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Changes in dental wear magnitude in the last ~8000 years in southwestern Iberia

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ABSTRACT

Objective: This study examines changes in dental wear magnitude in the past ~8000 years, i.e., since Mesolithic until the 19th century, in southwestern Iberia. Thus, it encompasses the transition from hunting-gathering to agro-pastoralism, and then to the industrialization of food production and pre-processing.

Design: Dental wear magnitude was scored in a total of 191 individuals and 1557 teeth from Mesolithic (individuals=56; teeth=643), Neolithic (individuals=35; teeth=169), Chalcolithic (individuals =35; teeth=221), Modern Age (individuals=17; teeth=209), and Late Modern Age (individuals=48; teeth=315) samples originating in southwestern Iberia (i.e., present central and southern Portugal) and according to the 8 levels ordinal scale of Smith (1984).

Results: Results show a general trend for decreased wear magnitude in these two major transitions and during this timespan (although the hunting-gathering – agro-pastoralism transition had larger impact). The only meaningful differences in wear rate were found between the Late Modern Age and all remaining samples.

Conclusion: Dental wear generally decreased during this timespan (although wear magnitude was less impacted by the industrialization of food production and pre-processing). Our results are consistent with studies documenting skull morphological gracilization associated with reduced masticatory demands due to the adoption of softer diets.

1. Introduction

Dental wear is the overall progressive loss of dental tissues due to inter-tooth contact (attrition), contact with exogenous material (abrasion) and chemical dissolution (erosion) (D'Incau et al., 2012; Kaidonis, 2008; Molnar et al., 1972). It is heavily impacted by the material properties of diet and extra-oral food pre-processing, which influences the material properties of food and may introduce or remove wear promoting contents from foodstuffs (Lucas, 2004; Molnar et al., 1972; Smith, 1984). Thus, dental wear is often used to examine past dietary habits across populations and time (Bernal et al., 2007; Deter, 2009; Eshed et al., 2006; Godinho et al., 2022; Greene, 1967; Kaifu, 1999; Larsen, 1997; Lubell et al., 1994; Smith, 1984).

Two major events with profound dietary implications occurred in recent modern humans: the transition from hunting-gathering to agro-pastoralism and industrialization of food production and pre-processing. The domestication of plants and animals enabled the rise of agriculture and animal husbandry and so an agro-pastoralist economy, which led to the adoption of mechanically less demanding foods that were further pre-processed by, e.g., grinding and cooking (Larsen, 1997; Pinhasi & Stock, 2011). Because dental wear is heavily impacted by food material properties and pre-processing, this resulted in decreased occlusal dental wear magnitude (Bernal et al., 2007; Deter, 2009; Eshed et al., 2006; Greene, 1967; Kaifu, 1999; Larsen, 1997; Lubell et al., 1994; Smith, 1984). Meng et al. (2011) show that in present China wear magnitude also generally decreased throughout the Neolithic due to agricultural intensification. More recently, industrialization led to further food pre-processing, resulting in removal of

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abrasive and fibrous contents and so in further reduction of dental wear (Kerr, 1988; Lavelle, 1970; Mays, 2002; Varrela & Varrela, 1991; Varrela, 1990).

Although multiple studies have focused on dental wear and documented changes in occlusal dental wear magnitude across some limited specific timespans (Esclassan et al., 2009; Liu et al., 2010; Meng et al., 2011, 2014), none provide an integrated analysis of dental wear spanning from Mesolithic hunter-gatherers to 20th century populations. This is regrettable because agriculture intensification from the Neolithic onwards impacted various aspects of oral health (Dong et al., 2016; Douglas & Pietrusewsky, 2007; Halcrow et al., 2013; Pechenkina et al., 2007; Roberts & Cox, 2007), and so dental wear magnitude may have decreased gradually along with increasing dependency on agriculture. This has only been shown by a limited number of studies which, incidentally, do not provide such wide chronological spans (Meng et al., 2011). Moreover, meta-analyses combining data from different studies targeting different chronological periods is challenging because different researchers frequently use contrasting dental wear magnitude scoring methods (Lovejoy, 1985; Molnar, 1971; Scott, 1979a; Shykoluk & Lovell, 2010; Smith, 1984), hence precluding direct comparison across studies.

In this study we examine dental wear throughout the last ~8000 years in southwestern Iberia and so encompass the two major events with dietary implications in recent modern humans: (i) the transition from hunting-gathering to agro-pastoralism and to (ii) industrialized diets and food pre-processing. Based on previous studies, we hypothesize that, overall, dental wear decreased meaningfully in the transition from Mesolithic hunting-gathering to ensuing agro-pastoralism (primary hypothesis). We further hypothesize that wear magnitude decreased during recent prehistory with the intensification of agriculture and then again meaningfully with the introduction of industrial food production and pre-processing (secondary hypothesis). Because dental wear magnitude is impacted by age at death, we also examine dental wear rate, which has been shown to be age independent (Chattah & Smith, 2006; Smith, 1972; Watson, 2008). We hypothesize that earlier populations with mechanically more demanding diets will have higher rates of wear (tertiary hypothesis).

2. Materials and methods

2.1. Sample

This study was based on the inferior teeth from 191 adult individuals collected from burial sites located in present day Portugal and dating from the Mesolithic, Neolithic, Chalcolithic, Modern Age and Late Modern Age (Fig. 1, Table 1). Although the best-preserved specimens were selected for use in other previous studies relating to dental wear (Godinho & Gonçalves, 2021) and mandibular morphology (Godinho et al., 2022, 2020), most are incomplete and display tooth loss (mostly post-mortem). Thus, 1557 out of a potential total of 3056 (i.e. 16 per individual times 191 individuals) teeth were observed. Anterior teeth are the most often absent (Supplementary Material Table 1).

