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Is root exposure a good marker of periodontal disease? *

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Abstract

In bioarchaeological studies dental root exposure is often used as a marker of periodontal disease; these studies are based on classical methods assuming alveolar resorption as the only (or the main) cause of root exposure. However, several papers suggested that root exposure depends not only on alveolar resorption, but also on other mechanisms. Continuous eruption and compensatory eruption might also cause root exposure in absence of periodontal disease. We investigated this topic on a skeletal sample from the medieval cemetery of Pieve di San Pancrazio in Sestino (Arezzo, Italy). We collected data on root exposure, dental wear and alveolar bone status on permanent mandibular teeth of individuals from juvenile to senile and tested the relationship among these features. The results show that root exposure strongly correlates with dental wear, also in absence of morphological markers of periodontal disease. In our sample, the use of root exposure as a marker of periodontal disease led to a mis-diagnosis in 10% to 50% of the teeth. For assessment of periodontal disease, we encourage the use of methods based on alveolar bone morphology, which allow discriminating periodontal disease independently of root exposure.

Keywords: periodontal disease; root exposure; compensatory eruption

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Introduction

Teeth and jaws are probably the most informative anatomical regions of the human skeleton. They provide information on many different aspects: taxonomy and evolution (1-6), genetic distance among populations (7-9), paleodemography (10,11), development and life history (12-15), diet (16-18), cultural practices (19-23).

Dental and oral pathologies are of particular relevance to anthropological research, because they are reflective of the health status and health-related quality of life of an individual (24-27). Thus, they are used to infer the health status of single specimens (3, 28), as well as to investigate their prevalence in past species or populations (24,29-31). Also, they can provide information on social differences among groups (32-36) or temporal changes in socio-economic conditions (37-39).

Periodontal disease is among the most common (and among the most commonly analyzed) oral pathologies. It is the result of the body's immune response to the infection of the periodontium (40), the supporting structure of teeth. When bacteria from the dental plaque invade the gingival space, the infection produces an immune response, resulting in inflammation of the tissues and alveolar bone loss (41). Chronic periodontal disease can lead to the loss of the affected tooth. Its association with risk of morbidity and mortality from other diseases (24,40,42,43) makes the periodontal disease a good indicator of general health status in past populations.

The first methods for the assessment of periodontal disease in skeletal materials were based on the measurement of root exposure, assuming that root exposure > 2 mm was indicative of a pathological condition (44,45).

Some problems with these methods arose when, starting from the 1980s, several works suggested that various mechanisms, other than alveolar resorption, could be responsible for root exposure (46-50). In particular, continuous and compensatory eruption can lead to root exposure in absence of any pathological condition. Continuous eruption occurs gradually throughout the whole life of an individual, while compensatory eruption occurs in response to extreme dental wear (51,52 and citations therein). Both deposition of cementum at the apex of the roots and remodeling of alveolar bone (with migration of the socket) contribute to the process (51).

To overcome these problems, new methods for the assessment of periodontal disease have been developed (52-54). Periodontal disease is assessed on the basis of the (micro- and/or macro-) morphology and texture of the alveolar bone, not considering root exposure. Nevertheless, many authors still use methods based on root exposure (24,55-58).

This paper aims to test the validity of root exposure as a marker of periodontal disease. In doing so, we investigated the relationship among root exposure, alveolar bone morphology, and dental wear, in an archaeological sample.

Materials and methods

The sample analyzed comes from the medieval cemetery of the Pieve di San Pancrazio (Sestino, AR, Tuscany, Italy). The Pieve di San Pancrazio is mentioned for the first time in a document of the 12th century A.D. (but some architectural remains seem to date back the rural church to the 9th and 10th centuries A.D.) (59). The cemetery was excavated in the 1980s and 1990s by the former Soprintendenza Archeologica della Toscana.

Figure 1. Root exposure was measured with a sliding caliper, on the labio/buccal side of the tooth. In single-rooted teeth, we measured the distance from the alveolar margin to the CEJ, over the midline of the root (red line on the second premolar). In multi-rooted teeth we measured the same distance on the distal root (red line on the first molar).

Human remains from this cemetery are very well preserved and represent a suitable skeletal collection for studies about skeletal biology and dental anthropology. Previous works provided sex and age estimates (60, 61). Using standard methods (62), sex was assessed by pelvic and cranial morphology, whereas age was estimated by dental development in subadults and by the

