International Journal of Osteoarchaeology
Int. J. Osteoarchaeol. **21**: 723–731 (2011)
Published online 7 July 2010 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/oa.1184

Dental Chipping: Contrasting Patterns of Microtrauma in Inuit and European Populations

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ABSTRACT While the study of dental wear has enjoyed wide popularity for over 100 years, dental chipping, or microfractures of the tooth crown, has received little attention. Observations on dental chipping in populations from the Arctic (St. Lawrence Island, Alaska) and Europe (medieval Norway and Spain) reveal patterns of microtrauma that provide insights into the dietary and tooth-tool use behaviour of earlier populations. St. Lawrence Island Inuit, with an emphasis on consuming tough and frozen foods, in combination with extensive tooth-tool use, exhibit a pattern of chipping that is characterised as 'molar dominant'. The two European samples exhibit an 'incisor-dominant' pattern but contrast markedly in frequencies, with medieval Norwegians showing significantly more chipping than medieval and post-medieval Spanish. The systematic study of chipping promises to provide a new perspective on how populations used and/or abused their dentitions in earlier times. Copyright © 2010 John Wiley & Sons, Ltd.

Key words: tooth crown; chipping; microfractures

Introduction

At the outset, tooth crown wear should be distinguished from dental chipping. Crown wear is the gradual removal of tooth substance (enamel and eventually dentine) through some combination of attrition and abrasion. Attrition occurs primarily through the action of tooth-on-tooth contact during normal mastication. Abrasion involves the introduction of one or more foreign elements into the masticatory system that either exacerbates attrition (e.g. small stone particles in milled flour) or contributes directly to tooth wear through non-masticatory means (e.g. chewing or softening hides with the anterior teeth). In terms of rates, crown wear involves the gradual, incremental removal of tooth substance. In terms of appearance, a worn tooth presents a surface that is smooth and flat, almost polished. When wear extends through the enamel into the dentine, the tooth shows 'cupping' because dentine wears more quickly than enamel. Even in these instances, the surfaces remain smooth and regular whether the plane is flat or angled. Dental chipping, or pressure-chipping, in contrast to normal crown wear, is manifested in irregular, jagged surfaces.

In solid mechanics, there are three primary responses to force: elasticity, plasticity and fracture (Sandor, 1978; Courtney, 2000). Elasticity refers to the ability of a solid to change shape temporarily but return to its original form when the stress is removed. Plasticity is the ability of a solid object to change shape permanently in response to a constant stress but still remain in one piece (e.g. cranial deformation). A fracture occurs when a solid object is split permanently into two or more pieces. While bone has viscoelastic properties that allow it to deform before finally breaking, the enamel of a tooth crown has essentially none.

The concept of strength refers to a solid material's elastic and plastic ranges. The three primary types of strength – compressive, shear and tensile – are determined by the direction of force applied to an object (Parker, 1977). Compressive force involves pushing or pressing two objects together, often resulting in shortening. Tensile stress, the opposite of compression, describes an object that is pulled apart or stretched longitudinally. Shear refers to the lateral deformation of an object produced by an external force or stress. After a solid material deforms elastically, yield

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Received 21 December 2009
Revised 29 April 2010
Accepted 13 May 2010

strength refers to the point where the material starts to deform plastically. Brittle materials have no yield point and fracture with little or no plastic deformation prior to breakage (Courtney, 2000).

Teeth are strong but brittle. On Moh's hardness scale, apatite, the primary component of tooth enamel, has a 'hardness' of 5. Enamel can withstand a great deal of stress but when it reaches a breaking point, that is just what it does – break. Dental chipping occurs when the strength of enamel is surpassed by bite force pressure exerted between the opponents in the two jaws. The resultant fracture is usually precipitated by the presence of a foreign element between two occluding teeth (such as a grain of sand, a bone, a bottle cap, etc.) although unusually pronounced compressive force between opponents can also cause chipping. For a detailed discussion of the fracture mechanics of enamel, see the appendix in Lucas (2004: 257) and additional studies on mammalian, primate and hominid dental structure and function by Lucas and his colleagues (Lucas *et al.*, 2008a, 2008b, 2009; Constantino *et al.*, 2009).