The specimens used in this study are housed in different institutions. Access was formally requested to each individual institution, specifying

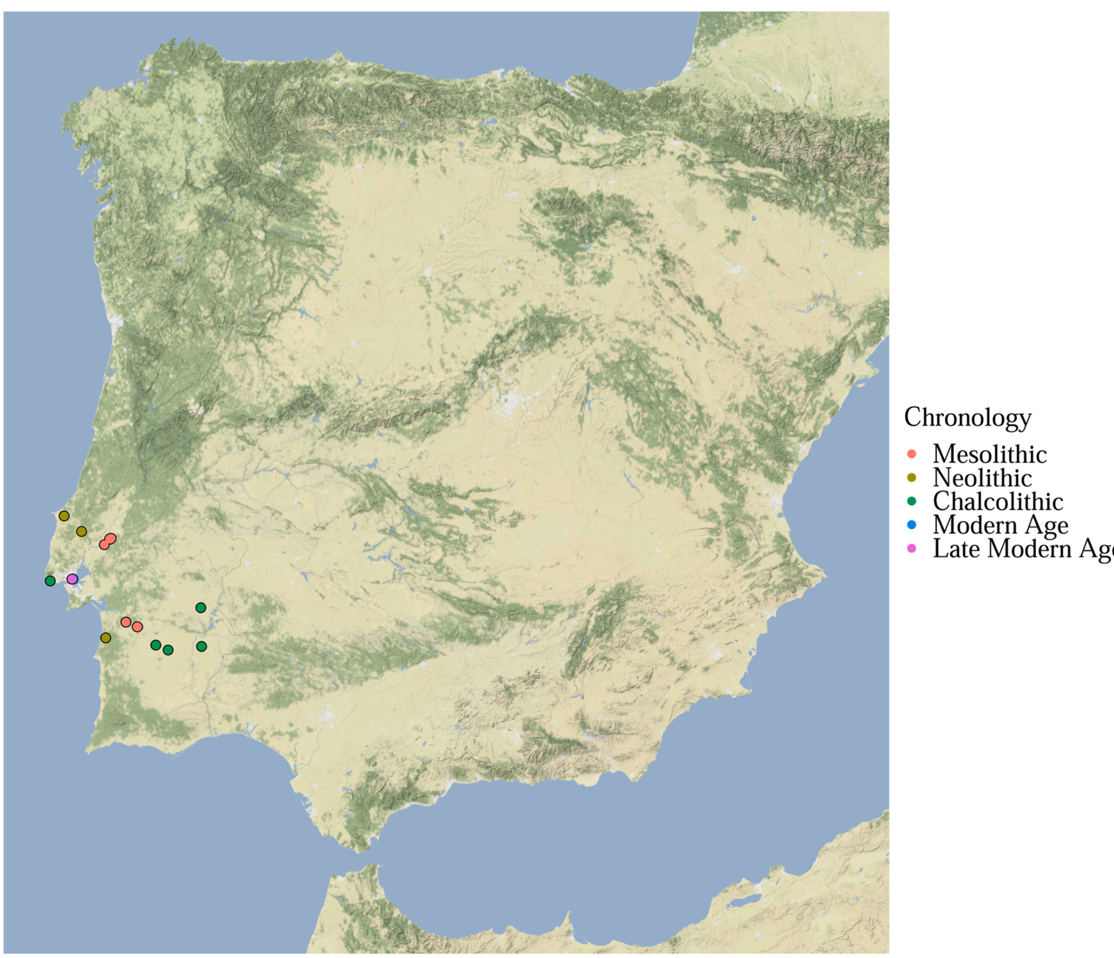

Fig. 1. Geographic and chronological origin of the samples used in this study. Iberian Peninsula is depicted in the figure and the archeological sites sampled are located in present Central – South Portugal. Note that the Modern and Late Modern Age sites are located very closely, and so the circle depicting the location of the former is almost completely behind the circle locating the later.

Table 1
Inventory of individuals used in this study (grouped per site and chronology) examining dental wear magnitude in southwestern Iberia.

Site	Chronology	N
Arapouco	Mesolithic	5
Cabeço da Amoreira	Mesolithic	1
Cabeço da Arruda	Mesolithic	15
Cabeço de Pez	Mesolithic	2
Cova da Onça	Mesolithic	1
Moita do Sebastião	Mesolithic	30
Vale de Romeiras	Mesolithic	2
Algar do Bom Santo	Neolithic	23
Casa da Moura	Neolithic	5
Gruta do Zambujal	Neolithic	6
Grutas de Melides	Neolithic	1
Cinco Reis 5	Chalcolithic	9
Grutas do Poço Velho	Chalcolithic	4
Monte da Guarita 2	Chalcolithic	9
Monte do Carrascal 2	Chalcolithic	4
Perdigões	Chalcolithic	9
Colégio de Santo Antão o Novo	Modern Age	17
Colecção Luís Lopes	Late Modern Age	48
Total		191

the study and data collection procedures. Access was only granted after this procedure, and all rules and regulations of each institution were followed.

