Rates of anterior tooth wear in Middle Pleistocene hominins from Sima de los Huesos (Sierra de Atapuerca, Spain)

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This study presents quantitative data on the rates of anterior tooth wear in a Pleistocene human population. The data were obtained for the hominin sample of the Sima de los Huesos site in Atapuerca, Spain. The fossil record belongs to a minimum of 28 individuals of the same biological population, assigned to the species *Homo heidelbergensis*. We have estimated the original and the preserved crown height of the mandibular incisors (I1 and I2) of 11 individuals, whose age at death can be ascertained from the mineralization stage and tooth eruption. Results provide a range of 0.276–0.348 and 0.288–0.360 mm per year for the mean wear rate of the mandibular I1 and I2, respectively, in individuals ≈16–18 years old. These data suggest that incisors' crowns would be totally worn out toward the fifth decade of life. Thus, we expect the life expectancy of this population to be seriously limited. These data, which could be contrasted with results obtained on hominins at other sites, could be of interest for estimating the death age of adult individuals.

The study of the patterns and rates of dental micro wear and macro wear in extinct hominin species and more recent human populations may be an important source of information about dietary habits, the type and consistency of the food, and methods of food preparation (1–6). It could also provide information on different cultural activities and nondietary habits (7–12). Tooth wear stems from dental attrition, which is the frictional contact between adjacent and opposing (maxillary and mandibular) teeth, and dental abrasion, which is caused by contact between teeth and food, certain abrasive particles contained in food, and some nondietary items. Both processes produce a progressive removal of enamel and dentine from the crowns of teeth. The rate of wear of the crown (i.e., the amount of crown height worn relative to a time unit) depends basically on the type of diet, the amount and kind of abrasive particles it contains, possible paramasticatory use of the teeth, the masticatory frequency (which is related to dietary mechanical properties), the type of occlusion (which in this population is edge to edge), and the strength produced by the upper and lower jaws during the masticatory process. Thus, rate of wear is a variable with probably high between-population variation (13), and whose descriptive statistics (mean, standard deviation, range, etc.) can be estimated for each population. Tooth wear rate could yield information about (*i*) tooth durability (i.e., the time period during which dentition is operative and capable of carrying out its biological function efficaciously), and (*ii*) the approximate age at death of individuals of a certain population. For this purpose, it is necessary to ascertain the amount of crown removed during the life of these individuals by using an appropriate variable, i.e., original crown height.

The aim of this article is to tackle these questions for the European Middle Pleistocene population by using evidence derived from the fossil human sample recovered from the Sima de los Huesos (SH) site in the Sierra de Atapuerca, northern Spain (14). This sample is exceptional, not only because of the large number of specimens (>4,000, including $n = 476$ teeth), but also because it represents a minimum of 28 individuals of the same biological population (15).

Materials and Methods

Recent radiometric studies (U-series) of a 14-cm-thick, *in situ* speleothem overlying the mud-breccia containing the human bones has provided a minimum age of 350,000 years for the SH hominins (16). Estimations of the speleothem growth rate, correlation of the SH fauna (micro and macro mammals) to other Atapuerca sites (e.g., TD6, TD8, TD10, and TD11 levels of Gran Dolina), and the normal magnetization of the SH fossiliferous mud provide an interval of 400,000–500,000 years (oxygen isotopic stages 12–14) for these hominins (16).

For technical reasons, we have chosen the anterior teeth to estimate the dental wear in SH hominins because the simpler morphology of incisors compared with cheek teeth makes it easier to obtain the necessary variables. We have selected the mandibular central (I1) and lateral (I2) incisors, because they are the best-represented anterior teeth in the SH sample ($n = 29$ and 31, respectively). In addition, lower I1 and I2 represent a minimum of 13 (I1) and 14 (I2), whereas the maxillary I1 ($n = 29$) and the maxillary I2 ($n = 21$) represent a minimum of 8. Isolated mandibular incisors, which could not be assigned to any individual, were not included in the analysis.