Forces that cause trauma in bone include tension, compression, torsion, bending and shearing. Because enamel is less elastic than bone, the forces that lead to trauma are more straightforward. Bending or shearing forces could lead to dental trauma but, in such cases, the entire crown would be broken off at or near the gum line. Lukacs (2007) discusses this form of dental trauma for Canary Islanders, which he attributes to accidental falls in rocky terrain and interpersonal conflict or sport. This extreme form of total crown loss was rare in our samples. The majority of the microfractures we observed were produced by compressive force.

Smith (1984: 39) notes that 'tooth wear may record important stages in human biological and cultural evolution, including evidence of food resources utilised by ancestral hominids, development of fire and cooking, invention of food processing utilising grinding tools, adoption of agriculture, invention of pottery, and other refinements in the way food is processed'. As a form of tooth wear, dental chipping can provide additional insights on these same hallmarks of hominid evolution. Despite the potential of dental trauma for providing information on how past peoples used their teeth, few studies have provided information on the frequency and distribution of damaged teeth. Available data on chipping are also reported differently because of disparate methods and varied research objectives (Milner & Larsen, 1991).

Although a few studies have focused on or dealt tangentially with dental chipping (cf. Turner & Cadien, 1969; Lukacs & Hemphill, 1990; Bonfiglioli *et al.*, 2004; Belcastro *et al.*, 2007), the potential of chipping to provide another line of evidence for variation in behaviour through time and space has not been fully exploited. In this study, two skeletal samples from Europe and one sample from the Arctic have been studied to determine how data on chipping can be used to augment data on dental pathology and crown wear to help us understand the dietary and tooth-tool use behaviour of earlier human populations.

Materials and methods

From an observational standpoint, the contrast between scoring crown wear and dental chipping is this: there is no postmortem process that simulates the appearance of crown wear whereas postmortem 'dental chipping' is common if not ubiquitous in museum collections. A key decision is how to distinguish antemortem from postmortem fractures.

1. *Postmortem chipping*. After death, the enamel matrix slowly dehydrates. This decreases the strength of the crystalline structure to the point where the enamel chips or flakes easily. Museum collections include thousands of specimens that exhibit such 'postmortem' chipping. Even careful handling can lead to chipping under these circumstances. Only proper curation can stabilise a tooth crown and impede this process. It is usually possible to distinguish postmortem chipping from antemortem chipping by colour and appearance. Postmortem chipping is generally characterised by exposed enamel that is whiter than adjacent surfaces. As enamel is brittle but dentine is not, the enamel frequently fractures at the level of the dentine, which is generally dull yellow in colour. As for appearance, postmortem chipping results in exposed enamel with sharp and well-defined edges (Figure 1).
2. *Antemortem chipping*. Tooth crowns that are chipped during the life of an individual have affected areas where the removed chip is similar in colour to the adjacent areas of the crown. Moreover, since a tooth chipped antemortem remains in functional occlusion for the life of the individual, the edges become smoothed or blunted (Figure 2).

Beyond determining whether chipping is postmortem or antemortem, another consideration includes the decision to score chipping by individual or by tooth. In their classic study of Arctic groups, Turner & Cadien (1969) recorded chipping by individual. Although the authors found a clear distinction between Eskimos viz.

Figure 1. Postmortem dental chipping; note sharp, angular fractures of enamel and dentine. The enamel surface is white while the dentine surface is dull yellow. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

Aleuts and Arctic Indians, there are drawbacks to the individual count method. For example, if a skull has only one tooth and it is not chipped, the individual would be scored as 0 for chipping. An individual with 32 unchipped teeth would be scored the same as the individual with one tooth. If that single tooth is chipped, the individual is scored as 1 (or +), the same as an individual with 1 of 32 chipped teeth or 32 chipped teeth. In other words, highly variable conditions can result in the same score for two individuals. Also, the different tooth types exhibit different chipping frequencies so whether or not an individual was scored as 0 or 1 would be strongly influenced by which teeth remained in the jaws.