2.2. Age at death estimation

Pervasive post-excavation mixing of many of the Mesolithic specimens (Jackes & Meiklejohn, 2004) precluded age at death estimation based on skeletal elements other than the mandibles. Moreover, Neolithic and Chalcolithic specimens originate from collective tombs in which skeletal remains are mostly commingled (Antunes-Ferreira, 2005; Miguel & Simão, 2017; Valera et al., 2014), again precluding age estimation based on elements other than the mandibles. Thus, age estimation is based only on dental growth and development of the mandibular teeth (AlQahtani et al., 2010). Because most of the specimens were CT-scanned for previous studies (Godinho & Gonçalves, 2021; Godinho et al., 2020), the development of non-erupted teeth and of roots of teeth in sockets could also be used for age at death assessment (AlQahtani et al., 2010). Only individuals with 18 or more years of age at death were selected. Dental wear-based age at death estimation was not used because dental wear is heavily impacted by differences in diet, food preprocessing and paramastication, and so it is frequently an unreliable age proxy within and across heterogeneous populations (Benazzi et al., 2008; Clement & Hillson, 2012; Romero et al., 2019).

2.3. Dental wear assessment

Dental wear magnitude of each tooth was scored based on direct observation of the specimens according to the ordinal 8 levels scale of Smith (1984). Because dentitions were frequently incomplete (see above) the left and right sides were pooled to increase sample size, similarly to previous studies (Clement & Hillson, 2012; Molnar et al., 1989).

Dental wear magnitude is related to age, but the rate (i.e., how fast teeth wear relative to each other) has been shown to be independent of age (Miles, 2001; Scott, 1979b; Smith, 1972). Thus, we use rates of dental wear to examine dental wear independently from age, similarly to other studies (Chattah & Smith, 2006; Smith, 1972; Watson, 2008). To that end, magnitude of wear of the first molar is regressed against that of the second molar.

All scoring was undertaken by one of the authors (RMG), thus bypassing inter-observer error. A previous study based on a large sample of the Mesolithic teeth ($n = 412$) in which dental wear magnitude was scored twice by the same observer (RMG) revealed no meaningful differences between scores (Godinho & Gonçalves, 2021). Thus, scoring of specimens in which it was not possible to undertake several observation rounds is considered valid.

2.4. Statistical analysis

To ensure no meaningful side differences in wear existed and so enable pooling of left and right sided teeth to increase sample size (see above), pair-wise Wilcoxon ranked-sum tests were used. No statistically significant ($p < 0.05$) differences between contralateral teeth were found and so dental wear per tooth type was averaged between sides (scores of single teeth were used when only one of the two teeth was present).

ANOVA variance homogeneity, normality and independence assumptions for dental wear magnitude across samples were tested using Levene's, Shapiro's and Durbin Watson's tests and implemented using the car R package (Fox et al., 2012). Because such assumptions were not met, overall differences in wear across different chronologies were examined using the non-parametric Kruskal-Wallis test, implemented using the ggstatsplot R package which uses Dunn post-hoc comparisons (Patil, 2021). Statistical differences were considered significant at p level < 0.05, but results also specify for other levels of significance (p level: * < 0.05; ** < 0.01; *** < 0.001; see Supplementary Material Fig. 1). Statistical differences between rates (i.e., slopes) of dental wear were examined using the pairs function of the emmeans R package (Lenth, 2021) and were considered significant at p level < 0.05.

3. Results

Tooth loss (pre and post-mortem) ranges from 33% to 70% and is consistently higher in the anterior dentition (which is common due to post-mortem tooth loss; Supplementary Material Table 1). Although this leads to lower sampling of the anterior teeth, results of the full dentition are presented below.

The Kruskal-Wallis test revealed statistically significant differences in dental wear magnitude across all teeth. This is visually apparent in Fig. 2, in which anterior dental wear is generally comparable between the prehistoric populations and somewhat lower in the Late Modern Age. Posterior dental wear decreases from the Mesolithic to the Neolithic and appears to remain generally stable until it further decreases in the Modern and Late Modern Age (Fig. 2).

Despite these overall differences, statistically significant differences in the anterior dentition are only found between Mesolithic and Modern and Late Modern Age populations (Supplementary Material Fig. 1). Premolar occlusal wear is statistically significantly different between the Mesolithic and the Chalcolithic, Modern Age and Late Modern Age (Supplementary Material Fig. 1). Molar one and two dental wear is significantly higher in the Mesolithic when compared to most other chronologies and significantly lower in the Late Modern Age when compared to most other populations (Supplementary Material Fig. 1).

Visual assessment of molar dental wear rate shows generally comparable rates of wear (slopes of the regression models) amongst the different chronological periods, despite some differences (Fig. 3). Pairwise statistical comparison of slopes reveals that statistically meaningful differences are only found between the Late Modern Age and all other periods (with wear rate being lower in the Late Modern Age; Supplementary Material Table 2).

4. Discussion

Overall, as predicted and consistently with previous studies, higher magnitudes of dental wear were detected in the Mesolithic populations than in all other ensuing periods (Bernal et al., 2007; Deter, 2009; Eshed et al., 2006; Greene, 1967; Kaifu, 1999; Larsen, 1997; Lubell et al., 1994; Smith, 1984). Some evidence of further decreased dental wear during recent prehistory (i.e., Neolithic and Chalcolithic) was also found.

