Diet reduces the effect of exogenous grit on tooth microwear

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Abstract: Exogenous grit adherent to the surface of food items and food fracture properties have each been considered important factors contributing to pattern and degree of tooth wear in mammals. However, the interactions between these two factors in generating distinctive microwear textures have remained understudied. Here the authors revisit in-vitro results from simulated chewing to explore how adherent grit and physical properties of foods act together to create dental microwear textures on occlusal enamel surfaces. Results suggest that the effect of exogenous grit on microwear texture is dependent on the material properties foods to which they adhere. Grit in the absence of food causes more complex microwear surface textures than foods covered with similar levels and types of grit (for a given number of chews and angle of approach between opposing teeth). Different foods covered in grit also yield different complexity values. Grit-laden, plant meat, for example, results in a less complex texture than does resistant, grit-laden raw carrot. This work implied that tooth wear assessment can benefit from considering grit load and food material properties together.

1 Introduction

Dental microwear has been used for decades to reconstruct the diets of fossil mammals and bioarchaeological populations [1–4]. Recent work has focused on the aetiology of specific microwear textures – particularly whether abrasive types or inherent food fracture properties are more important to distinguishing patterns. The debates include the questions: (i) can microwear be formed in the absence of exogenous grit, and (ii) do specific patterns of microwear reflect abrasive type or food material properties? Lucas et al. [5, 6], for example, described the role of dust, grit and phytoliths in dental wear formation, and proposed that silica particles reported to be softer than enamel do not cause tissue removal. However, Xia et al. [7, 8] countered that silica softer than quartz grit can and does scratch enamel surfaces. The take-home message was that the effect of an abrasive depends not just on relative hardness; softer materials can impact harder ones under certain circumstances. That said, there is little doubt and no disagreement that exogenous grit can cause tooth wear, and that a high-grit environment contributes to rapid loss of enamel tissue during mastication [9]. Nevertheless, the relationship between grit level and tooth wear rate is complex and not always as expected. For example, Sanson et al. [10] found that while adult African buffalos in Kruger National Park chew on average 28,000 times per day with a given food bolus containing up to more than 21,000 exogenous grit particles, their molars only wear at an average rate of 1.94 mm per year. This is extraordinary in light of tribological experiments showing scratch depths of 200 to 600 nm using an Al₂O₃ nano-scratch tip with loads ranging from 20 to 100 mN/min, implying wear to a depth of 0.294–0.850 mm/day, or 107.310–310.250 mm/year [11–14].

This leads to the question ‘why, given up to thousands of chew cycles per day on foods covered in abrasive quartz particles, do teeth wear so slowly?’ Some hints that may help us begin to address this question can be found in Hua et al.’s [15] in-vitro study of microwear formation using the BITE Master II. In that paper, chewing simulations were run on grit-covered meat, grit-covered carrots, and a control with no food (but grit covering the teeth) under different contact angles. Results indicated that variation in wear texture pattern could be explained in large part by the angle of approach between opposing teeth. It was also found that microwear textures varied with food type for a given grit load and angle of approach – though this was not the main focus of that study. For example, in that study, meat samples coated in grit did not produce measurable microwear, whereas similarly coated carrots produced clear microwear features. Here we revisit and highlight these results, present a new simulation model to contextualise them and further discuss their implications.