We assume that timing and patterning of dental developmental in the population represented by the SH hominins were similar to those of modern human populations (17). In the latter, the mandibular I1 and I2 present gingival eruption at ≈6 and 7 years of age, respectively, and reach the occlusion plane (occlusal eruption) 6 months later (18). Maxillary I1 and I2 reach the occlusal plane at ≈7.2 and 8.5 years of age, respectively (18). Thus, the mandibular I1 comes into physical contact with the maxillary I1 at 7 years old, whereas the mandibular I2 comes into physical contact first with the maxillary I1 ≈7.5 years old, and 1 year later with the maxillary I2 (18, 19). Therefore, the attritional and abrasional processes for these teeth would also begin in this time period. If we estimate the age at death of each individual, we can ascertain the time of use of its incisors from the moment in which they came into occlusion. Age at death, however, can only be estimated within reasonable limits on immature individuals by using information about their developing dentitions.

Abbreviation: SH, Sima de los Huesos.

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Table 1. Estimation of the age at death in some SH individuals by using the mineralization stage of their teeth

Individual	Estimated sex	Developing teeth	Mineralization stage	Age ATP	Age MFH
I	Female	LM3	Rc − A 1/2	17.9	18.3
II	Male	LP4	A 1/2	13.6	13.9
		LM2	A 1/2 − Ac	13.4	13.5
XVI	Female	LP4	R 1/2+	11.8	13.0
		LM2	Ac	13.8	13.5+
		UM2	A 1/2+	13.5	13.6
XVIII	Male	LC	R 1/2–R 3/4	8.7	9.3
		LM2	R 1/2	10.5	10.6
		LM3	Cr 3/4 − Crc	12.8	12.1
		UI2	A 1/2	10.0	8.9
		UC	R 1/2–R 3/4	8.8	9.3
		UP4	R 1/2	9.7	10.1
		UM2	R 1/2	10.6	10.6
		UM3	Cr 3/4 − Crc	12.8	12.1
XX	Male	LP3	Ac−	13.2	—
		LP4	Rc	11.9	12.2
		LM2	Ac	14.8	—
XXIII	Female	LM3	R 1/2+	16.6	16.4
XXIV	Female	LM2	A 1/2 − Ac	13.4	13.5+
		LM3	R 1/4	15.4	15.2
XXV	Female	LP3	Rc	9.9	10.5
		LP4	R 3/4	9.6	10.3
		LM2	Rc	11.8	11.8
		LM3	R 1/4−	15.2	15.0

ATP, data from Anderson *et al.* (20); MFH, data from Moorrees *et al.* (22).

Table 1 lists the SH immature individuals who are represented by one or more developing teeth. We used the data published by Anderson *et al.* (20) on the mean age of attainment of mineralization stages of the Caucasian children experimental group of the Burlington Growth Centre (Burlington, ON, Canada) to estimate the chronological age of the individuals. The mineralization stage of the teeth was assessed either by naked-eye observation in isolated teeth or by means of radiographs in *in situ* teeth. We have also predicted ages corresponding to the mineralization stages of teeth according to the data on permanent teeth published by Smith (21) from data of Moorees *et al.* (22) on white children from Boston and Ohio. According to the standard values used in this study, third molars (M3) systematically appear advanced in their formation with regard to second molars (M2) from 1.5 years in individual XVIII to 3.4 years in individual XXV. In individual XVIII, calcification of the canine is delayed relative to the rest of the dentition. Moreover, in individuals XVI, XVIII, XX and XXV, the premolars exhibit a certain delay in their formation with regard to M2. If we calculate a mean from all tooth mineralization ages in individuals XVIII and XXV, we obtain a mean age at death that coincides with the mineralization age of M2, which seems to be the best predictor for the age at death for this individuals. This assumption would imply that in this Middle Pleistocene population, M3 reached gingival eruption at ≈15 years, whereas occlusal eruption occurred at ≈16 years (see ref. 18). Individual XX presents either a considerable relatively long delay of lower P3 formation or a relatively accelerated M2 formation that has its roots completely formed. In this case we have decided to assign to individual XX an intermediate age taken between the premolars and the M2 mineralization ages.

In individual III, the right lower M2 has no interproximal distal wear facet, whereas the left lower and upper M2 show minimum facets. Therefore, we infer that the M3s would have reached occlusal eruption just a bit earlier than death, and we can assume a likely age of 16 years old for individual III. Finally, in individuals XII and XV, the mandibular M3 root is completely formed. The wear of these teeth is very similar or slightly higher than in individual I. Hence, we consider that the likely age at death for these individuals is ≈1 year later than individual I. The inclusion of these individuals in the sample provides important information for this study. The estimations are reasonably conservative and use a 24-month interval for the estimation of probable age at death (Table 2).