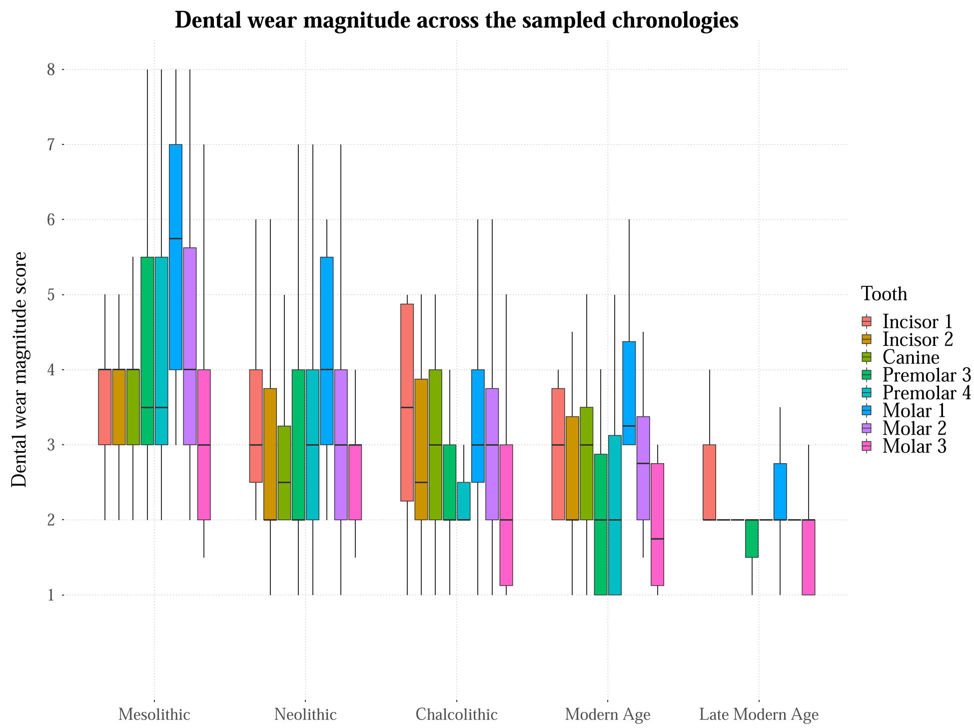

Fig. 2. Dental wear magnitude scores (according to Smith, 1984) from the Mesolithic to the Late Modern Age. Results are grouped by chronology to facilitate comparison between different teeth of the same periods.

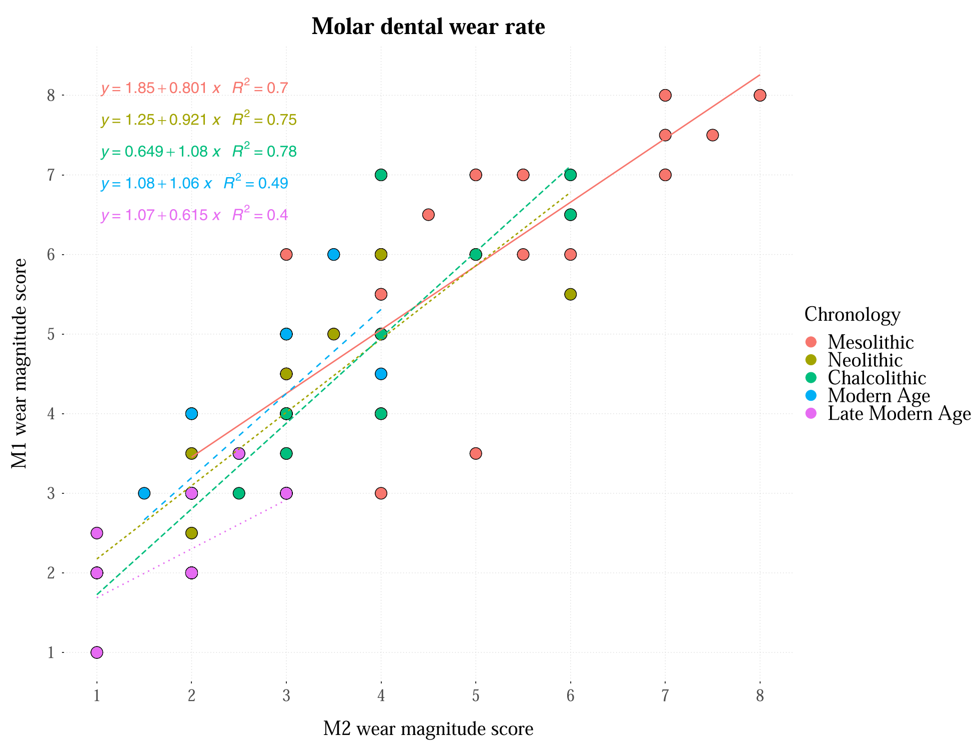

Fig. 3. Dental wear rate from the Mesolithic to the Late Modern Age in southwestern Iberia. Note that steeper regression lines denote higher rates of dental wear.

Similarly, we also recorded some decreased dental wear magnitude in the transition from the Modern to the Late Modern Age, and so with industrialization of food production and pre-processing. Interestingly, and despite these dental wear magnitude differences across the sampled periods, rates of dental wear were fairly similar between most different periods, and the only significant difference found was between the Late Modern Age and all other sampled chronologies (in which rate of wear was lower in the Late Modern Age). This mismatch between wear magnitude and rate differences may suggest that differences in wear magnitude could also relate to contrasting ages-at-death of the samples (see below). Despite these overall trends a more detailed examination reveals several relevant details.

