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Brief Communication: Intertooth and Intrafacet Dental Microwear Variation in an Archaeological Sample of Modern Humans From the Jordan Valley

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KEY WORDS biomechanics; compression; shear

ABSTRACT Dental microwear was recorded in a Bronze-Iron Age (3570–3000 BP) sample of modern humans recovered from Tell es-Sa'idiyeh in the Jordan Valley. Microwear patterns were compared between mandibular molars, and between the upper and lower part of facet 9. The comparison revealed a greater frequency of pits and shorter scratches on the second and third molars, compared to the first. Pit frequency also increased on the lower part of the facet on the first molar, compared to the upper part. These results support previous calls for standardization when selecting a molar type for a diet-microwear study. Otherwise the microwear variations along the tooth row could mask any diet-microwear correlations. The results also suggest that there may be a need to choose a consistent location on a facet in order to enhance comparability among studies. Am J Phys Anthropol 129:39–44, 2006.

Chewing hard abrasive particles can produce microscopic wear on teeth. Such wear (dental microwear) was observed among extant species of known diet (e.g., Covert and Kay, 1981; Teaford and Oyen, 1989a,b) and simulated during experimental studies on extracted teeth (Peters, 1982; Ryan, 1979). Indeed, consistent correlations have emerged between dental microwear patterns (frequency and size of pits and scratches) and some abrasive diets (e.g., Teaford and Walker, 1984; Walker et al., 1978). Given this, microwear patterns are often used to infer aspects of diet in fossil humans and nonhuman primates (e.g., Puech, 1976; Teaford et al., 1996, 2001; Ungar, 1996).

As part of their methodology, such studies control for nondietary variables that can influence microwear formation processes because they can potentially mask diet-microwear correlations. For instance, the position of a molar along the tooth row or the type of wear facet (shearing or grinding) examined appears to influence the relative frequency of pits or scratches in chimpanzees (Gordon, 1982). Subsequent research confirmed this relationship in nonhuman primates (King et al., 1999; Teaford, 1985; Teaford and Oyen, 1989a), and also indicated that the location examined on a (shearing) wear facet from a marsupial has a similar effect on microwear patterns (Robson and Young, 1990). These variables seem to reflect the biomechanics of mastication, such as the type and amount of force (i.e., compression and shear) acting on the tooth surface and movements of the jaw. It is usual, therefore, to only select identical teeth and facet types for diet-microwear studies, though facet location is generally not standardized.

Perhaps surprisingly, these nondietary variables have not received the same level of scrutiny in humans (Maas, 1991, 1994; Mahoney, 2003), even though microwear comparisons between deciduous lateral incisors and first molars suggest that they may exert a similar influence (Bullington, 1991). Given this, the present study examines the relationship between microwear, the position of a mandibular molar along the tooth row, and location on facet 9 in an archaeological sample of adult modern humans.

MATERIALS AND METHODS

Skeletal and dental sample

Ten age-matched (18–28 years) skeletons were selected from human remains recovered from one archaeological site, Tell es-Sa'idiyeh, located in the Jordan Valley (Tubb et al., 1997). The skeletons date from the Bronze-Iron Age period (3570–3000 BP) and were chosen because mandibular molar facet 9 (Maier and Schneck, 1982) was clearly delineated.

Twenty-eight mandibular molars were selected from the human skeletons. Eight skeletons provided examples of the three molar types. The third molar was unerupted in one skeleton, and the first molar was absent in another. Molars from the left side of the mandible from some individuals and right side from others were included (Table 1).

