

ORIGINAL ARTICLE

Enamel erosion and mechanical tooth wear in medieval Icelanders

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Abstract

Objectives: The Icelandic Sagas are an important source of information on the way of life and diet habits in Iceland and possibly other Nordic countries 1000 years ago. Archaeological human skull material worldwide has revealed extensive tooth wear, with the main cause believed to be coarse diet. From a graveyard near volcano Hekla, 66 skeletons dated from before 1104 were excavated. The purpose of this study was to determine the main causes of tooth wear in Icelanders 1000 years ago. **Materials and methods:** Forty-nine skulls were available for research. Two methods were used to evaluate tooth wear and seven for age estimation. An attempt was made to determine the main causes of tooth wear in the light of likely diet and beverage consumption according to a computer search on food and drink customs described in the Icelandic Sagas. **Results:** Tooth wear was extensive in all groups, increasing with age. The highest score was on first molars, with no difference between sexes. It had all the similarities seen in wear from coarse diet. In some instances it had similar characteristics to those seen in erosion in modern Icelanders consuming excessive amounts of soft drinks. According to the Sagas, acidic whey was a daily drink and used for preservation of food in Iceland until recently. **Conclusions:** Since acidic whey has considerably high dental erosive potential, it is postulated that consumption of acidic drinks and food, in addition to a coarse and rough diet, played a significant role in the dental wear of ancient Icelanders.

Keywords: Paleodontology, tooth wear, erosion, medieval Icelanders

Introduction

Extensive tooth wear seems to have been the norm in all ancient societies and considered to be a major cause of tooth problems [1–3]. Tooth wear studies based on skull material from archaeological excavations have mainly been attributed to factors related to the diet [4,5]. Hardly ever is acid erosion mentioned as a possible cause of this observed tooth wear [6].

In dentistry, wear is a generic term used to describe phenomena of attrition (proximal and occlusal inter-dental friction), abrasion (friction with the intervention of particles) and erosion (chemical dissolution). This longstanding terminology suggests that these three phenomena act independently, whereas in fact it is more often the case that they interact simultaneously, which makes the diagnosis more difficult [3].

Skeletal remains from ancient populations can provide evidence for dental health. Investigating the ancient dentition can assist in reconstructing the lifestyle patterns and shed light on the dental and

general health. Among the conditions to be looked at are ante mortem tooth loss, root abscesses, caries frequency, alveolar bone loss and occlusal tooth wear [7]. Hypomineralization of enamel, enamel hypoplasia, appearing as lines or pits, particularly on incisors, can be an indication of malnutrition or infections during tooth formation [8].

Observation of dental wear patterns is one of the most commonly utilized methods of age estimation in adult skeletal remains in archaeology. The popularity of this method arises from the high survival rate of teeth within archaeological contexts and the relative ease with which dental wear patterns can be observed and scored [9].

Research by trained dental personnel on dental health in ancient Icelanders has been almost non-existent. Archaeologists and anthropologists have, however, noticed, registered and commented on excessive tooth wear without classifying or categorizing the type of wear [4,5].

In the years 1931–1939, an archaeological and anthropological research was undertaken at the

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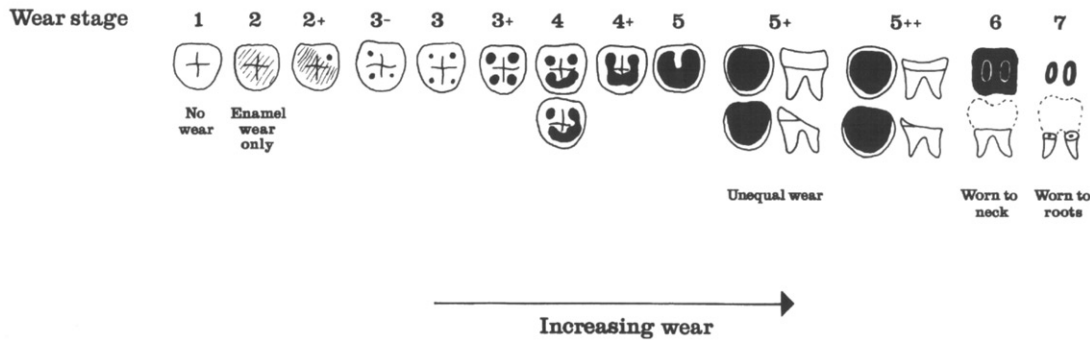


Figure 1. Brothwell classification of molar wear. White denotes enamel, black exposed dentine. (From Mays S. *The archaeology of human bones*. Routledge 2003: 59. Adapted from Brothwell 1981: Figure 3.9 [24]).