Although dental wear magnitude is generally higher in the Mesolithic, such differences are only statistically significant in the anterior dentition when compared to the Modern and Late Modern Age. Moreover, despite dental wear is generally lower in the Neolithic than in the Mesolithic, it is only statistically significantly lower in the M2. Indeed, when compared to the Mesolithic, posterior dental wear is only consistently significantly lower from the Chalcolithic onwards. Thus, our results support decreased dental wear magnitude in the Mesolithic – Neolithic transition, but which then generally decreases further in the Chalcolithic (when it becomes statistically significantly lower when compared to the Mesolithic). This is consistent with previous studies which found an association between decreased dental wear and agricultural intensification during recent prehistory (Meng et al., 2011), along with other changes in oral health (Douglas & Pietrusewsky, 2007; Halcrow et al., 2013; Pechenkina et al., 2007; Roberts & Cox, 2007). Moreover, because the anterior dentition is mostly used in food acquisition and paramastication and the posterior dentition in food size reduction/comminution (Lucas, 2004), the absence of meaningful differences in the anterior teeth between the prehistoric populations supports that the dental wear magnitude differences found across the dentition are indeed related to changes in the material properties of the foodstuffs consumed (i.e., softer foods after the transition to agro-pastoralism). Notwithstanding, our results do document decreased anterior dental wear in the Mesolithic – Neolithic transition and then a slight increase in the Chalcolithic. Future studies will address hypothetical evidence of changes in paramasticatory behavior using activity induced dental modifications (e.g., lingual surface attrition of the maxillary anterior teeth, notching, chipping).

Modern and Late Modern Age samples were included to assess the impact of the transition to industrialized diets on dental wear magnitude. We found that some teeth (first incisor, canine, first and second molars) do indeed display lower wear magnitude in the Late Modern Age than in the Modern Age. Yet, such differences are small and do not reach statistical significance (except for the first molar), and so appear not as relevant as those found in the hunting-gathering – agro-pastoralism transition (especially when comparing Mesolithic and Chalcolithic populations).

Despite these differences in dental wear magnitude, only slight differences in wear rate were found across most sampled chronologies (Mesolithic to the Modern Age). This is somewhat surprising because faster wear is usually associated with diets that are mechanically more demanding and with reduced food pre-processing (Watson et al., 2013), and so we expected to find higher rates of wear in earlier populations. Indeed, the only statistically significant difference was found between the Late Modern Age and all other previous chronologies, in which rate of wear was clearly lower in the former. Because dental wear rate has been shown to be age-independent, this suggests the significant differences in dental wear magnitude between the periods in which no significant differences were found in wear rate may relate to contrasting ages at death (i.e., higher magnitudes of wear may relate higher ages at death). This hypothesis finds support in the relationship between age and magnitude of wear (Lovejoy, 1985; Mays et al., 1995). Regrettably, the nature of the samples precludes age estimation based on skeletal elements other than the mandibles (see above) on most of the samples and so controlling for the effect of age on dental wear.

Previous skull morphological studies have reported form changes (e.g., size reduction and gracilization) in the transition from the Mesolithic to the Neolithic and from pre-industrial to industrial food production and pre-processing (Galland et al., 2016; Godinho et al., 2022; May et al., 2018; Pokhojaev et al., 2019; Rando et al., 2014; von Cramon-Taubadel, 2011). As bone is known to adapt to various aspects of mechanical loading (Currey, 2006; Judex & Rubin, 2010; Judex et al., 1997; Lanyon, 1984; Mosley & Lanyon, 1998; Turner, 1998), such form changes have been related to the introduction of softer foodstuffs and so decreased masticatory mechanical demands (Galland et al., 2016; Godinho et al., 2022; May et al., 2018; Pokhojaev et al., 2019; von Cramon-Taubadel, 2011). Thus, our dental wear (which relates to the material properties of foodstuffs; see above) results are generally consistent with skull morphology studies because both document decreased masticatory mechanical demands after the introduction of agro-pastoralism and with industrialization of food production and pre-processing.

Despite our results and interpretations, this study presents some limitations that should be addressed. Although we have a large sample (nearly 200 individuals) and almost all chronologies have sample sizes ranging from 35 to 56 individuals, the Modern Age sample is limited to 17 individuals (Table 1) of generally young adults (Godinho, 2008). Tooth loss (mostly post-mortem) also results in reduced representativeness of some teeth (especially in the anterior dentition). Moreover, although our sample encompasses approximately 8000 years and includes several periods within this timespan, it does not include specimens from all chronologies. Last, because this study covers such a wide timespan it did not examine any hypothetical intra-chronological variation related to, e.g., environment (Chattah & Smith, 2006) and sex (Berbesque et al., 2012; Esclassan et al., 2014; Slaus et al., 1998). Thus, future research may test if the trend detected in this study holds. To that end, such research could include samples from the chronologies missing in this study (e.g., Bronze Age, Roman Period, Medieval Age) and expand the sample size of the Modern Age. Moreover, chronologically focused studies should examine if there are any intra-chronological variation related to, e.g., geographic and environmental differences such as those detected in the Chalcolithic in the Levant (Chattah & Smith, 2006), or between sexes in different chronological and geographic contexts (Berbesque et al., 2012; Clement & Hillson, 2012; Meng et al., 2011).

CRediT authorship contribution statement

Ricardo Miguel Godinho: Conceptualization, Methodology, Data collection and analysis, Drafting and final approval of the submitted version, Funding acquisition. **Cláudia Umbelino**: Conceptualization, Funding acquisition, Drafting and final approval of the submitted version. **Susana Garcia**: Conceptualization, Drafting and final approval of the submitted version. **Célia Gonçalves:** Conceptualization, Funding acquisition, Drafting and final approval of the submitted version.

Declarations of interests

None.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.archoralbio.2023.105626.

References

AlQahtani, S. J., Hector, M. P., & Liversidge, H. M. (2010). Brief communication: The London atlas of human tooth development and eruption. *American Journal of Physical Anthropology, 142*(3), 481–490. https://doi.org/10.1002/ajpa.21258

Antunes-Ferreira, N. (2005). Paleobiologia de grupos populacionais do Neolítico final/Calcolítico do Poço Velho (Cascais). Instituto português de arqueologia.