To evaluate the original and the preserved height crown of lower I1 and I2 we proceeded as follows. First, the mandibular I1 and I2 were photographed in mesial and distal views with a digital Nikon D1 camera fitted with a AF MicroNikkor 105-mm f/2.8D lens. To achieve maximum depth of field, the aperture was set at f/32. The magnification ratio was adjusted to 1:1, and a scale was included in each photograph. Next, on a paper image of the mesial or distal face of each specimen, the worn part of the crown was reconstructed by continuing the curvature of the buccal surface, as indicated in Fig. 1. Likewise, a vertical line, perpendicular to the crown base, was drawn to prolong the direction of the lingual face plane. The point of intersection between the two lines was taken as indicating the highest point of unworn crown (a in Fig. 1) in a tooth without occlusal wear. The estimated crown-height variable was obtained by measuring the paper image with a planimeter Ushikata (Tokyo) X-Plan 360d the distance between point a and the most buccal point of the enamel-cementum junction (b in Fig. 1). The preserved crown height variable was obtained by measuring the distance between b and the point of intersection (c in Fig. 1) of the line ab with the worn surface of the crown. When an individual was represented by the right and left antimeres, we calculated a mean value of the measures obtained in both teeth.

Results

The results obtained are shown in Table 2. The estimated crown height ranges from 10.5 to 12.5 for I1 and from 11.0 to 13.2 for I2. As expected, the difference between the estimated height and the preserved height increases with the death age of the individuals. In Table 2 we have included the interval of wear time for the lower I1s and I2s of each individual, assuming that these teeth begin to wear at 7.0 and 7.5 years, respectively. Knowing the amount of worn crown (difference between the estimated and the preserved crown height in mm) and the number of months of use, it is possible to calculate a mean wear rate for each individual. For example, for individual II, whose estimated age of death is 13.5 years old, we obtain a mean wear rate for its mandibular I2 of 0.033 mm per month. As shown in Table 2, mean wear rate decreases with age. Fig. 2 illustrates, for example, that for the mandibular I2, this mean decreases from 0.037 in individual XVIII to 0.027 in individuals I and XV. Toward the end of development in this population, the mean wear rate of lower I1 ranges from 0.029 and 0.023 mm per month, whereas the mean wear rate of lower I2 varies from 0.30 and 0.024 mm per month.

If we take a 12-month interval for the occlusal eruption age for lower I2 in SH population (between 7.0 and 8.0 years old), the range would be 0.031 to 0.023 mm per month for individual I and 0.032 to 0.024 for individual XII, so the results would not vary significantly.

Discussion

This study examines the rate of wear of anterior teeth of a Pleistocene population. The results show a high wear rate for incisors in the population represented by the SH hominins. This high value could be the result of a highly abrasive diet (6), the edge-to-edge occlusion, and/or some nonmasticatory activities, as has been suggested for other Pleistocene populations (23–25).

Table 2. Estimation of the individual mean wear rate (mm per month) of the mandibular I1 and I2 of the of the SH Middle Pleistocene hominin sample from Sierra de Atapuerca