The microwear procedure

All contaminants were removed from the dental surface using ethanol and cotton wool. An impression of the

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TABLE 1. Skeletal and dental sample

Sk No^3 M3	M1	M2	
T77	1^1	1^1	1^1
T144	1^1	1^1	1^1
T53	1^2	1^2	1^2
T199	1^2	1^2	1^2
T218.b	1^1	1^1	1^1
T159	1^1	1^1	1^1
T91	1^1	1^1	1^1
T345		1^1	1^2
G406.a	1^2	1^2	
G350	1^2	1^2	1^2
Total	9	10	9

[1] Left side of mandible.
[2] Right side of mandible.
[3] Skeletal Number.

occlusal surface was taken using a rubber-based addition-curing silicone (Coltène, President Jet, lightbody®). Following Nystrom et al. (2004), facet 9 was excised from each impression using a scalpel, thus reducing scanning electron microscope (SEM) image distortion due to angulation of the tooth surface (Gordon, 1982). The excised facet was surrounded with dental putty (Coltène, President Putty®) to create a depression. An epoxy resin (Araldite MY 753, hardener HY 956, Ciba-Geigy) was poured into the depression to produce a cast of the facet. Each cast was mounted on an aluminium stub after its base had been coated with an electrode paint (Electrodag 1415 M). The top (toward the cusp tip) and bottom (toward the intercuspal fissure) of each facet was marked on each stub to help orient the facet in the SEM specimen chamber. The stub was placed into a sputter coating unit (EMSCOPE SC500) for 3 min to receive a 20-nm coating of gold-paladium. Digitized micrographs were taken using an SEM (camscan) at the Sorby Centre for Electron Microscopy and Microanalysis (University of Sheffield). The CAMSCAN was operated in the secondary electron emission mode with a spot size of 3.0 and an accelerating voltage of 15 kv. The dental casts were orientated perpendicular (tilt angle 0°) to the primary beam. Throughout, an attempt was made to standardize the working distance, although sometimes slight variation between sample surfaces meant that the stub had to be moved toward or away from the primary beam by 1 or 2 mm. For each cast, the entire facet was examined at a magnification of 50×. The length of the bottom edge of the facet was measured on the SEM viewing screen, using a ruler. After the midpoint was identified, the magnification was increased to 500×, and a micrograph was taken. Where a facet terminated in a point, the apex of the point was chosen. The procedure was repeated at the top of the facet, although ultimately the dental locations varied between individuals because of differences in facet size. Each digitized micrograph (700 × 500 pixels) represented approximately 0.03 mm^2 of the tooth surface.

A 4:1 length-to-width ratio was used to distinguish between pits and scratches, which were measured and counted using a semiautomated image analysis computer program (Microware Version 3.0$_{\text{Beta}}$; Ungar, 1997). A resolution of 0.333 μm per pixel (DPI 152) was selected, although this could have missed a few very small features (Ungar, personal communication). Eight microwear variables were created for analysis, from each micrograph: total number of features, mean number of pits, mean number of scratches, percent pits, mean length and width of pits, and mean length and width of scratches.

Statistical procedures

A one-factor within-subjects analysis of variance (ANOVA) was used to compare microwear variables from the top of the facet between the different molars (intertooth comparison). An equivalent comparison was undertaken at the bottom of the facet. The normality of data was checked with a Kolmogorov-Smirnov test (KS test). A within-subjects ANOVA also assumes homogeneity of covariance, and this was checked with Mauchly's sphericity test (Zar, 1999). Outlying cases were identified through a detrended normal Q-Q plot, and their influence was reduced through either a log or square root transformation (percent pits arcsine-transformed; Zar, 1999; Tabachnick and Fidell, 2001). Paired-samples *t*-tests (described below) were used to localize any significant differences between molars.

A paired-samples *t*-test was used to compare microwear variables from the top of the facet with the bottom on the first, and then the second molar (intrafacet comparison). This test assumes that the differences, calculated for each pair, have an approximately normal distribution. However, even when transformed (see above), the data for the third molar failed the assumption. Therefore, the nonparametric version of the paired-samples *t*-test (the Wilcoxon test) was used to examine the distribution of variables upon the third molar. All statistical tests were conducted using SPSS 10 for Windows. The significance level was set at $P \leq 0.05$. Box plots (which show the median value, 50% of the values closest to the median, and the largest and smallest values) were chosen to illustrate all significant results.