Benazzi, S., Bonetti, C., Cilli, E., & Gruppioni, G. (2008). Molar crown height: Not always a reliable method for the evaluation of age-at-death. *Journal of Archaeological Science, 35*(8), 2371–2378. https://doi.org/10.1016/j.jas.2008.03.005

Berbesque, J. C., Marlowe, F. W., Pawn, I., Thompson, P., Johnson, G., & Mabulla, A. (2012). Sex differences in Hadza dental wear patterns. *Human Nature, 23*(3), 270–282. https://doi.org/10.1007/s12110-012-9145-9

Bernal, V., Novellino, P., Gonzalez, P. N., & Perez, S. I. (2007). Role of wild plant foods among late Holocene hunter-gatherers from Central and North Patagonia (South America): An approach from dental evidence. *American Journal of Physical Anthropology, 133*(4), 1047–1059. https://doi.org/10.1002/ajpa.20638

Chattah, N. L.-T., & Smith, P. (2006). Variation in occlusal dental wear of two Chalcolithic populations in the southern Levant. *American Journal of Physical Anthropology, 130*(4), 471–479. https://doi.org/10.1002/ajpa.20388

Clement, A. F., & Hillson, S. W. (2012). Intrapopulation variation in macro tooth wear patterns—a case study from Igloolik, Canada. *American Journal of Physical Anthropology, 149*(4), 517–524. https://doi.org/10.1002/ajpa.22153

von Cramon-Taubadel, N. (2011). Global human mandibular variation reflects differences in agricultural and hunter-gatherer subsistence strategies. *Proceedings of the National Academy of Sciences, 108*(49), 19546–19551. https://doi.org/10.1073/pnas.1113050108

Currey, J. D. (2006). *Bones, structure and mechanics*. Princeton University Press.

Deter, C. A. (2009). Gradients of occlusal wear in hunter-gatherers and agriculturalists. *American Journal of Physical Anthropology, 138*(3), 247–254. https://doi.org/10.1002/ajpa.20922

D'Incau, E., Couture, C., & Maureille, B. (2012). Human tooth wear in the past and the present: Tribological mechanisms, scoring systems, dental and skeletal compensations [review]. *Archives of Oral Biology, 57*(3), 214–229. https://doi.org/10.1016/j.archoralbio.2011.08.021

Dong, G., Zhang, S., Yang, Y., Chen, J., & Chen, F. (2016). Agricultural intensification and its impact on environment during Neolithic Age in northern China. *Chinese Science Bulletin, 61*(26), 2913–2925.

Douglas, M. T., & Pietrusewsky, M. (2007). Biological consequences of sedentism: Agricultural intensification in Northeast Thailand. In M. N. Cohen, & G. M. M. Crane-Kramer (Eds.), *Ancient health: Skeletal indicators of agricultural economic intensification* (pp. 300–319). University Press of Florida.

Esclassan, R., Grimoud, A. M., Ruas, M. P., Donat, R., Sevin, A., Astie, F., & Crubezy, E. (2009). Dental caries, tooth wear and diet in an adult medieval (12th–14th century) population from mediterranean France. *Archives of Oral Biology, 54*(3), 287–297. https://doi.org/10.1016/j.archoralbio.2008.11.004

Esclassan, R., Hadjouis, D., Donat, R., Passarrius, O., Maret, D., & Vaysse, F. (2014). A panorama of tooth wear during the medieval period. *Anthropologischer Anzeiger, 72*. https://doi.org/10.1127/anthranz/2014/0442

Eshed, V., Gopher, A., & Hershkovitz, I. (2006). Tooth wear and dental pathology at the advent of agriculture: New evidence from the Levant. *American Journal of Physical Anthropology, 130*(2), 145–159. https://doi.org/10.1002/ajpa.20362

Fox, J., Weisberg, S., Adler, D., Bates, D., Baud-Bovy, G., Ellison, S., Graves, S. (2012). car: Companion to applied regression. In.

Galland, M., Van Gerven, D. P., Von Cramon-Taubadel, N., & Pinhasi, R. (2016). 11,000 years of craniofacial and mandibular variation in Lower Nubia. *Scientific Reports, 6*, 31040. https://doi.org/10.1038/srep31040. ⟨http://www.nature.com/articles/srep31040#supplementary-information⟩

Godinho, R. M., & Gonçalves, C. (2021). Testing the reliability of CT scan-based dental wear magnitude scoring. *American Journal of Physical Anthropology, 176*(3), 521–527. https://doi.org/10.1002/ajpa.24374

Godinho, R. M., O'Higgins, P., & Gonçalves, C. (2020). Assessing the reliability of virtual reconstruction of mandibles. *American Journal of Physical Anthropology, 172*(4), 723–734. https://doi.org/10.1002/ajpa.24095

Godinho, R. M., Umbelino, C., & Gonçalves, C. (2022). Mesolithic and Chalcolithic mandibular morphology: Using geometric morphometrics to reconstruct incomplete specimens and analyse morphology. *Open Archaeology, 8*(1). https://doi.org/10.1515/opar-2022-0247

Godinho, R. M. (2008). Vestígios de um império passado: a necrópole de Santo Antão-o-Novo e a Lisboa dos séculos XVI-XVIII. University of Coimbra, Coimbra.

Greene, D. (1967). Dentition of meroitic, X-group, and Christian populations from Wadi Halfa Sudan. *University of Utah Anthropological, 85*.