Individual	Range of estimated age at death, years			Tooth	Estimated crown height, mm	Preserved crown height, mm	Difference	Time of wear, months, for the age at death			Individual mean rate of wear, mm per month, for the age at death		
	A	B	C					A	B	C	A	B	C
XVIII	9.5	10.5	11.5	I1	11.3	9.90	1.40	30	42	54	0.046	0.033	0.026
				I2	11.6	10.25	1.35	24	36	48	0.056	0.037	0.028
XXV	10.8	11.8	12.8	I1	11.0	8.72	2.28	46	58	70	0.049	0.039	0.032
				I2	11.6	9.73	1.87	40	52	64	0.047	0.036	0.029
II	12.5	13.5	14.5	I1	10.9	8.54	2.36	66	78	90	0.036	0.030	0.026
				I2	12.2	9.85	2.35	60	72	84	0.039	0.033	0.028
XVI	12.5	13.5	14.5	I1	10.6	7.79	2.81	66	78	90	0.042	0.036	0.031
				I2	11.1	8.69	2.51	60	72	84	0.040	0.033	0.028
XX	12.5	13.5	14.5	I1	12.5	9.80	2.70	66	78	90	0.041	0.034	0.030
				I2	13.2	10.61	2.59	60	72	84	0.043	0.036	0.031
XXIV	12.5	13.5	14.5	I1	10.7	8.20	2.50	66	78	90	0.038	0.032	0.028
				I2	11.4	9.08	2.32	60	72	84	0.039	0.032	0.028
XXIII	14.0	15.0	16.0	I1	11.4	8.44	2.96	84	96	108	0.035	0.031	0.027
				I2	11.8	9.08	2.72	78	90	102	0.035	0.030	0.026
III	15.0	16.0	17.0	I1	10.8	8.05	2.75	96	108	120	0.029	0.025	0.023
				I2	11.5	8.77	2.73	90	102	114	0.030	0.027	0.024
I	16.0	17.0	18.0	I1	10.5	7.40	3.10	108	120	132	0.029	0.026	0.023
				I2	11.2	8.16	3.04	102	114	126	0.030	0.027	0.024
XII	17.0	18.0	19.0	I2	12.2	8.69	3.51	114	126	138	0.031	0.028	0.025
XV	17.0	18.0	19.0	I1	10.6	7.28	3.32	120	132	144	0.028	0.025	0.023
				I2	11.0	7.53	3.47	114	126	138	0.030	0.027	0.025

In this estimation we consider that I1 and I2 come into occlusion at 7.0 and 7.5 years, respectively

The apparent decrease in the individual mean wear rate of the SH sample associated with age could be related to the progressive increase of relative occlusal surface. The more an incisor crown is worn out, the larger becomes the exposed occlusion area (Fig. 2). It is, nevertheless, also possible that the mean wear rate decreases to some extent when wear affects last third of the crown, where a conspicuous gingival eminence increases the wearable area. This effect, however, might be counteracted by considerable wear of the interproximal facets, which might contribute to a decrease of the size of this surface (Fig. 2). We, therefore, believe that the mean wear rate of a 16- to 18-year-old individual would probably remain constant from that age on. Thus, assuming a range of 0.348–0.276 mm per year wear rate for the lower I1, a crown of 11.5 mm in height would last between 33.0 and 41.7 years. Given that the functional age of this tooth is at 7 years of age, the mandibular I1 crown would disappear when the individual was ≈40–49 years old. In the same way, a range of 0.360–0.288 mm per year for the I2 mean wear rate (with an original height of 12 mm) suggests a durability of 33.3–41.6 years for the crown of this tooth. Hence, this crown would be completely worn out when the individual is between 41 and 49 years old.

The high level of physical activity of Pleistocene hominins would require the frequent intake of food, which implies a high degree of dependence on hard, poorly processed plant foods, such as roots, stems, and seeds (6). This lifestyle and the technological level of these hunter-gatherer populations make difficult the possibility of processing food to provide a "soft diet" for the elderly, who may have completely lost their anterior teeth crowns. The strong wear also noticed in posterior teeth (26) of SH hominins suggests that teeth of European Middle Pleistocene populations would cease being operative during the fifth decade of life. Consequently, the potential longevity of this population would necessarily be limited by this circumstance. This might

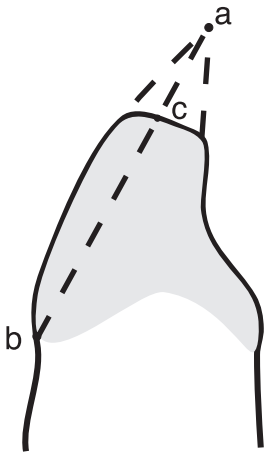

Fig. 1. Reconstruction of the original crown height of lower incisors (ab); bc, estimated height of the crown.

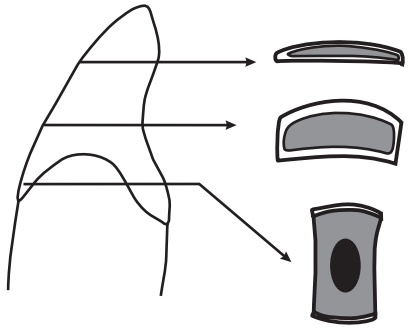

Fig. 2. Sections of a lower incisor at different planes of wear. Scheme based on lower incisors from the SH collection.