RESULTS

Intertooth comparison

Statistically significant differences were found for two variables: percent pits and mean scratch length (Table 2 provides all descriptive statistics; Table 3 provides statistical results). The percentage of pits increased from 16.7 ± 8.3% on the first molar at the top of the facet to 42.8 ± 7.0% on the second molar and 40.1 ± 10.1% on the third molar ($P = 0.002$). Tests to localize the difference in percentage of pits along the tooth row indicated that the first molar differed significantly from both the second molar ($P = 0.000$) and third molar ($P = 0.000$).

Scratch length decreased from 39.4 ± 5.4 μm on the first molar at the bottom of the facet to 22.2 ± 6.6 μm on the second molar and 24.5 μm ± 4.8 on the third molar ($P = 0.007$). Tests to localize the difference in length of scratches indicated that the first molar differed significantly from the second molar ($P = 0.000$) and third molar ($P = 0.000$). Box plots of these values are presented in Figures 1 and 2.

Intrafacet comparison

A statistically significant difference was found for one variable: mean number of pits (Table 4 gives statistical results). Pit frequency increased from 14.0 ± 8.5 at the top of the facet to 20.3 ± 7.0 at the bottom of the facet on the first molar ($P = 0.038$). Box plots of these values are shown in Figure 3. Representative micrographs are displayed in Figure 4.

TABLE 2. Mean values and standard deviations for each microwear variable

	First molar		Second molar		Third molar	
Variable	Mean	SD	Mean	SD	Mean	SD
Top of facet						
Total number of features	83.7	36.7	131.5	43.5	93.2	28.5
Mean number of pits	14.0	8.5	56.4	21.3	37.4	17.6
Mean number of scratches	69.7	28.2	75.1	22.2	55.8	14.8
Percent pits	16.7	8.3	42.8	7.0	40.1	10.1
Mean pit length	6.9	3.3	6.2	2.7	8.2	3.2
Mean pit width	2.2	1.0	2.6	1.6	2.9	2.6
Mean scratch length	37.4	12.6	32.2	9.9	23.4	6.1
Mean scratch width	1.6	0.3	2.0	0.5	1.7	0.1
Bottom of facet						
Total number of features	91.6	13.6	127.2	36.4	89.3	48.2
Mean number of pits	20.3	7.0	35.4	13.7	27.3	17.6
Mean number of scratches	71.3	6.6	91.8	29.9	62.0	30.6
Percent pits	22.1	3.1	27.8	7.0	30.5	9.0
Mean pit length	5.9	1.2	7.3	2.3	7.3	1.1
Mean pit width	2.8	0.3	3.0	0.6	3.2	0.3
Mean scratch length	39.4	5.4	22.2	6.6	24.5	4.8
Mean scratch width	1.6	0.1	1.5	0.1	1.7	0.2

TABLE 3. Comparison between molars (significant differences in bold)[1]

	Top of facet			Bottom of facet		
Variable	f	df	*P*	f	df	*P*
Total number of features	0.857	2	0.460	1.017	2	0.440
Mean number of pits	4.563	2	0.062	0.991	2	0.447
Mean number of scratches	1.687	2	0.245	1.090	2	0.417
Percent pits	**14.900**	**2**	**0.002**[2]	0.893	2	0.478
Mean pit length	1.735	2	0.237	0.542	2	0.619
Mean pit width	2.223	2	0.171	0.449	2	0.572
Mean scratch length	1.240	2	0.371	**21.606**	**2**	**0.007**[3]
Mean scratch width	1.291	2	0.208	2.131	2	0.181

[1] Within-samples ANOVA.

[2] Paired-samples *t*-tests were used to localize significant difference in percentage of pits between molars: M1 vs. M2 ($P = 0.000$); M1 vs. M3 ($P = 0.000$); M2 vs. M3 ($P = 0.359$).

[3] Paired-samples *t*-tests were used to localize significant difference in length of scratches between molars: M1 vs. M2 ($P = 0.000$); M1 vs. M3 ($P = 0.000$); M2 vs. M3 ($P = 0.281$).