Halcrow, S. E., Harris, N. J., Tayles, N., Ikehara-Quebral, R., & Pietrusewsky, M. (2013). From the mouths of babes: Dental caries in infants and children and the intensification of agriculture in mainland Southeast Asia. *American Journal of Physical Anthropology, 150*(3), 409–420. https://doi.org/10.1002/ajpa.22215

Jackes, M., & Meiklejohn, C. (2004). Building a method for the study of the Mesolithic-Neolithic transition in Portugal. *Documenta Praehistorica, 31*, 89–111.

Judex, S., Gross, T. S., & Zernicke, R. F. (1997). Strain gradients correlate with sites of exercise-induced bone-forming surfaces in the adult skeleton. *Journal of Bone and Mineral Research, 12*(10), 1737–1745. https://doi.org/10.1359/jbmr.1997.12.10.1737

Judex, S., & Rubin, C. T. (2010). Is bone formation induced by high-frequency mechanical signals modulated by muscle activity. *Journal of Musculoskeletal & Neuronal Interactions, 10*(1), 3–11. <Go to ISI>://000275955700002.

Kaidonis, J. A. (2008). Tooth wear: The view of the anthropologist. *Clinical Oral Investigations, 12*(1), 21–26. https://doi.org/10.1007/s00784-007-0154-8

Kaifu, Y. (1999). Changes in the pattern of tooth wear from prehistoric to recent periods in Japan. *American Journal of Physical Anthropology, 109*(4), 485–499.

Kerr, N. W. (1988). Diet and tooth wear. *Scottish Medical Journal, 33*(4), 313–315. https://doi.org/10.1177/003693308803300415

Lanyon, L. E. (1984). Functional strain as a determinant for bone remodeling. *Calcified Tissue International, 36*(1), S56–S61. https://doi.org/10.1007/bf02406134

Larsen, C. S. (1997). *Bioarchaeology: Interpreting behavior from the human skeleton*. Cambridge University Press.

Lavelle, C. L. B. (1970). Analysis of attrition in adult human molars. *Journal of Dental Research, 49*(4), 822–828. https://doi.org/10.1177/00220345700490042001

Lenth, R. V. (2021). Estimated marginal means, aka least-squares means [R Package Emmeans Version 1.6. 0]. Comprehensive R Archive Network.

Liu, W., Zhang, Q. C., Wu, X. J., & Zhu, H. (2010). Tooth wear and dental pathology of the Bronze–Iron Age people in Xinjiang, Northwest China: Implications for their diet and lifestyle. *HOMO, 61*(2), 102–116. https://doi.org/10.1016/j.jchb.2010.02.002

Lovejoy, C. O. (1985). Dental wear in the Libben population: Its functional pattern and role in the determination of adult skeletal age at death. *American Journal of Physical Anthropology, 68*(1), 47–56. https://doi.org/10.1002/ajpa.1330680105

Lubell, D., Jackes, M., Schwarcz, H., Knyf, M., & Meiklejohn, C. (1994). The Mesolithic-Neolithic transition in Portugal: Isotopic and dental evidence of diet. *Journal of Archaeological Science, 21*(2), 201–216.

Lucas, P. W. (2004). *Dental functional morphology – how teeth work*. Cambridge University Press.

May, H., Sella-Tunis, T., Pokhojaev, A., Peled, N., & Sarig, R. (2018). Changes in mandible characteristics during the terminal Pleistocene to Holocene Levant and their association with dietary habits. *Journal of Archaeological Science: Reports, 22*, 413–419. https://doi.org/10.1016/j.jasrep.2018.03.020

Mays, S. (2002). The relationship between molar wear and age in an early 19th century AD archaeological human skeletal series of documented age at death. *Journal of Archaeological Science, 29*(8), 861–871. https://doi.org/10.1006/jasc.2001.0751

Mays, S., de la Rua, C., & Molleson, T. (1995). Molar crown height as a means of evaluating existing dental wear scales for estimating age at death in human skeletal remains. *Journal of Archaeological Science, 22*(5), 659–670. https://doi.org/10.1016/S0305-4403(95)80151-0

Meng, Y., Shao, J.-L., Jiang, N., Pan, F., Gu, Y.-C., & Zhao, Z.-H. (2014). The frequency and distribution of caries among the Iron Age population (about 2200 years BP) buried in the Mausoleum of Emperor Qinshihuang. *Archives of Oral Biology, 59*(2), 207–216. https://doi.org/10.1016/j.archoralbio.2013.11.012

Meng, Y., Zhang, H.-Q., Pan, F., He, Z.-D., Shao, J.-L., & Ding, Y. (2011). Prevalence of dental caries and tooth wear in a Neolithic population (6700–5600 years BP) from northern China. *Archives of Oral Biology, 56*(11), 1424–1435. https://doi.org/10.1016/j.archoralbio.2011.04.003

Miguel, L., & Simão, P. (2017). Minimização de Impactes sobre o Património Cultural decorrentes da execução dos Blocos de Rega de Pias (Fase de Obra) - Relatório dos Trabalhos Arqueológicos Monte da Guarita 2. ⟨https://biblioteca.edia.pt/BiblioNET/Upload/PDFS/M03608.pdf⟩.

Miles, A. E. W. (2001). The miles method of assessing age from tooth wear revisited. *Journal of Archaeological Science, 28*(9), 973–982. https://doi.org/10.1006/jasc.2000.0652

Molnar, S. (1971). Human tooth wear, tooth function and cultural variability. *American Journal of Physical Anthropology, 34*(2), 175–189. ⟨https://doi.org/10.1002/ajpa.1330340204⟩.