To record chipping, we used a tooth count method that allows frequencies to be calculated for all individual teeth of the upper and lower jaws. Using the tooth count method, there are several variables at play when scoring chipping: (1) degree (slight chip to loss of entire cusp), (2) number of chips on a single crown and (3) the location of the affected areas (such as mesiodistal, distolingual, etc.). Bonfiglioli *et al.* (2004) used a three-scale classification to score degree of chipping that is based on the size and depth of the modification. Belcastro *et al.* (2007) scored the number of chips per tooth. These factors were also taken into account to record chipping in prehistoric St. Lawrence Island Inuit (Scott & Gillispie, 2002). In later studies, however, the senior author focused on whether or not individual teeth showed clear evidence of antemortem chipping without regard to degree or location. Thus, in this report, we focus on the number of chipped teeth but do not consider degree, number or location of the fractures.

Figure 2. The first and second lower molars both exhibit antemortem fractures on the distolingual cusp. In contrast to postmortem fractures, these microfractures are the same colour as the rest of the tooth and the edges are blunted from wear. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

When chipping is scored, an observer has to make a decision on how much crown wear can be present. When the cusps of an enamel crown are largely removed by wear, there is no way to determine if a tooth was ever chipped so a worn tooth is not scored. As a rule, chipping should only be scored when about two-thirds of the tooth crown is intact, with at least an enamel rim around the entire crown. When the enamel forms a rim around the entire tooth and dentine is exposed on much of the crown surface, this weakens the enamel edge which can then be more easily chipped than an intact and mostly unworn crown. This condition also increases the probability of postmortem chipping. Intraobserver error was not measured directly but is probably minimal, given the contrast between postmortem and antemortem chipping and the scoring focus on presence/absence.

Samples

Observations on dental chipping were made on three skeletal samples by one observer (GRS). First, 67 prehistoric Inuit from St. Lawrence Island, Alaska, dating from ca. AD 200 to 1700, were scored for chipping and other dental characteristics (Scott & Gillispie, 2002). The second sample comes from a medieval cemetery in Trondheim, Norway, where 167 individuals were scored. Finally, observations were made on a sample of 241 medieval and post-medieval skeletons from the Cathedral of Santa Maria in Vitoria, Spain. Information on chipping in the Inuit and Norse samples have been reported in condensed form elsewhere (Scott *et al.*, 1992; Scott & Gillispie, 2002), but data were not presented by individual tooth. The Spanish data, obtained in 2005, have not been reported. The stimulus for considering these three samples was the discovery of their distinct patterns of chipping.

Results

In the 3 samples, 4036 teeth were scored for chipping. Each European sample is more than twice as large as the Inuit sample, due largely to the greater frequency of postmortem tooth loss in Inuit jaws. Observations summarised in Table 1 show the following pattern of chipping.

St. Lawrence Island Inuit

For the Inuit, about half of the anterior teeth show chipping with a slightly higher frequency in the maxillary dentition. Over half the premolars show chipping, reaching a high of 90% on UP2 of males. The first molar shows by far the highest frequency of chipping in both sexes with similar frequencies in the two jaws (85–100%). Second molars also show a high frequency of chipping (66–86%), but there is a drop off from the first molars. Third molars show the least chipping (0–33%). Overall, two out of three teeth are chipped in the Inuit sample.