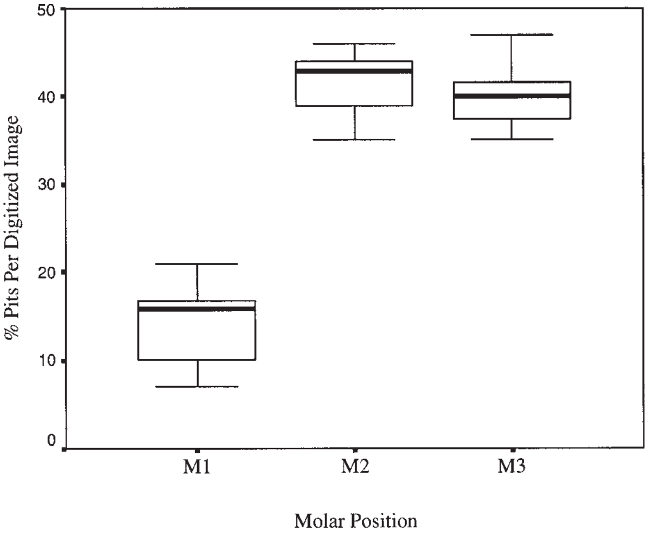

Fig. 1. Box plot illustrates statistically significant increase in percentage of dental pits on second and third molars at top of facet, compared to first molar.

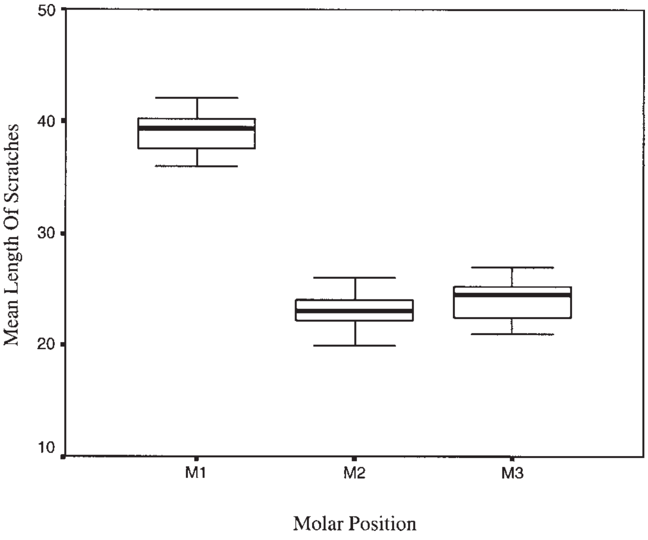

Fig. 2. Box plot illustrates statistically significant increase in length of scratches on first molar at bottom of facet, compared to second and third molars.

DISCUSSION

Microwear patterns were compared between human mandibular molars, and between the upper and lower part of facet 9. It was found that the position of a molar along the tooth row and location on a facet significantly influenced the frequency and length of microwear features. However, while these results raise some important issues for microwear methodology, they only provide preliminary insights and should be treated with caution because of the small sample size.

The percentage of pits increased on the second and third molars, compared to the first molar (Tables 2 and 3). If the explanatory model of Gordon (1982), that an increase in pit frequency relates to an increase in compression (teeth moving towards each other), is extrapolated into the present study, it suggests that human bite force increases on the more posterior molars. This finding seems to accord well with human in vivo research (Mansour and Reynick, 1975; van Eijden, 1991), studies on enamel thickness (Schwartz, 2000; Spears and Macho, 1998), and microwear comparisons between deciduous incisors and first

TABLE 4. Comparison between top and bottom of facet (significant differences in bold)