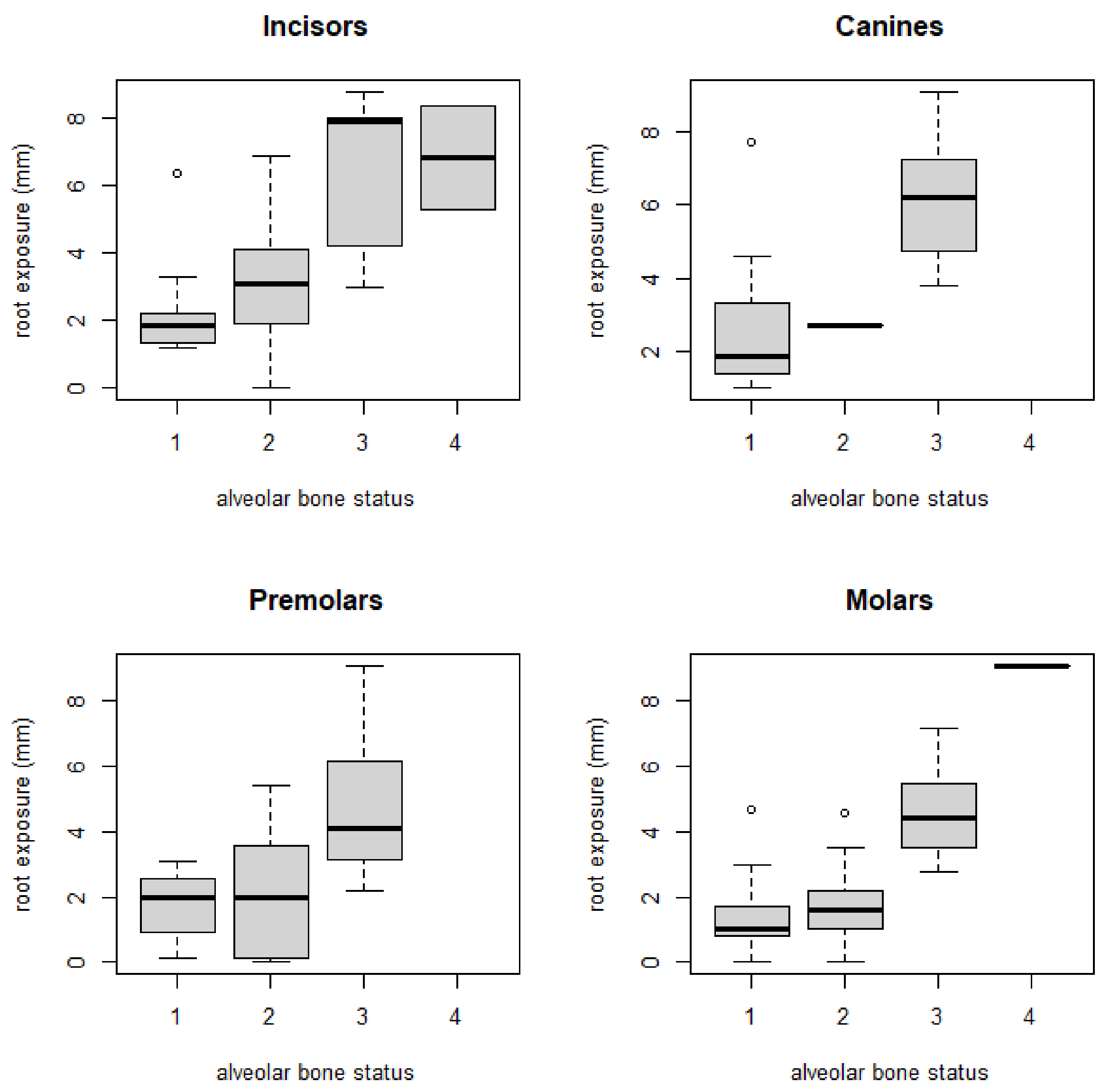

Figure 2. Alveolar bone status vs root exposure. The boxplots show the variation of root exposure for the four classes of alveolar bone status (52). Class 1 represents healthy alveolar bone. The black line is the median of the distribution; the box encloses the interquartile range (1st to 3rd quartile); whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box.

morphology of auricular surface and pubic symphysis in adults.

We selected 26 mandibles belonging to 11 adult females, 10 adult males and 5 subadults. We analyzed only erupted permanent teeth, from both emi-arches. The sample ages range from subadult to senile. In this way we maximized tooth wear range for each tooth. The dental sample is summarized in table 1.

For each tooth we measured root exposure, scored dental wear, and assessed periodontal disease by alveolar bone status. Root exposure was measured, with a sliding calliper, on the labio/buccal side from the alveolar margin over the midline of the root, perpendicular to the cemento-enamel junction (CEJ), Figure 1 (45).

Dental wear was analyzed by visual inspection of the occlusal surface of each tooth, and scored with an 8-grade scale by comparison with a reference chart, specific for tooth class (incisor or canines, premolars and molars) (63).

Periodontal disease was evaluated by visual inspection of the conditions of the alveolar bone and scored by the 4-grades scale proposed by Ogden (52). This method is based on the observation of the buccal surface of alveolar bone.