Medieval Norwegians

Norwegians match or exceed the Inuit for chipping in UI1 and UI2, both of which show frequencies of 45–75%. The upper canine also shows a high frequency (52–66%) but there is a much lower frequency in the lower canine (18–23%). Premolars in both jaws show less chipping than anterior teeth with frequencies of 15–30%. First molar frequencies fall to 10–20% with a further reduction in the second and third molars where the frequencies are less than 10%. Overall, one out of four teeth are chipped in the Norwegian sample

Spanish

For the Spanish sample, the upper and lower incisors show the highest chipping frequencies, but these are only 10–20%. The upper canines have a chipping frequency of about 5%, but no chipping was observed on the lower canine. Premolars also show little chipping with frequencies between 0 and 6%. Molar chipping shows the same gradient as the above two

Table 1. Dental chipping frequencies (by tooth) in St. Lawrence Island Inuit and Europeans

Sample	Sex	Jaw	Tooth								
			I1	I2	C	P1	P2	M1	M2	M3	TOTAL
Inuit (St. Lawrence Island, Alaska)	Male	Maxilla	0.615	0.714	0.563	0.750	0.900	0.977	0.805	0.333	0.733
			8/13	10/14	18/32	24/32	27/30	43/44	33/41	10/30	173/236
		Mandible	0.571	0.545	0.571	0.517	0.692	1.000	0.865	0.333	0.687
			4/7	6/11	16/28	15/29	18/26	39/39	32/37	8/24	138/201
	Female	Maxilla	0.500	0.500	0.316	0.471	0.826	0.846	0.666	0.000	0.534
			6/12	7/14	6/19	8/17	19/23	33/39	24/36	0/33	103/193
		Mandible	0.571	0.222	0.444	0.500	0.409	0.914	0.730	0.194	0.547
			4/7	2/9	8/18	10/20	9/22	32/35	27/37	6/31	98/179
	Total		0.564	0.521	0.495	0.582	0.723	0.936	0.768	0.203	0.632
			(22/39)	(25/48)	(48/97)	(57/98)	(73/101)	(147/157)	(116/151)	(24/118)	(512/809)
St. Gregory's Cathedral (Trondheim, Norway)	Male	Maxilla	0.770	0.544	0.524	0.267	0.317	0.170	0.063	0.057	0.280
			20/26	12/22	22/42	12/45	13/41	7/39	4/64	3/53	93/332
		Mandible	0.455	0.706	0.189	0.259	0.161	0.216	0.083	0.073	0.227
			10/22	24/34	10/53	15/58	9/56	8/37	5/60	4/55	85/375
	Female	Maxilla	0.622	0.447	0.661	0.224	0.295	0.096	0.082	0.039	0.285
			23/37	17/38	37/56	11/49	13/44	5/52	6/73	2/51	114/400
		Mandible	0.548	0.535	0.236	0.206	0.167	0.182	0.070	0.073	0.219
			17/31	21/40	13/55	14/68	8/48	6/33	5/71	4/55	88/401
		TOTAL	0.603	0.552	0.398	0.236	0.228	0.161	0.075	0.061	0.252
			(70/116)	(74/134)	(82/206)	(52/220)	(43/189)	(26/161)	(20/268)	(13/214)	(380/1508)
Cathedral of Santa Maria (Vitoria, Spain)	Male	Maxilla	0.200	0.224	0.060	0.049	0.065	0.070	0.038	0.033	0.092
			10/50	11/49	4/67	3/61	4/62	3/43	2/53	1/30	38/415
		Mandible	0.132	0.119	0.000	0.000	0.043	0.065	0.023	0.043	0.049
			5/38	5/42	0/50	0/52	2/47	2/31	1/44	1/23	16/327
	Female	Maxilla	0.153	0.101	0.048	0.014	0.066	0.037	0.000	0.026	0.052
			9/59	6/59	4/84	1/72	5/76	3/81	0/83	1/39	29/553
		Mandible	0.122	0.069	0.000	0.016	0.017	0.020	0.018	0.000	0.033
			6/49	4/58	0/59	1/61	1/58	1/49	1/55	0/37	14/426
		Total	0.153	0.125	0.031	0.020	0.049	0.044	0.017	0.023	0.056
			(30/196)	(26/208)	(8/260)	(5/246)	(12/243)	(9/204)	(4/235)	(3/129)	(97/1721)

samples (M1 > M2 > M3), but frequencies are far lower, at 4.4%, 1.7% and 2.3%, respectively. Overall, one out of 20 Spanish teeth exhibits dental chipping.

