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What did ancient people eat?

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With the aid of confocal microscopy, bioarchaeologists can quantitatively assess tooth wear and determine diet.

Bioarchaeologists rely heavily on the study of teeth to understand the ways of life of ancient humans. In particular, reconstructions of diet often focus on dental remains, since teeth are so closely connected with consumed foods. Through the study of dental microwear, we can determine, for example, if a population was eating wild, poorly processed foods such as those consumed by hunter-gatherers or the domesticated foods consumed by farmers and pastoralists. Dental microwear texture analysis (DMTA) is not limited to humans; it has been applied to a wide range of fossil and extant specimens of fish, dinosaurs, primates, and other animals.

Microwear consists of scratches and pits created during chewing as lower and upper teeth come into contact. Of particular interest to microwear analysts like us are the molars, which are responsible for much of the mechanical breakdown of food. As the upper and lower molars approach each other, the lower jaw deviates laterally from its so-called midline position. Once the molars come together, their cusps interpenetrate and, as the lower jaw moves back toward the midline, the molars shear the food. This is the power stroke of the chewing cycle and is when most of the microwear forms. Once the lower jaw has returned to the midline, the molars crush whatever material is between them to form what are termed phase II facets. The study of microwear generally focuses on those facets, which manifest the effects of both shearing and crushing.

To measure the depth of microwear, we use a white-light confocal profiler. Confocal microscopes collect light that passes through a pinhole or slit; as a result they detect well-focused light from a plane at a single, known depth. In practice, only a small portion of the tooth can be illuminated, so to build up the confocal image we need to scan across the surface at each vertical step. In the end, we obtain highly detailed topographic surface data whose errors are greatly reduced compared with earlier microwear procedures that used scanning electron microscopes to yield two-dimensional micrographs. Indeed, the quality of the data obtainable with confocal microscopy has already inspired new bioarchaeological applications such as the study of ancient cut marks.

Because the teeth we examine come from ancient people, they often have adhering microscopic particles or microwear-mimicking scratches created during exca-

vation or curation. Both kinds of debris need to be removed before the microwear analysis can proceed. That cleaning process is carried out not on the physical teeth but with the help of specialized software packages that process the data we take. Figure 1 shows a digitally cleaned surface with its evident pitting and scratching.

It matters how closely you look

In our DMTA studies of phase II facets, we use two variables to distinguish patterns of wear and thus indicate the diets of ancient populations. One variable describes the complexity of the wear on the tooth, and the other looks to see whether the wear distinguishes any preferred direction.

To specify surface unevenness or complexity, we use a variable called area-scale fractal complexity. The idea behind the variable is that the area of a surface can depend on how finely you go about measuring it. If you measure the area of a plane by covering it with triangles of a given scale (that is, area), counting how many triangles you need, and multiplying that number by the scale, you get the same planar area no matter what kind of triangle you use. But if you are measuring an uneven surface, smaller triangles will climb hills and descend into valleys inaccessible to the large triangles. The area determined by smaller triangles will be larger, reflecting the roughness of the surface.

Complexity analyses, implemented with software packages, look at how the relative area of a dental surface varies with the scale of the triangles assisting in the measurement. ("Relative" here means relative to the area of the surface projected onto a plane.) To obtain the area-scale fractal complexity, we plot the log of relative area versus the log of the scale in square microns, find the maximum negative slope, and multiply by -1000 . Surfaces that are heavily pitted have higher complexity values, and smoother ones have lower values. In humans, complexity values tend to range between 0.50 and 3.0. Populations with higher values tended to be foragers living in places where nuts and seeds were dietary staples, whereas populations with lower values are thought to have had greater dependence on highly processed domesticates like wheat, rice, and maize.

The quantitative tool we use to analyze anisotropy is called the exact proportion length-scale anisotropy of relief. It quanti-

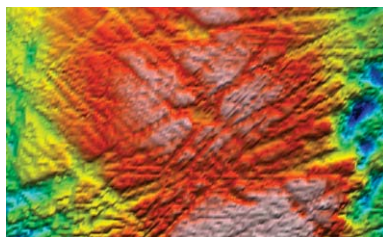


FIGURE 1. SCRATCHING THE SURFACE.

This three-dimensional map shows the scratches and pits on the teeth of a citizen of Herculaneum, a small Roman town (red indicates higher areas; blue, depressed areas). Analysis of such features provides insight into the Herculaneum diet.