	First molar[1]			Second molar[1]			Third molar[2]	
Variable	*t*	df	*P*	*t*	df	*P*	z	*P*
Total number of features	−0.282	2	0.804	−0.055	2	0.960	−1.429	0.153
Mean number of pits	**−5.000**	**2**	**0.038**	0.565	2	0.612	−1.582	0.114
Mean number of scratches	0.370	2	0.747	−0.503	2	0.650	−1.020	0.308
Percent pits	−4.227	2	0.064	−1.873	2	0.158	−1.070	0.285
Mean pit length	0.861	2	0.480	−2.680	2	0.806	−1.225	0.221
Mean pit width	0.672	2	0.571	0.170	2	0.875	−0.764	0.445
Mean scratch length	0.890	2	0.468	1.505	2	0.229	−0.357	0.721
Mean scratch width	0.190	2	0.867	−0.055	2	0.960	−0.357	0.721

[1] Paired-samples *t*-test.
[2] Wilcoxon test.

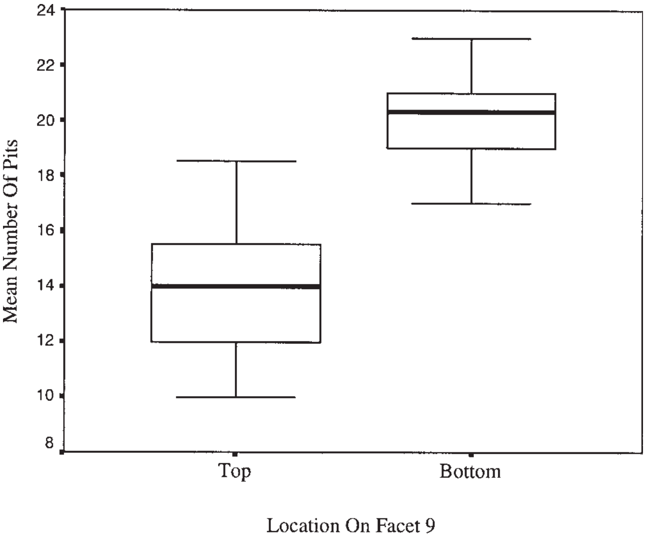

Fig. 3. Box plot illustrates statistically significant increase in mean number of pits at bottom of facet on first molar, compared to top of facet.

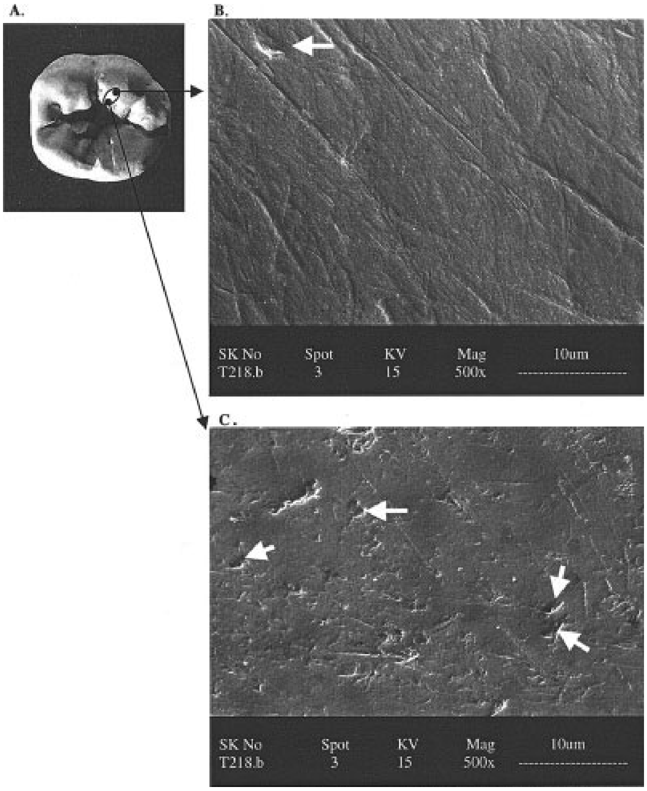

Fig. 4. Micrographs (B and C) illustrate increase in pit frequency at bottom of facet on first molar, compared to top (arrows indicate dental pits). **A:** Right first permanent mandibular molar. Facet 9 is highlighted area. **B:** Representative dental microwear at top of facet. **C:** Representative dental microwear at bottom of facet. SK No T218.b, Tell es-Sa'idiyeh, skeletal number T218.b; Spot, spot size; KV, accelerating voltage; Mag, magnification ×500 (original magnification before image was imported into text). Size bar, 10 μm.

molars (Bullington, 1991), all of which reported increased occlusal loads on more posterior teeth.

