fabric from the power spectra?

Author: One method of comparing the plots of integrated intensity versus degrees is to use the ratio of the peak intensity to the lowest off-peak intensity. If the curve is flat, this number should approach 1.0; the more spiked the curve, the greater would be the ratio. More detailed comparisons could be based on examination of within and between sample variation at various points along the curve of intensity versus degrees. Essential prerequisites for these comparisons are the centering of the peak intensity of all plots at 90 degrees and the adjustment of brightness in the power spectrum (see below). Considerable information can be gained from a power spectrum about the size, orientation and spacing of objects on an image. The geometry of the power spectrum of an image has a characteristic reciprocal effect--when points on the target are widely spaced, the points or lines of the diffraction patterns will be narrow; when they are close together, the patterns will be further apart; when they have a preferred orientation the diffraction pattern will have an orientation at right angles to the original (see Taylor, 1978).

P.G.T. Howell: (1) What differences would the alteration of the brightness and contrast in the recorded image have on the subsequent plots of power spectra versus angle of measurement in degrees derived from your samples? (2) Has the author considered omitting the recording of the micrograph from his sample but rather pass a digital signal of the intensity of the signal from his SE detector directly to a computer for analysis? This would cut out two stages in his analysis.

Author: The problem of brightness and contrast difference has been dealt with by adjusting the areas under the intensity/angle curves to 1.00 and equalizing the average contrast of the power spectra. The idea of passing a digital signal of image intensity directly to the computer for analysis is a good one but the equipment for this is not available to me.