Table I. Modification of brothwell tooth wear.

Brothwell wear stages (1981)	1	2	2+	3-	3	3+	4	4+	4	5+	5++	6	7
Brothwell wear stages, modification	0	1	2	3	4	5	6	7	8	9	10	11	12

Skeljastadir farm in Thjosardalur in Iceland. Sixty-six skeletons were excavated from an ancient graveyard; five infants, two children and 59 adults. Volcanic ash from the mountain Hekla, dated from 1104, covered the skeletons. The skeletons are preserved in the National Museum of Iceland. The purpose of this investigation was to undertake detailed and thorough odontological investigation on the skulls to cast a light on dental health in Viking Age Icelanders, especially prevalence and type of tooth wear [4,7].

Materials and methods

The skeletons are in a relatively good condition and were examined at the stores of The National Museum of Iceland. Of the 66 skeletons, 51 skulls could be used for the general dental health investigation and 915 teeth in 49 skulls were evaluated for the tooth-wear examination.

The two authors examined blinded the skulls and teeth. Agreement was more than 90% on all measurements. When there was a disagreement, an agreement was reached based on re-examination and discussion.

The adult skeletons were sexed using morphological characteristics from the skull, mandible and, in a few instances, pelvis [10–14]. Seven methods were used for age estimation, five were based on tooth development [15–19], one on tooth wear [20] and one on ectodermal suture closure [21]. Two methods were used to register tooth wear. The first method was simply to register the wear into four categories: (1) no wear, (2) wear in enamel, (3) dentin exposed and (4) exposure of the pulp cavity. The second method was that developed by Brothwell [22], where wear was registered into 13 groups, as shown in Figure 1. The Brothwell method was

limited to skeletons of subjects 18 years and older: 22 males, 21 females and one that could not be sexed. For statistical calculations, the scale for the wear stages was modified and numbered from 0–12, as shown in Table I.

Tooth wear was examined with a dental probe under good lighting and loupes with 2.8× magnification (Exam Vision ApS, Samsø, Denmark) and photographs with high resolution (Lester A. Dine Inc., Olympus Digital Camera Model No C-5060, Palm Beach Gardens, FL). For analyzing abscesses, conventional dental and radiographic examination was performed. For X-ray analysis, a portable X-ray unit was used (Sirona, Helio Dent, Bensheim, Germany) and digital X-ray technology (Trophy RVG Digital X-ray Systems, Eastman Kodak Company, Rochester, NY). Statistical analyses were made in the StatView statistical software package (StatView Software, SAS, Cary, NY) and the *t*-test was used for significance testing.

Results

A total of 1001 teeth were present in the 51 skulls examined. The number of missing teeth ante mortem in both jaws were 95, or less than 10% of teeth present, 36 in the maxilla and 59 in the mandible. A total of 28 individuals had lost teeth ante mortem, from one to 13 teeth. Missing teeth post mortem were 281 and missing teeth with no information 225, which could raise the ratio of lost teeth ante mortem.

Available for tooth wear examination were 49 skulls. Gender distribution was equal, 24 females, 24 males and one of unknown sex. Tooth wear for each tooth number is shown in Table II, where 0 means no detectable wear, 1 wear in enamel, 2

Table II. Mean tooth wear for each tooth number according to the classification: 0 = no wear, 1 = wear in enamel, 2 = dentin exposed and 3 = exposure of pulp cavity.

		Mean tooth wear; 915 teeth in 49 skeletons															
<i>n</i> of teeth	18	27	37	33	28	28	19	23	21	18	33	31	33	32	26	20	
Mean wear	1.2	1.8	2.2	2.1	1.8	1.9	1.8	2	2.1	1.7	1.9	1.9	1.9	2.2	1.7	1.2	
SD	0.9	0.7	0.6	0.7	0.7	0.5	0.6	0.2	0.2	0.7	0.7	0.7	0.7	0.1	0.1	0.2	
Tooth #	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28	
Tooth #	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38	
SD	0.9	0.6	0.4	0.7	0.5	0.6	0.5	2.2	0.3	0.4	0.6	0.5	0.7	0.4	0.4	0.9	
Mean wear	1.2	1.8	2.3	1.8	1.8	2	2	2.2	2.1	2.1	2.1	1.9	1.8	2.2	1.8	1.2	
<i>n</i> of teeth	25	38	39	31	32	28	28	25	23	32	34	37	26	34	32	24	

Table III. Mean tooth wear according to Brothwell modification.