The length of scratches decreased on the second and third molars, compared to the first molar (Table 2 and 3). The difference in scratch length suggests that more shear (teeth sliding past each other) is exerted on the first molar. This pattern might be expected, given that the first molar experiences a relatively greater lateral excursion of the mandible during chewing (Gordon, 1982), though it is less clear why scratch length did not vary between the second and third molars. Perhaps one influencing factor was the physical properties of the food consumed. For instance, lateral movements of the mandible can be less important when chewing soft foods (Luschei and Goodwin, 1974), which might have been available to the Bronze-Iron Age inhabitants of Tell es-S'aidiyeh (Clapham, 1988). In that case, the molars positioned more posteriorly may have experienced predominantly vertical movements during chewing and thus retained shorter scratches. However, it should be borne in mind that the age of individuals selected for the present study might have predetermined that the third molars would have had a limited role in mastication and hence influenced the microwear pattern.

Microwear features on facet 9 are most probably created during the chewing cycle from a combination of both compressive forces during phase I of the power stroke and grinding forces (shear and compression) during phase II (Kay and Hiiemae, 1974), though they may not necessarily form in equal measures during the different phases (e.g., Hylander et al., 1987). The intertooth microwear pattern suggests that different locations on the facet experience relatively more or less of these forces. More shear, resulting in longer scratches, appears to be exerted at the bottom of the facet on the first molar, compared to the second and third molars (Tables 2 and 3). In contrast, more compression, resulting in more pits, seems to be exerted at the top of the facet on the second and third molars, compared to the first molar (Tables 2 and 3). The intrafacet pattern lends some support to this interpretation, because it also shows a decrease in compression (fewer pits) at the top of the facet on the first molar (Tables 2 and 4).

It is less clear why the microwear patterns seem to have been influenced by location on the facet. If either the anisotropic properties of prismatic enamel (Maas, 1991) or different formation processes, such as attrition vs. abrasion (Teaford and Runestad, 1992), had been causal agents, then differences in size (width) of the microwear features between locations on the facets might have been expected, which were not found. However, perhaps an analysis of average feature width might prove more informative. That is to say, if microwear patterns are not subdivided into pits and scratches, perhaps average feature width can distinguish between different dental locations.

The biomechanics of mastication provide one explanation for the variation in the frequency and length of microwear patterns between different facet locations (e.g., Robson and Young, 1990; Teaford, 1988). For instance, the greater compression on the upper part of the facet on the posterior molars (Table 3), compared to the first molar, might have been possible because the mandible moves more vertically toward the temporomandibular joint, and when this occurs, bending in the tooth is minimized (Spears and Macho, 1998). Away from the joint, bending seems to be minimized if high forces are applied toward the intercuspal fissure, at least on first mandibular molars (Macho and Spears, 1999, their Table 3). Indeed, this latter location seems to be particularly well-designed for this purpose because of the wide buccal-lingual base (Khera et al., 1990), and this seems to be reflected in studies on the physical properties of enamel as well (Cuy et al., 2002). In this case, the increase in shear (Table 3) and compression (Table 4) on the lower part of the facet on the first molar would seem to occur at a dental location that is capable of withstanding these forces. Given this, if the lateral movements of the mandible contribute toward high shear on the lower part of the facet (see above), does the intrafacet pattern reflect the high forces that can occur during phase I of the power stroke (e.g., Hylander et al., 1987), perhaps as some foods are compressed toward the tooth basin?

CONCLUSIONS

In order to enhance comparability between human diet-microwear studies, this study suggests that there may be a need for standardization in both molar type and location on a facet.

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