Table 3. Estimation of the age at death of three SH adult individuals, using the range of the mean rate of wear of the mandibular I1 and I2 obtained for individuals aged 16–18 years (see text for details)

Individual	Estimated sex*	Tooth	Estimated crown height, mm	Preserved crown height, mm	Difference	Range of mean rate of wear, mm per year	Range of age at death
VII	Male	I1	12.0	6.3	5.7	0.348–0.276	23.4–27.6
			12.5	6.3	6.2		24.8–29.5
		I2	12.5	6.7	5.8	0.360–0.288	23.6–27.6
			13.0	6.7	6.3		25.0–29.4
XXII	Male	I1	12.0	7.2	4.8	0.348–0.276	20.1–24.4
			12.5	7.2	5.3		22.2–26.2
		I2	12.5	8.0	4.5	0.360–0.288	20.0–23.1
			13.0	8.0	5.0		21.4–24.9
XXXI	Female	I1	11.0	5.2	5.8	0.348–0.276	23.7–28.0
			11.5	5.2	6.3		25.1–29.8
		I2	11.5	6.4	5.1	0.360–0.288	21.7–25.2
			12.0	6.4	5.6		23.0–26.9

*Ref. 28.

partially explain the low number of hominins older than 40 years of age from the European Middle Pleistocene fossil record (27).

On the other hand, it is possible that the variability of strength exerted by the main masticatory muscles (temporals, masseters, external pterigoids) of the SH hominins could contribute to the individual wear rate of their incisors. Individuals with more powerful muscles (and possibly bigger teeth) might have a higher rate of attrition, whereas individuals with less muscular power (and probably smaller teeth) might have a lower rate. However, the larger or smaller occlusal surface could also compensate for the muscular power exerted during mastication. In the 16- to 18-year-old group of the SH sample, individual XII is probably male (28) and his mean wear rate very similar to that of individuals I, II and XV, who are probably female (28). In any case, the analyzed sample size does not allow us to draw definitive conclusions that could be of interest in the practical case of ascertaining the death age of adult individuals.

Applying the range of mean wear rate obtained to the adult SH individuals VII, XXII, and XXXI, we obtain a reasonably precise range of age at death (Table 3). The sizes of the teeth of individuals VII and XII are in the upper limit of the SH sample variability (29). For this reason, it is possible to assume that the sizes of their mandibular I1 and I2 are also in the upper limit of their range (Table 3). Taking into account the preserved height of these teeth and the variation of the rate of wear, we obtain a range of age at death for individual VII of 23.4–29.5 years and one of 20.0–26.3 years for individual XXII. The dimensions of individual XXXI's teeth fall in the middle of the SH sample interval (29), so we estimate a height of between 11.0 and 11.5 mm for this individual's lower I1 crown and between 11.5 and 12.0 mm for its lower I2. Although the preserved crowns of these teeth are lower than individual VII incisors, the tooth-wear rate of these teeth (i.e., the proportion of worn crown) is very similar in both individuals. The range of age at death obtained for individual XXXI is between 21.7 and 29.8 years. In this case, the lower I1 is proportionally more worn down than the mandibular I2, and the age-at-death range obtained for these teeth (23.7–29.8), which is similar to individual VII, appears to be more precise.

Finally, it is important to realize that the dental attrition rates obtained in this work cannot be indiscriminately applied to other populations. The type of diet and the method of preparing food can definitely influence interpopulation differences and variability. As an approach to this area of study in other hominins, we obtained the mean-wear rate of the mandibular I2 of Hominid 1 of the TD6 level in the Gran Dolina site, in Sierra de Atapuerca (30). TD6 hominins, which have been assigned to the *Homo antecessor* species (31), have been dated to 800,000 years (32, 33). The age at death of Hominid 1 has been estimated at 13.5 years old (34). The mean rate of attrition of its mandibular I2 (0.048–0.034) does not differ from the one obtained for the individuals of the same age range (12.5–14.5 years) in the SH sample. In summary, it would be very interesting to obtain new data in other Pleistocene samples to create a database that will allow us to expand this line of research. In addition, it would be interesting to apply this procedure to archaeological modern human samples where diet and cultural activities are known.

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