		Brothwell mod. 18 years and older; 337 teeth in 44 skeletons					
<i>n</i> of teeth		19	26	36	31	24	16
Mean wear		2.3	4.5	7.6	6.9	4.4	1.8
SD		0.6	0.7	0.5	0.4	0.6	0.5
Tooth #		18	17	16	26	27	28
Tooth #		48	47	46	36	37	38
SD		2.6	3	2.6	2.6	2.5	2.1
Mean wear		2.2	5.6	7.5	7.7	5.2	1.9
<i>n</i> of teeth		23	38	39	32	32	21

Table IV. Mean tooth wear in 18–36 years and 36 years and older according to Brothwell modification.

	Age 18–35 121 teeth in 13 skeletons						≥ Age 36 207 teeth in 31 skeletons					
	<i>n</i> of teeth	7	9	9	11	10	7	11	16	26	19	13
Mean wear	0.4	1.6	5.0	5.5	2.6	0.3	3.6	6.4	8.7	7.9	6.1	3.3
SD	0.7	0.9	1.8	2.0	2.1	0.5	0.8	0.7	0.4	0.5	0.8	0.8
Tooth #	18	17	16	26	27	28	18	17	16	26	27	28
Tooth #	48	47	46	36	37	38	48	47	46	36	37	38
SD	1	1.5	1.6	1.9	1.8	0.7	0.9	0.5	0.4	0.5	0.4	0.6
Mean wear	0.8	2.4	5.4	5.9	2.9	0.5	4.1	7.0	8.7	8.8	6.4	3.2
<i>n</i> of teeth	12	13	12	10	11	10	10	25	26	21	21	11

Table V. Mean tooth wear in males and females according to Brothwell modification.

	Male 18 years and older 163 teeth in 21 skeletons						Female 18 years and older 143 teeth in 22 skeletons					
	<i>n</i> of teeth	12	14	17	15	10	8	4	10	16	13	11
Mean wear	2.7	5.2	8.4	7.1	4.7	1.9	2.0	4.2	7.4	7	4.5	2.2
SD	2.9	3.6	2.5	2.3	3.7	2.0	2.1	3.0	2.3	2.2	2.3	2.7
Tooth #	18	17	16	26	27	28	18	17	16	26	27	28
Tooth #	48	47	46	36	37	38	48	47	46	36	37	38
SD	2.4	3.0	2.9	2.7	2.8	2.4	2.9	3.2	2.2	2.3	2.3	1.0
Mean wear	2.2	5.5	7.7	8.1	5.6	2.6	2.6	5.8	7.8	7.5	4.9	1.0
<i>n</i> of teeth	9	18	17	15	16	12	11	18	19	14	14	7

wear exposing dentin and 3 wear exposing the pulp cavity.

Assessment of tooth wear according to age and sex, using the Brothwell method, is shown in Tables III–V. The tooth wear was only measured in skulls of subjects classified as being aged 18 years and older: 21 males, 21 females and one skull that could not be sexed. Tooth wear was significantly higher in the age group 36 and older than for the 18–35 years group ($p < 0.001$) (Table IV), but no statistical difference between genders was noted

(Table V). Tooth wear with cuppings was registered in most molars in the younger age group and in the older age group where enamel was left (Figures 2 and 3). Root abscesses were found in 22 skulls out of 49, or in 45% of cases. The abscesses were significantly more common in the 36 years and older group and significantly more common in males than females ($p < 0.001$) (Table VI) and the first molar showed the highest rate of abscesses (Table VII). Caries were almost non-existent, being registered in just two teeth.

Discussion

Tooth wear can be seen in archaeological material from all over the world. This wear is generally far



Figure 2. Secondary dentin formation is seen in tooth 46. Tooth 36 has excessive wear, with pulp exposure and root abscess formation.



Figure 3. Increasing tooth wear according to time of eruption. Pulp exposure in tooth 16.

more extensive than can be seen in current living populations. Ancient people consumed a more coarse and rough unprocessed diet, resulting in extensive occlusal tooth wear. This wear has been shown to gradually increase with age [4,10]. Usually the wear is most dominating on molars, starting in occlusal enamel and gradually reaching into dentin. Even though the wear reaches well into the dentin, the teeth appeared to remain functional, since the odontoblastic activity prevents the wear reaching into the pulpal cavity because of secondary dentin formation [22] (Figure 2).