2 Materials and methods

2.1 In-vitro experiments

The experimental protocol was as described by Hua et al. [15]. Non-carious molars of white-tailed deer (Odocoileus virginianus) and Dog (Canis lupus familiaris) were each mounted in self-setting polymeric resin. In order to get a smooth occlusal surface for chewing experiments, each sample was ground by grinding papers of 240, 400, 600, 1500 and 2000 grit, then polished using a diamond paste with particles ranging from 0.3 to 0.05 μm in diameter. Both grinding and polishing were conducted in one direction while samples were hydrated [15]. Grit powder (#600 grit) was used to coat (i) cubes of uncooked fresh pork shoulder (called grit-on-meat, 10 mm thick), (ii) slices of raw carrot (called grit-on-carrot, sliced into 20 mm sections) and (iii) individual enamel samples with no food interposed (called grit only). Upper and lower tooth samples were mounted on a computer-controlled testing machine, the BITE Master II [16] for chewing simulation. The machine’s table moves along three axes: up-and-down (F1, vertical); side-to-side (F2, corresponding to bucco-lingual); and fore-to-aft (F3, corresponding to antero-posterior). Three different chewing angles of approach were used for grit-only, grit-on-carrot and grit-on-meat: (i) an angle of 0° (or parallel motion, the greater force is exerted in the parallel direction, F1<F2), (ii) an angle of 45° (or oblique motion, the
force applied in an approximately equal fashion in perpendicular and parallel directions, \( F_1 = F_2 \) and (iii) an angle of 90° (or perpendicular motion, the greater force pressing downward, \( F_1 > F_2 \)). The same samples were used each time, but ground and polished between sets of chewing simulations to ‘erase’ and reset the surface. Each combination of food/non-food and chewing angle (nine total) was subject to 100 chewing cycles.

All surfaces were measured both before and after chewing by white-light confocal profilometry (Plu NEOX, Sensofar Corp.). The work envelop was 133 × 100 \( \mu \text{m} \) with a \( \times100 \) objective. The lateral point spacing was 0.17 \( \mu \text{m} \) and the vertical step was set to 0.2 \( \mu \text{m} \) (with a reported vertical resolution <1 nm). Solarmap software (Solarius Development Inc.) was used for levelling and de-spiking individual point clouds using standard techniques.

Fig. 1  Finite-element models. Elasticity moduli of the tooth block and grit are 90 and 190 GPa constant, and the elasticity moduli of food medium are 11.25, 5.60 and 2.80 GPa, respectively.
Surface texture was characterised quantitatively using scale-sensitive fractal analysis software Toothfrax (Surfract Crop.) for both baseline surfaces and those following 100 chew cycles. Area-scale fractal complexity ($A_{sc}$) and exact proportion length-scale anisotropy of relief ($epLsar$) were calculated to provide measures of surface texture complexity (change in roughness with scale of observation) and anisotropy (directionality of surface texture), respectively. $A_{sc}$ and $epLsar$ are both standard

![Fig. 2](image1)

**Fig. 2** Results for the parallel, oblique, perpendicular motion experiments for grit-only, grit-on-carrot and grit-on-meat. The curves represent surface relative areas at the scales noted. Surface complexity ($A_{sc}$) is the steepest part of each curve.

![Fig. 3](image2)

**Fig. 3** Raw complexity ($A_{sc}$) and anisotropy ($epLsar$) results for parallel motion experiments

- **a** Grit only
- **b** Grit on carrot
- **c** Grit on meat
- **d** Percent change between baseline and 100-bite samples for (a−c). Each bar represents means for four sets of runs
measures in microwear texture analysis, and are described in detail in Scott et al. [17].

2.2 Simulation modelling

Abaqus FEA software (Dassault Systèmes) was used for finite-element modelling. In the modelling illustrated in Fig. 1a, a three-block simulation was employed: (i) lower block (simulating the tooth surface), (ii) middle block (simulating grit) and (iii) upper block (simulating food medium). The pressure between upper and lower blocks was set at 100 MPa. The Young’s modulus of the lower block was set at 90 GPa, the middle block at 190 GPa and the upper block was varied at 11.25, 5.60 and 2.80 GPa. The Poisson’s ratio was 0.3 for all blocks. The aim of this simulation was to determine whether grit would more easily compress into a food’s surface than into a tooth’s surface given a decrease of food hardness (with concomitant increase of stress and deformation on the food).

