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Biosurface and Biotribology ▮ (▮▮▮▮) ▮▮▮–▮▮▮

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Dental biotribology: Wearing away the boundary between biology and engineering

"Breakthrough innovation occurs when we bring down boundaries and encourage disciplines to learn from each other"
Gyan Nagpal
Talent Economics: The Fine Line Between Winning and Losing the Global War for Talent

This journal and the Tribology Research Institute at Southwest Jiaotong University hosted a workshop on dental biotribology in Chengdu, China 20–22 October, 2017. Workshop participants came from Australia, China, France, Germany, Japan, Kuwait, Poland, the United Kingdom, and the United States. The aim of the workshop was to bring together biotribologists and evolutionary biologists who study tooth wear. All of these researchers have two common goals: to understand dental wear and to use lessons learned to advance our respective fields of inquiry. However, these engineers and scientists approach teeth from different perspectives and very different pedagogical traditions, and despite a common interest in tooth wear, they typically attend different conferences and run have little opportunity to interact and learn from one another. The idea of this workshop was to facilitate discussion and hopefully lead to collaborations that can wear away the boundary between biology on the one hand and materials science and mechanical engineering on the other to benefit each discipline.

The workshop was divided into three parts over three days. The first day was devoted to the study of mammalian tooth wear considered from a biological perspective. The second day included presentations on human dental biotribology considered from a materials science and mechanical engineering perspective. The third day entailed an open discussion among workshop participants of how these disciplines might inform one another, and what directions we might take moving forward, with an eye toward future collaborations. We here summarize and integrate some of the salient points raised by participants in their presentations over first two days. More details can be found in the papers that follow. A synopsis of the workshop discussion is presented in a separate editorial piece at the end of this special issue.

Peer review under responsibility of Southwest Jiaotong University.

1. Mammalian tooth wear

The first set of presentations focused on mammalian tooth wear. Most considered dental microwear, the micron-scale scratches and pits that form on the crown surface during feeding. There were several themes covered during this session, and these represented current discussions, debates, and the state of the science. Some were methodological, and concerned the comparability of surfaces, instruments, data treatments and measurement types. Others considered the types of samples used to relate microwear to diet – those collected from the wild with appropriate provenience and other metadata, live animals employed in laboratory-based experimental study, and fossils. Yet others tackled current hot-topic issues, including the roles of grit and phytoliths in microwear formation and scale-related effects of tooth wear ranging from micron-level to gross enamel chipping. Many of these presentations affirmed that, despite the challenges to interpreting microwear, the signal can rise above the noise, and even provide insights into diet differences between species for which traditional adaptive evidence remains silent given similarities in craniodental functional morphology.

The first presentation was by Peter Ungar, Claire Hartgrove, Alexa Wimberly, and Mark Teaford, on dental topography and microwear textures in primates. Ungar and his colleagues considered possible interactions between wear patterns at different scales. Dental microwear is said to reflect diet because different foods require different angles of approach between opposing teeth; and those angles of approach and contact are determined, in part, by tooth shape. Theory dictates that steeply angled primate molars guide chewing movements for shearing tough foods, whereas flatter crowns serve for crushing hard, brittle items. Theory also dictates that microwear reflects occlusal dynamics such that shearing tough foods leaves anisotropic surfaces with long, parallel scratches whereas crushing hard, brittle ones results in complex surfaces dominated by pits. Thus, if teeth become flatter with gross wear, it may be that occlusal dynamics change over time, and microwear patterning is thus affected. Ungar and his colleagues tested this idea with a sample of variably worn capuchin monkey teeth, and found no consistent effect of occlusal topography on microwear

https://doi.org/10.1016/j.bsbt.2017.11.002

texture. This suggested to them that microwear of variably worn surfaces may be compared directly.

The second presentation, by Ellen Schulz-Kornas, Caroline Braune, Daniela Winkler, and Thomas Kaiser, considered the role of endogenous silica, namely plant phytoliths, in tooth wear. Phytoliths form as monosilicic acid from the soil is taken up by a plant and deposited as hydrated amorphous silica within the lumen of its epidermal cells. There has been considerable debate in the literature about the role of phytoliths (as opposed to exogenous grit or dust adherent to foods) in causing dental wear at various scales. Much of the argument has revolved around whether phytoliths are hard enough and angular enough to cause enamel tissue loss during chewing. Schulz-Kornas and her colleagues took a closer look at phytoliths, and considered their ultrastructure. They found these biogenic silica bodies to be highly anisotropic, varying in both shape and hardness. Their study emphasized the importance of considering the structure and chemistry of both enamel and abrasives when studying the etiology of dental wear.