The amount of wear can be graded by several methods. The simplest scoring of tooth wear is using only four categories; no wear, wear in enamel, wear into dentin and wear exposing the pulp cavity. When more detailed grading is preferred, several systems are available. The Brothwell method was elected to be used in the present study [14,22] (Figure 1). Mean wear of each tooth type can be seen in Table II. The third molars have the least wear and the first molars the most, with the second molars in between.

The amount of wear of the first molar indicates 6 years of wear when the second molar erupts. When third molar erupts, the first molar has ~ 12 years wear and the second molar 6 years wear. This can clearly be seen in Figures 3 and 4, which shows worn dentition from two angles. Different eruption times for the molars are, therefore, the basis for the age estimation. If, for example, the second molar shows that it has been in the mouth for 12 years and the third for 6 years, it is likely that the individual has been ~24 years old. If second molar shows 18 years of wear, it is likely that the individual is ~30 years. Most of the adulthood can be determined the same way. The study by Miles [23] indicated small differences in the wear rate between the three molars. He found the first molar to wear fastest, with a decreasing rate in the posterior direction. Thus, he showed that it took second molars 6.5 years and third molars 7 years to wear the same as first

Table VI. Prevalence of root abscesses according to two age groups and sex.

Gender	Age	n skeletons	n with abscesses	% with abscesses	% abscesses
Female	35 years and below	11	2	18	36
	36 years and above	14	7	50	
Male	35 years and below	6	2	33	54
	36 years and above	18	11	61	
Both sexes	35 years and below	17	4	24	45
	36 years and above	32	18	56	

Table VII. Prevalence of root abscesses presented for each tooth.

Prevalence of abscesses for each tooth																
n	1	9	3			2		1		1	1	1	5	1		
18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28	
48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38	
n	1	6	1			1	2	1	1	3			5	1		

molars in 6 years. These differences can be seen in Figures 3, explaining the age estimation method by Miles. Some studies have reported similar wear differentials [24], but others have reported equal rates of wear [25]. The Miles method was one of the methods used for age estimation in the present study. Many investigators have confirmed the usefulness of tooth wear for age estimation [24,26,27].

Using material from many British archaeological investigations, Brothwell [22] investigated teeth from young people and found tooth wear had changed little from Neolithic time (4000 BC) to late middle ages (16th century). These findings helped to develop a chart estimating tooth wear and age at death for these populations [14,22] (Figure 5).

When the tooth wear is so excessive that it opens into the pulp cavity, the effects on tooth physiology and pathology need to be considered. Tooth wear is the cumulative loss of enamel and dentin and it has been considered natural that teeth wear throughout life. Usually the odontoblasts compensate for this wear with new, reactive,

secondary dentin being laid down inside the pulp cavity, making the teeth functional and healthy [14]. Therefore, many investigators have used secondary or tertiary dentin as a foundation for developing methods for age estimation. These methods are based on radiographic measurements on formation of new dentin and shrinkage of the pulp cavity [19,28].

Several teeth in this investigation had wear exposure into the pulp cavity. Steffensen [4], who excavated and originally investigated this bone material, found only one definite case where bone changes indicated scurvy or more likely vitamin D deficiency, although scurvy was known to be a common disease in Iceland until the 19th century [5,29]. Pindborg [30], supported by other authors, stated that scurvy could harm the odontoblasts, leading to irregular dentin formation that possibly wears at a faster rate. Furthermore, Brothwell [22] stated that in some instances tooth wear could be so much and so fast that the normal odontoblastic activity is not enough to compensate for the wear, resulting in an exposure into the pulp cavity. Excessively worn dentition is shown in Figure 2, where tooth number 36 has an exposure into the pulp cavity, while visible secondary dentin formation has still compensated for the wear of tooth number 46. It is doubtful that vitamin C or D deficiency has resulted in exposure in only one first molar, although uneven wear is a possibility.

Root abscesses were found in almost half of the skulls. Since the caries rate was very low for the population it cannot explain the high root abscess incidence. A likely explanation is that excessive wear in some instances reached into the pulp cavity. This explanation is supported by the fact that first molars, which showed the highest score of tooth wear (Table II), also had the greatest frequency of root abscesses (Table VII).



Figure 4. Root abscess in tooth 16 due to tooth wear.