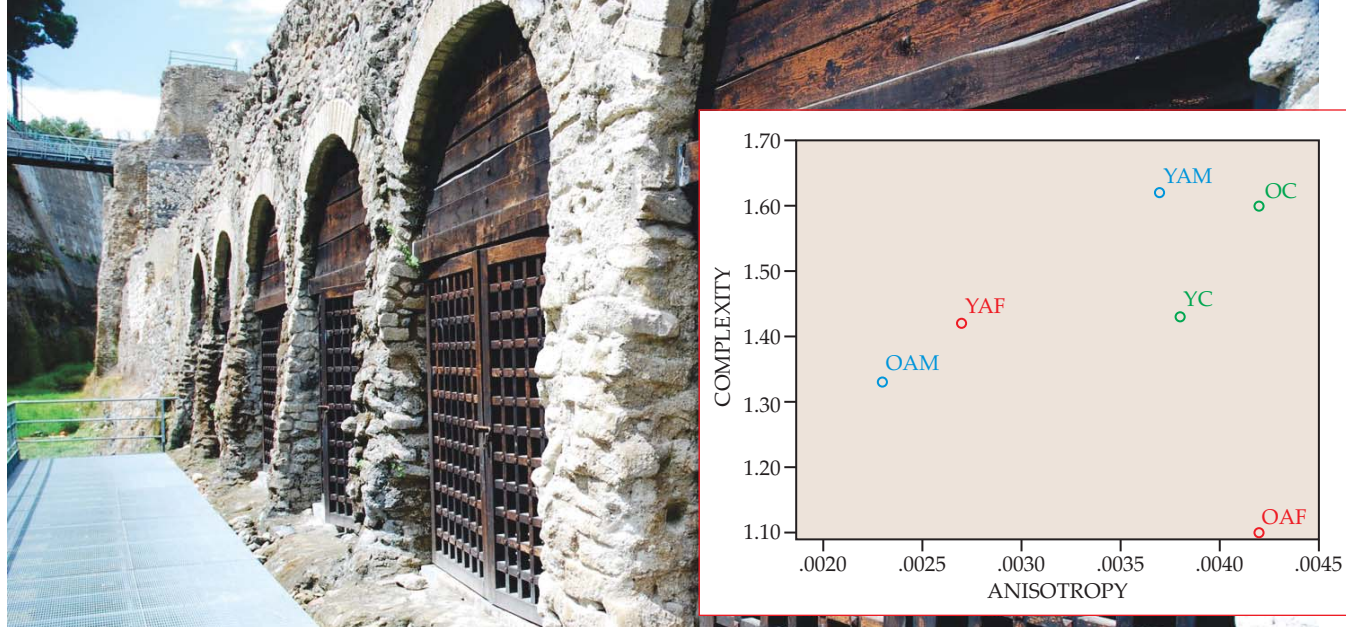


FIGURE 2. TOOTH WEAR BY DEMOGRAPHIC. Following the eruption of Mount Vesuvius in AD 79, the people of Herculaneum sought refuge on the beach or in boathouses, including those seen here. (Courtesy of the photographer, Gregory A. Reinhardt.) As described in the text, we analyzed the anisotropy and complexity of dental wear. This plot shows the results for six demographic groups: young children (YC), older children (OC), young adult males (YAM), young adult females (YAF), old adult males (OAM), and old adult females (OAF).

fies how tooth wear depends on direction; a high degree of anisotropy means that the jaw moves in a consistent direction during chewing. Agricultural diets tend to be homogeneous and create anisotropic wear. Foraging diets, on the other hand, tend to be diverse; as a result, the lower jaw moves in many directions and microwear is less anisotropic.

To evaluate the orientation of dental wear, we first measure the length of wear features. In practice, we approximate those lengths as sums of small line segments obtained by measuring wear features at a sequence of depths. And just as surface-area measurements depend on scale, the measured length depends on how closely spaced those depth observations are. We obtained wear features at depth increments of $1.8 \mu\text{m}$, the finest scale available for our observations. The relative length of the wear feature is defined to be its measured length divided by the length of the straight line that connects its initial and final points.

To obtain the anisotropy, we take 36 relative length (relL) measurements across the tooth at 5° intervals; each individual measurement is denoted relL_a , where the subscript denotes the measurement angle. For each measurement, we create a vector whose direction is the measurement direction and whose length is $(\text{relL}_a - 1)/\Sigma_a(\text{relL}_a - 1)$. The length of the mean of those 36 vectors is our anisotropy parameter. For most human populations, anisotropy ranges from 0.0020 to 0.0045.

A case study at Herculaneum

Located along the Bay of Naples in Italy, Herculaneum was a prosperous Roman town that was destroyed in AD 79 by the eruption of Mount Vesuvius. During excavations in the 1980s, archaeologists found more than 300 individuals who had been seeking refuge from the eruption in boathouses or on the beach. We had the privilege to study 100 of those people, who are now curated at the museum of the “G. d’Annunzio” University of Chieti–Pescara under the direction of Luigi Capasso and Ruggero D’Anastasio. We were able to get useful data from 81 of them, a high percentage for us. Usually we find suitable microwear in only about half of the people we study. What made the people of Herculaneum particularly interesting is that they died at a single time; thus their diet represents what

they were eating just days or weeks before the eruption. Usually in bioarchaeology we study cemetery populations who died over extended periods of time. Due to variations over time, it is rare for such populations to yield differences in diet based on age and sex. The Herculaneum sample, however, gave us a unique opportunity to look for those distinctions.

Our DMTA data, summarized in the plot in figure 2, indicate that anisotropy values distinguish young adult males (ages 18–35) from old adult males (over age 35). Young adults—male and female—had higher complexities than did their old adult counterparts; moreover, the young adult males had the widest range of complexities. The complexity data suggest that the old adults enjoyed an increase in the consumption of meat, which generates almost no microwear features, a finding consistent with the high regard for meat in Roman society and the elevated social status of elders. The diet of children and young adults seems to have included both desirable and less desirable foods.

Perhaps the most distinct group is the old adult females. Their diet got softer, but their dental wear is rather anisotropic. Those features may indicate that females ate fewer types of food but that, like the males, their higher social status entitled them to increased meat consumption. At least one old adult female we studied seemed to have high status indeed: She died wearing gold rings and bracelets.

Additional resources

- R. S. Scott et al., “Dental microwear texture analysis shows within-species diet variability in fossil hominins,” *Nature* **436**, 693 (2005).
- R. S. Scott et al., “Dental microwear texture analysis: Technical considerations,” *J. Hum. Evol.* **51**, 339 (2006).
- C. W. Schmidt, C. R. Moore, R. Leifheit, “A preliminary assessment of using a white light confocal imaging profiler for cut mark analysis,” in *Forensic Microscopy for Skeletal Tissues: Methods and Protocols*, L. Bell, ed., Springer (2012), p. 235.
- C. W. Schmidt et al., “Distinguishing dietary indicators of pastoralists and agriculturists via dental microwear texture analysis,” *Surf. Topogr.: Metrol. Prop.* **4**, 014008 (2016). **PT**