The next presentation, by Mugino Kubo, Eisuke Yamada, Tai Kubo, and Naoki Kohno, focused on methodology, namely the effects of instrumentation and surface treatment on dental microwear texture characterization. As more researchers in more laboratories around the world adopt texture analysis as the preferred method for microwear study, it becomes increasingly important to recognize that surface representations are affected by vagaries of the instrument being used to generate point clouds, and the treatments of those point clouds prior to quantitative characterization. Indeed, different treatments lead to different degrees of variation in measurement due to instrumentation, and these in turn affect different characterizations (i.e., ISO standards and attributes derived from scale-sensitive fractal analysis) in different ways. Nevertheless, Kubo and her colleagues reported that the diet signal rises above this “noise” when instrumentation and treatment are controlled; sika deer that eat grass have microwear textures that differ consistently and predictably from those that eat browse.

The presentation that followed, by Mark Purnell, Robert Goodall, Scott Thomson, and Cory Matthews, presented on dental microwear textures of toothed whales, namely the beluga. Most microwear studies of mammals have focused on specific wear facets on the molars of heterodont species, which signify predictable points of contact between opposing teeth and foods. These facets occur in fairly fixed locations on the crown, and reflect occlusal dynamics that have been long associated with specific phases of chewing. A focus on homologous wear facets, combined with a fixed bauplan for masticatory actions in most mammals, affords confidence in the comparability of microwear between species that have similarly shaped molars. But what about homodont taxa that do not chew, such as odontocete whales? How can researchers identify diet-specific microwear texture patterns on conical teeth that lack homologous facets for comparison? Purnell and his colleagues began to address this question by looking for variation in pattern by dental tissue type, degree of gross wear, location of the tooth in the jaw, and position of the facet on the tooth. They demonstrated that each of these factors can affect microwear texture pattern and potentially obfuscate diet signal; and they conclude that future studies will need to pay careful attention to the magnitude of dietary differences in texture parameters compared to those caused by non-dietary factors. As with studies of microwear in heterodont terrestrial mammals considered to date, a standardized sampling strategy would facilitate the use of microwear texture for dietary discrimination in homodont marine mammals.

The next presentation was by Mark Teaford, Peter Ungar, Andrea Taylor, Callum Ross, and Christopher Vinyard. Teaford and his colleagues reported on an *in vivo* study of laboratory primates fed foods with different material properties to determine whether they caused dental microwear with an eye toward wear rate. They fed capuchins and lemurs different diets representing hard and softer foods, and took impressions of teeth before and after single feeding bouts to look for the addition of microscale features. The first conclusion drawn was that replicating microwear surfaces of living mammals is not a trivial task. Individual microwear features are often 1 μm or less in depth. Organic film covering enamel is difficult to remove, and any remaining on the surface can obscure texture. That said, results of this study demonstrated that microwear features can appear even following a single feeding bout, and that the number of features added depends in part on the material properties (e.g., hardness) of items eaten as well as individual variation in chewing behavior.

The presentation that followed, by Gildas Merceron, Cécile Blondel, Noël Brunetiere, Arthur Francisco, Denish Gautier, and Anusha Ramdarshan, also described an *in vivo* study of dental microwear, in this case, of sheep. Merceron and his colleagues ran controlled feeding experiments, varying seed size and hardness as well as grit load, to address the debate concerning whether phytoliths alone can cause microwear features. Their study demonstrated that microwear can form in the absence of exogenous grit, and that grass, forbs, and browse foliage all produce distinctive and distinguishable textures. Merceron and his colleagues also found that the effect of grit does not obscure differences between diets. Another important result of their study was that patterns differ between wear facets on upper and lower molar teeth, suggesting that tooth position should be considered when comparing microwear textures among these ruminants.

The next presentation was by Gordon Sanson, Stuart Kerr, and Jennifer Read. Sanson and his colleagues also focused on the contributions of exogenous grit and endogenous plant silica to tooth wear. They compared African buffalo in South Africa's Kruger National Park that live in settings with varying dust loads and graze on grasses with varying silica concentrations. Both dust and biogenic silica concentrations vary by location (associated with differing bedrock types) and season. One of the most remarkable findings of their study was that, despite consumption of up to 28 kg of grit and 400 kg of endogenous silica, buffalo molars were worn an average of less than 2 mm/year. Moreover, there were no clear differences in abrasion rate with observed variation in silica consumption. This implies a minimal affect of phytolith concentration on gross wear. And it leads us back to the issue, given results of