3 Results and discussion

Results are presented in Figs. 1–5. Fig. 2 presents texture data (relative area over scale of observation), for both the baseline

![Fig. 4](image)

**Fig. 4** Raw complexity (Asfc) and anisotropy (epLsar) results for oblique motion experiments

a Grit only
b Grit on carrot
c Grit on meat
d Percent change between baseline and 100-bite samples for (a–c). Each bar represents means for four sets of runs

![Fig. 5](image)

**Fig. 5** Raw complexity (Asfc) and anisotropy (epLsar) results for perpendicular motion experiments

a Grit only
b Grit on carrot
c Grit on meat
d Percent change between baseline and 100-bite samples for (a–c). Each bar represents means for four sets of runs

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surfaces and samples following 100 simulated chewing strokes for the different combinations of sample (grit-only, grit-on-carrot and grit-on-meat) and angle of approach (parallel, oblique and perpendicular). The steepest part of each curve defines Asfc of the given dental enamel surface. For all angles of approach, the difference between baseline and follow up surfaces is greatest for the grit-only studies (Figs. 2a, d and g). Post-experiment surfaces also have greater relative areas at a given scale than baseline surfaces for grit-on-carrot samples (Figs. 2b, e and h), though to a lesser degree than the grit-only samples. Finally, there are no differences between baseline and follow-up samples for the grit-on-meat study for any of angles of approach (Figs. 2c, f and i).

The experimental design of this study called for four separate runs of each experiment (sample type × angle of approach). Higher Asfc values reflect wear, especially pitting. The Asfc values increased for both the grit-only and grit-on-carrot experiments in all cases. However, the baseline surface had relatively high values of epLsar. This was likely due to polishing preparation using grinding paper and diamond paste, which produced a flat surface with anteroposteriorly oriented fine scratched (high anisotropy). In the grit only experiments, buccolingual movement of the tooth produced additional scratches perpendicular to those on the baseline surface. This resulted in a decrease of epLsar. Changes in both Asfc and epLsar were consistent, with decreased amplitude (difference from baseline value) from grit-only to grit-on-carrot to grit-on-meat for experiments involving all three angles of approach between opposing surfaces (see in Figs. 3–5). In other words, food type affects the impact of exogenous grit on microwear surface texture for all angles of approach during simulated chewing.

Finite-element modelling supports results of the in-vitro experimental study. Fig. 1 presents a finite-element model simulating effects of a given load on materials of different hardness. The simulation results showed that the max stress in the tooth simulation block kept constant (max stress: 4.406 × 102), while the max stress in the food medium simulation block was 4.940 × 102 (E=11.25 GPa), 5.133 × 102 (E=5.60 GPa) and 5.266 × 102 (E=2.80 GPa) respectively. In addition, the max stress in the softer food medium was higher than in the tooth. The model suggests that both maximum stress and deformation increase with a decrease of hardness under the same normal load. These simulation results further suggest that the pliability of materials can cause a higher stress and larger deformation to absorb force on the surface.

The aim of this re-interpretation of Hua et al.’s data [15] was to a better understand the fact that some species evince low microwear turnover rates despite large numbers of chew cycles and abrasive diets in dusty or otherwise grit-laden environments. This phenomenon has been used to support the notion that endogenous abrasives (i.e. opal phytoliths) do not wear tooth enamel [18]. The results of the in-vitro study presented here raise another possibility. It seems that degree of enamel tissue loss relates both to dietary abrasives and to the material properties (e.g. pliability and porosity) of the foods being masticated. In other words, abrasives and food material properties likely interact in the formation of dental microwear.

4 Conclusion

While real-life mastication is clearly more complex and nuanced than can be replicated in vitro, chewing simulation allows for control of variables to better understand the aetiology of microwear formation. Our work indicates that while the role of exogenous grit in producing enamel microwear is undeniable, the impact of abrasives on enamel during chewing varies with the material properties of the foods to which they adhere. The stiffness of food items can have a substantive effect on whether adherent grit affects enamel surface texture and should be considered in models aimed at explaining variation in patterns of dental microwear.

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