Molnar, S., Barrett, M. J., Brian, L., Brace, C. L., Brose, D. S., Dewey, J. R., & Wright, G. A. (1972). Tooth wear and culture: A survey of tooth functions among some prehistoric populations [and comments and reply. *Current Anthropology, 13*(5), 511–526. https://doi.org/10.1086/201284

Molnar, S., Richards, L., McKee, J., & Molnar, I. (1989). Tooth wear in Australian Aboriginal populations from the river Murray valley. *American Journal of Physical Anthropology, 79*(2), 185–196. https://doi.org/10.1002/ajpa.1330790206

Mosley, J. R., & Lanyon, L. E. (1998). Strain rate as a controlling influence on adaptive modeling in response to dynamic loading of the ulna in growing male rats. *Bone, 23*(4), 313–318. https://doi.org/10.1016/S8756-3282(98)00113-6

Patil, I. (2021). Visualizations with statistical details: The'ggstatsplot'approach. *Journal of Open Source Software, 6*(61), 3167.

Pechenkina, E. A., Benfer, R. A., Jr, & Ma, X. (2007). Diet and health in the Neolithic of the Wei and Middle Yellow River basins, Northern China. In M. N. Cohen, & G. M. M. Crane-Kramer (Eds.), *Ancient health: Skeletal indicators of agricultural economic intensification* (pp. 255–272). University Press of Florida.

Pinhasi, R., & Stock, J. T. (Eds.). (2011). *Human bioarchaeology of the transition to agriculture*. Wiley-Blackwell.

Pokhojaev, A., Avni, H., Sella-Tunis, T., Sarig, R., & May, H. (2019). Changes in human mandibular shape during the Terminal Pleistocene-Holocene Levant. *Scientific Reports, 9*(1), 8799. https://doi.org/10.1038/s41598-019-45279-9

Rando, C., Hillson, S., & Antoine, D. (2014). Changes in mandibular dimensions during the mediaeval to post-mediaeval transition in London: A possible response to decreased masticatory load. *Archives of Oral Biology, 59*(1), 73–81. https://doi.org/10.1016/j.archoralbio.2013.10.001

Roberts, C., & Cox, M. (2007). The impact of economic intensification and social complexity on human health in Britain from 6000 BP (Neolithic) and the introduction of farming to the mid-nineteenth century AD. In M. N. Cohen, & G. M. M. Crane-Kramer (Eds.), *Ancient health - skeletal indicators of agricultural and economic intensification* (pp. 149–163). University Press of Florida.

Romero, A., Ramirez-Rozzi, F. V., Cuesta-Torralvo, E., & Pérez-Pérez, A. (2019). Age-relatedtooth wear in African rainforest hunter-gatherers. *American Journal of Physical Anthropology, 170*(4), 622–628. https://doi.org/10.1002/ajpa.23934

Scott, E. C. (1979aa). Dental wear scoring technique. *American Journal of Physical Anthropology, 51*(2), 213–217. https://doi.org/10.1002/ajpa.1330510208

Scott, E. C. (1979bb). Principal axis analysis of dental attrition data. *American Journal of Physical Anthropology, 51*(2), 203–211. https://doi.org/10.1002/ajpa.1330510207

Shykoluk, N. L., & Lovell, N. C. (2010). Technical note: Enhancement of Scott's molar wear scoring method. *American Journal of Physical Anthropology, 143*(3), 482–487. https://doi.org/10.1002/ajpa.21342

Slaus, M., Pećina-Hrncević, A., & Jakovljević, G. (1998). Dental disease in the late medieval population from Nova Rača, Croatia. *Collegium Antropologicum, 21*, 561–572.

Smith, B. H. (1984). Patterns of molar wear in hunter–gatherers and agriculturalists. *American Journal of Physical Anthropology, 63*(1), 39–56. https://doi.org/10.1002/ajpa.1330630107

Smith, P. (1972). Diet and attrition in the natufians. *American Journal of Physical Anthropology, 37*(2), 233–238. https://doi.org/10.1002/ajpa.1330370207

Turner, C. H. (1998). Three rules for bone adaptation to mechanical stimuli. *Bone, 23*(5), 399–407. https://doi.org/10.1016/S8756-3282(98)00118-5

Valera, A. C., Santos, H., Figueiredo, M., & Granja, R. (2014). Contextos funerários na periferia do Porto Torrão: Cardim 6 e Carrascal 2. In A. C. Silva, F. T. Regala, & M. Martinho (Eds.), *4° Colóquio de Arqueologia do Alqueva* (pp. 83–95). EDIA/DRCAlen.

Varrela, J. (1990). Occurrence of malocclusion in attritive environment: A study of a skull sample from southwest Finland. *European Journal of Oral Sciences, 98*(3), 242–247.

Varrela, J., & Varrela, T. M. (1991). Dental studies of a Finnish skeletal material: A paleopathologic approach. *Tandlaegebladet, 96*(7), 283–290.

Watson, J. T. (2008). Changes in food processing and occlusal dental wear during the early agricultural period in northwest Mexico. *American Journal of Physical Anthropology, 135*(1), 92–99. https://doi.org/10.1002/ajpa.20712

Watson, J. T., Arriaza, B., Standen, V., & Muñoz Ovalle, I. (2013). Tooth wear related to marine foraging, agro-pastoralism and the formative transition on the northern Chilean coast. *International Journal of Osteoarchaeology, 23*(3), 287–302. https://doi.org/10.1002/oa.1247