Dental chipping, unlike crown wear, is precipitated by accidents. Do these accidents favour one side of the jaw over the other? Several different methods were used to address this question and the results consistently show there is no side preference in chipping. The mean chipping frequency across all 16 teeth is almost identical for the three samples (Spain: L 5.5%, R 6.9%; Norway: L 24.8%, R 24.0%; Inuit: L 61.4%, R 59.1%). Interclass correlations for chipping frequencies on the left and right sides of the jaw range between 0.81 and 0.93, all significant at the 0.01 level. Spearman's rho and Kendall's tau show the same pattern.

When crown chipping frequencies for all left and right teeth from both jaws are plotted for the three samples, a distinctive pattern emerges (Figure 3). The Inuit show very high chipping frequencies overall but the emphasis is on the cheek teeth. We refer to this pattern as 'molar dominant'. By contrast, the

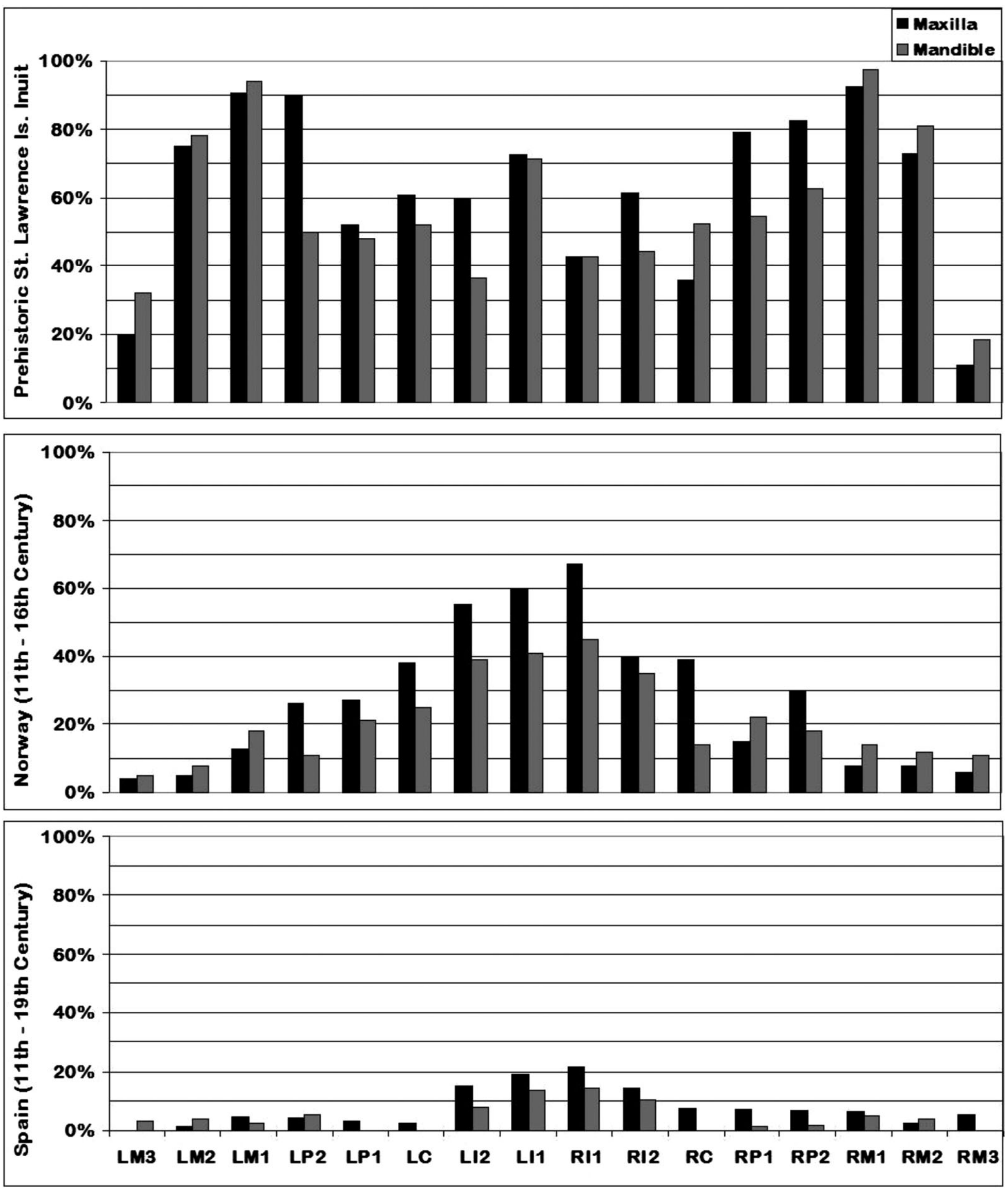

Figure 3. Histograms showing the chipping frequencies for all left and right teeth from both jaws showing the difference between the molar-dominant pattern of St. Lawrence Island Inuit and the incisor-dominant pattern of the European samples.

Table 2. Pattern of dental chipping frequencies in diverse populations by individual, tooth, anterior versus posterior teeth and sex

	Sample					
	Inuit (St. Lawrence Island)	St. Gregory's (Norway)	Santa Maria (Spain)	Taforalt (Morocco)	Quadrella (Italy)	Vicenne-Campochiaro (Italy)
Total individuals	67	167	241	33	64	84
Total teeth	809	1508	1721	571	1053	1582
% of individuals affected	97.0	56.9	24.1	93.9	100.0	97.6
% of teeth affected	66.4	21.9	5.9	29.2	48.4	38.9
Anterior tooth %	53.2	39.7	9.0	21.1	61.3	51.8
Posterior tooth %	68.7	13.9	4.0	32.8	40.8	30.9
Male %	72.3	23.6	6.9	32.4	53.0	40.2
Female %	59.2	23.5	4.3	22.1	45.5	37.3
Age of sample	2nd–17th century	11th-14th century	11th–18th century	11 000–12 000 BP	2nd–3rd century BC	4th–10th century