Age span	17-25			25-35			35-45			45+
Tooth	M1	M2	M3	M1	M2	M3	M1	M2	M3	
Wear pattern	 Or Or 	 Or Or 	No dentine exposed	 Or Or 	 Or Or 	 Or Or 	 Or Or 	 Or Or 	 Or Or 	More advanced wear

Figure 5. Estimated correspondence between adult age at death and molar wear phases for British material from Neolithic to medieval periods. (From Mays S. The archaeology of human bones. Routledge 2003: 63. Adapted from Brothwell 1981: Figure 3.9 [24]).



Figures 6–8. Similar appearance between the wear of medieval teeth and the erosion in young people today. Figure 4 with permission from Ulla Pallesen. Figure 5 with permission from Inga B. Arnadóttir.

The soft processed western diet of today usually produces minor tooth wear. Recently, however, enamel erosion caused by excessive consumption of acidic beverages, mainly soft drinks, fruit juices and sport drinks, has become an epidemic among young people in Iceland [31]. Many teeth in the present study showed similar wear patterns to those seen in young people today that suffer from dental erosion. Figures 6–8 show striking similarities between tooth wear in medieval teeth and in young people today with occlusal cupping. Cupping on tooth cusps and fissures has been used as a criterion to discriminate lesions on enamel and dentin caused by dental erosion from abrasional/attritional worn flat wear facets [4,5,32].

Figure 3 shows clearly that the buccal and lingual enamel surfaces show little or no tooth wear. This suggests that the observed tooth wear was not caused by gastric reflux, even though lifting and other heavy work might have caused problems such as hiatus hernia, which would lead to gastric acid reaching the mouth and causing this typical pattern of tooth erosion. Although tooth erosion associated with gastric reflux disease is now quite common in Iceland, and has a typical clinical appearance, the prevalence in the medieval period is not known [33].

Iceland's history of food and nutrition can shed light on tooth wear in ancient Icelanders. Because of

a lack of salt, drying was one of the two most popular ways for preserving food, mostly used for fish that was air-dried and cured as stockfish [34]. Meat was also dried, but most often it was soured in lactic acid. Due to the lack of grain, there are many tales in the literature about the dietary peculiarities of the Icelanders, including that they ate dry fish instead of bread [34]. It is more than likely that, in addition to coarse diet, dried foodstuffs contaminated by dust and in Thjorsardalur volcanic ash were responsible for the extensive tooth wear in the medieval Icelanders. Furthermore, the lack of grain and fruits could be the explanation for the low caries rate in the skull sample.

The most characteristic Icelandic foodstuffs are two dairy products. The first whey (Icel. *mýsa*), a watery part of milk that separates from the curds in the process of making the second major dairy product, *skyr*. Most of the whey was processed by pouring it into a wooden barrel with open holes in the lid for fermentation. When this process was finished *mýsa* had turned into lactic acid, *sýra*, which was then mixed with water in the proportion of one part acid with 11 parts water. This drink was the everyday thirst quencher in Iceland until the mid-20th century [35]. Lactose is a disaccharide sugar found in milk and makes up ~ 2–8% (by weight) of milk. As the whey fermented, about half of the



Figure 9. Barrel imprints in the storage room of the farm Stöng (from Ágústsson 1989 [38]).

lactose was converted to lactic acid along with other by-products [36]. The lactic acid was the most important food conservation medium in Iceland. Leathery meat was cooked and afterwards put into lactic acid to make it softer [35].

According to Saga literature, skyr was used in all Nordic countries during the middle Ages. In Iceland, skyr was eaten two or three times a day up to the 20th century [34].

Extensive studies have been made on erosion in young people in Iceland in recent years. Jensdóttir et al. [37] has been at the forefront of those who have studied the erosive effects of acidic beverages in the country. The capability of acidic beverages to erode dental enamel depends not only on the pH of the drink, but also on its buffering capacity. Her study showed that the erosive potential of whey, mysa, was very high. Mysa and sýra in the mediaeval period are believed to have contained much higher concentrations of lactic acid than can be found in the same modern products manufactured under much different and more controlled conditions [36].

During the Viking period, storage of food or production of dairy products took place in small outhouses next to the longhouse. Up to the 20th century, Icelandic farms always included a room for the production of whey and skyr and large wooden barrels or storage trunks were typical features of storage rooms, as can be seen in Figure 9 from the farm Stöng in Thorsardalur, not far from the archaeological site Skeljastadir.

Conclusion

In addition to coarse diet, dried meat and fish, probably contaminated by abrasive material, acidic

beverages and acidic food, were responsible for the extensive tooth wear in medieval Icelanders.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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