Reference	Present study	Present study	Present study	Bonfiglioli *et al.* (2004)	Belcastro *et al.* (2007)	Belcastro *et al.* (2007)

Norwegian sample shows high chipping frequencies on the anterior teeth but much reduced frequencies on the premolars and molars. The Spanish sample shows the same 'pattern' of chipping frequencies as the Norwegian sample, albeit with much lower frequencies. Both European samples exhibit what we refer to as an 'incisor-dominant' pattern.

Discussion

Pedersen (1949) was one of the first authors to note that traumatic crown fractures (i.e. dental chipping) were common in Greenlandic Eskimos. Turner & Cadien (1969) examined pressure-chipping in Aleuts, Eskimos and Indians to determine if there was significant between-group variation in chipping frequencies. Based on an individual count, they found that Eskimos had a much higher chipping frequency (71.9%) than Aleuts (22.8%) or Indians (18.4%).

Recent studies of dental chipping have focused on Circum-Mediterranean populations. Bonfiglioli *et al.* (2004) examined chipping in remains from the epipalaeolithic necropolis of Taforalt in Morocco that dates around 11–12 000 BP. Belcastro *et al.* (2007) compiled chipping data from two sites in Italy, one dating to the Roman Imperial Age and one from the early medieval period. As these authors noted chipping by individual, mandible, maxilla, anterior, posterior, young adult, middle adult and old adult, their findings are compared to those of the present study in Table 2.

The samples from Morocco and Italy are similar to the Inuit in chipping percentage reckoned by the individual, all of which are at or near 100%. However, chipping frequencies by tooth are notably lower in that 30–50% show chipping in contrast to 66% for the Inuit. Whether considered by individual or tooth, the frequencies of chipping in Norway and Spain are considerably lower than the other four samples.

To evaluate differences in chipping frequency by sex, jaw and tooth group, ratios for males:females, maxillary:mandibular and anterior:posterior teeth were calculated for each of the six groups (Table 3). Contingency analyses of chipped teeth were conducted for these ratios in the six samples (excluding the maxillary:mandibular ratio for Taforalt as the affected, unaffected numbers could not be determined). As chi-square is sensitive to sample size, only ratios that

Table 3. Chipping ratios by (1) sex, (2) jaw and (3) anterior–posterior teeth (based on tooth count frequencies)

Sample	Male:female	Maxillary:mandibular	Anterior:posterior
St. Lawrence Island Inuit (present study)	1.32*	1.04	0.77*
Norway (present study)	1.00	1.24*	3.40*
Spain (present study)	1.66	1.73	3.10*
Taforalt (Morocco) (Bonfiglioli *et al.*, 2004)	1.47	—	0.64*
Quadrella (Italy) (Belcastro *et al.*, 2007)	1.16	1.14	1.50*
Vicenne-Campochiaro (Italy) (Belcastro *et al.*, 2007)	1.08	1.17	1.68*

*Chi-square significant at 0.01 level.

differed significantly at the 0.01 level are noted in the table.

The ratios in Table 3 reveal several distinctive patterns across the six samples. First, all ratios for males:females equal 1.0 or higher, indicating that males typically exhibit more dental chipping than females. Only for the Inuit, however, was the ratio statistically significant. For the inter-jaw comparisons, in every instance the ratio exceeded 1.0, indicating that maxillary teeth chip more commonly than mandibular teeth. This can be largely attributed to the fracture mechanics of different tooth types, with the contrast between the upper and lower incisors particularly notable (Schatz *et al.*, 2001). Only for Norway, however, was the between jaw difference statistically significant. The most dramatic pattern of ratio variation was in the contrast between chipping in the anterior and posterior teeth. For all six samples, the ratios were statistically significant. However, not all samples showed ratios in the same direction. The Inuit and Taforalt samples showed significantly greater chipping frequencies in the posterior teeth, with anterior: posterior ratios of 0.77 and 0.64, respectively. All four European samples showed significantly more chipping in the anterior teeth. The two Italian samples had ratios around 1.5, while the Norwegian and Spanish samples had ratios above 3.0.

Milner (1983) and Emerson *et al.* (1983) observed dental chipping in two eastern North American Indian samples and found patterns similar to those reported for the European and African samples. The overall chipping frequencies for the two sites (Florence Street Site and East St. Louis Stone Quarry Site) were 36.8 and 53.8%, respectively. The maxillary:mandibular ratios for the two samples were 1.14 and 0.89, supporting the position that chipping does not differ by jaw. The anterior:posterior chipping ratios were 0.29 and 0.79, indicating an edge for chipping in the posterior teeth, similar to the Inuit and Taforalt samples.

Key variables that influence the pattern of chipping variation between groups include: (1) jaw mechanics, (2) diet and subsistence, (3) food preparation techniques and (4) tooth-tool use. The Inuit, for example, can generate a force of 240–280 psi between the first molars compared to 90–120 psi for modern Europeans (Hylander, 1977). This extreme bite force, made possible by a suite of distinct craniofacial features, results in the generation of force between the teeth when either eating or using the teeth as a third hand that exceeds the strength of enamel, leading to microfractures of the tooth crown. This likely contributes to the high frequency of chipping in the

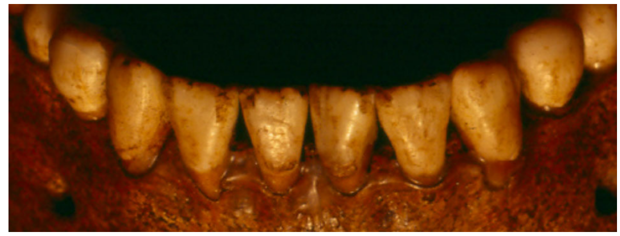

Figure 4. Small microfractures on all lower incisors of a medieval Norwegian, exhibiting a 'nibbling' effect. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

Inuit. Regarding diet and subsistence, hunter-gatherers show molar-dominant chipping as opposed to recent agricultural groups which are consistently incisor dominant in chipping frequencies. At the Neolithic site of Mehrgarh in Pakistan, Lukacs & Hemphill (1990: 355) note that 'Maxillary anterior teeth were frequently used in occupational activities . . . Evidence comes from antemortem chipping of the labial-incisal edge of the maxillary incisor and canine teeth'. However, two eastern North American Indian samples, who are also agriculturalists, exhibit molar-dominant patterns. That requires more consideration of food preparation techniques. The use of grinding stones to process small grains has been shown to impact normal tooth attrition by exacerbating wear through the addition of fine grained particles in the 'flour'. However, depending on the nature of the stone used, larger particles could be introduced into the flour and these particles could chip rather than simply wear teeth down. This observation could be tested by the analysis of chipping variation between groups using stone, wood and metal grinding implements. Finally, the use of the teeth as a third hand falls primarily on the anterior teeth. In hunting-gathering groups, the result is often pronounced and rounded wear on the incisors and canines (cf. Hinton, 1981). In agricultural groups where anterior tooth wear is not as pronounced, the loss of tooth substance may occur more frequently through chipping rather than simple wear.

Conclusions

Finding a difference between an Inuit sample and two European samples in the overall frequency and tooth by tooth pattern of chipping was not surprising, given the significant contrasts in jaw mechanics and dietary behaviour of these groups. Prehistoric Inuit commonly consumed frozen, tough, grit laden food that required significant use and abuse of the chewing teeth (premolars, molars). For this Arctic group, the demands of chewing outweighed the demands of incisal preparation and anterior tooth-tool use, resulting in higher premolar–molar chipping frequencies.

Less expected was finding congruent patterns of chipping across all teeth in the two European samples in spite of noteworthy frequency differences. Compared to the Spanish, there was a higher premium on incisal preparation in the Norwegians where the incisors and canines were often 'nibbled' along their incisal edges (Figure 4). Time might be a critical factor in this difference. The samples from Norway and Spain overlapped temporally to some extent with both including medieval elements. However, the sample from Norway was predominantly medieval while the sample from Spain had more post-medieval than medieval skeletons. For Spain, the post-medieval sample had significantly more caries and abscesses than the medieval sample, suggesting a shift to more highly processed foods, including refined sugar (Hopkinson, 2009). Enhanced food preparation techniques after AD 1500 that produced a lower volume of 'tooth chipping' particulates could have played a role in the lower chipping frequencies in Spain.

We have identified two dental chipping patterns tied to differences in geography and subsistence – a molar-dominant pattern in prehistoric Arctic hunters and an incisor-dominant pattern in late European agriculturalists. The method of scoring chipping on all individual teeth and portraying the frequencies by left and right and by maxilla and mandible should reveal a diversity of patterns relative to different subsistence strategies (such as intensive foragers, marine collectors, pastoralists, etc.) and food preparation techniques (such as stone mano-metate versus iron milling, cooking methods, etc.). Researchers who focus on crown wear and oral health in earlier populations are encouraged to score dental chipping. If additional patterns emerge, this will put us one step closer to the goal of understanding the diets and dietary behaviour of earlier human populations.

Acknowledgements

We extend our appreciation to museum personnel and researchers at the Seminar für Urgeschicte in Bern, Switzerland (H. G. Bandi), the University Museum in Trondheim Norway (Lars F. Stenvik) and the Cathedral of Santa Maria in Vitoria, Spain (Augustin Azkarate Garai-Olaun) who helped facilitate our research on the Inuit and European samples. We also thank the anonymous reviewers whose suggestions led to several improvements in the final manuscript.

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