The absence of disease (grade 1) is assessed when “alveolar margin meets tooth at a knife-edged acute angle”; mild periodontitis (grade 2) is present when “alveolar margin is blunt and flat-topped with a slightly raised rim”; in grade 3 (moderate periodontitis), “alveolar margin is rounded and porous, with a trough of 2–4 mm depth between tooth and alveolus”; eventually, in grade 4 (severe periodontitis), “alveolar margin is ragged and porous, with an irregular trough or funnel > 5 mm depth between tooth and alveolus” (52, p.293). In this scoring root exposure is completely irrelevant to the diagnosis.

Statistical analysis was conducted using R version 4.0.3 (64). The focus of this paper is on the mechanism of bone resorption and we are not

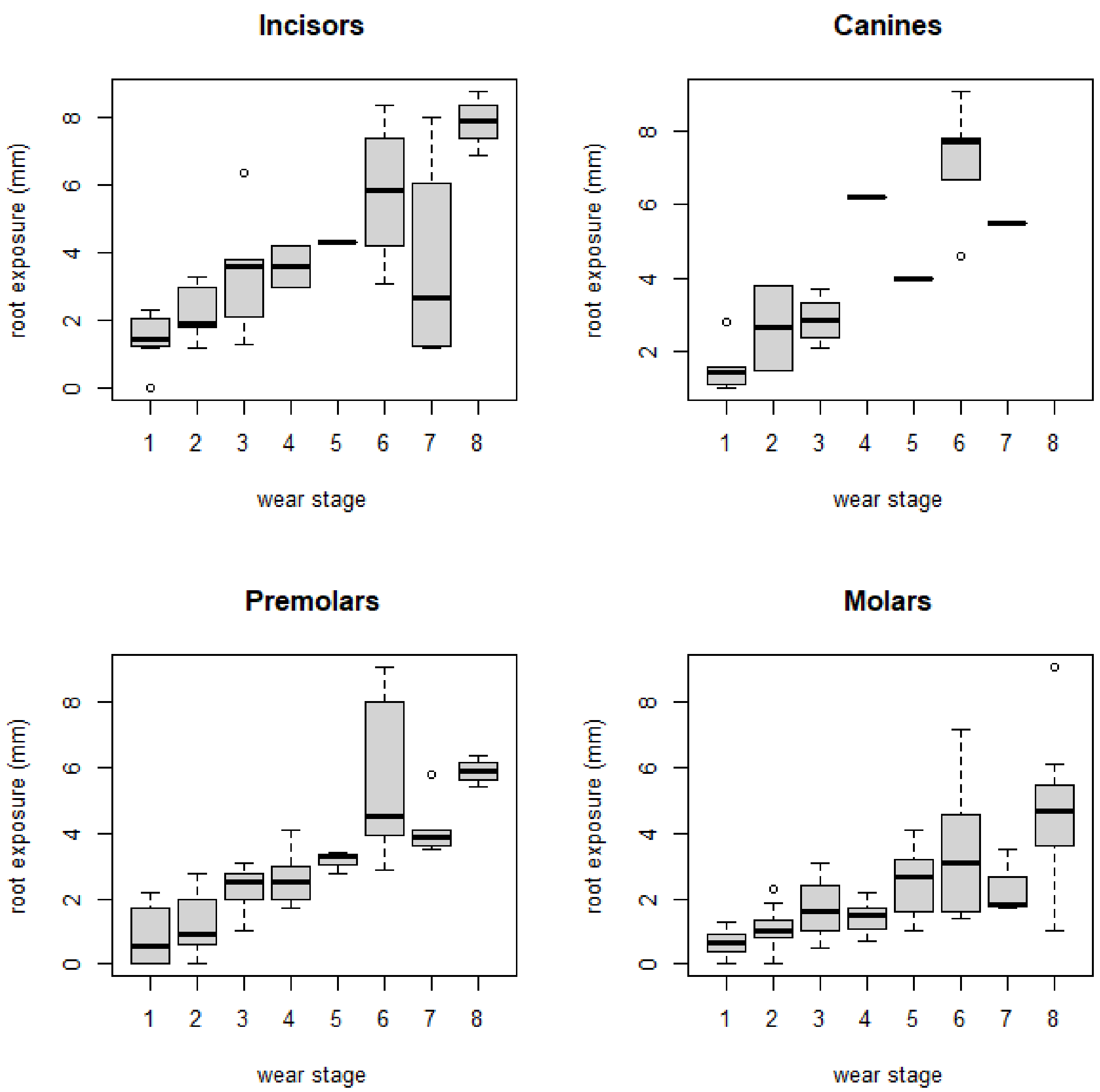

Figure 3. Dental wear stage vs root exposure. The boxplots show the variation of root exposure for the eight classes of dental wear stage (60). The black line is the median of the distribution; the box encloses the interquartile range (1st to 3rd quartile); whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box.

interested in prevalence differences between sexes or age classes; therefore, we analyzed the entire sample with pooled ages and sexes.
This, also allowed us to increase the sample size. We analyzed each tooth type separately (i.e. I1, I2, C, P3, P4, M1, M2, M3) and merged by tooth class (incisors, canines, premolars and molars). We investigated the relationship among root exposure (dependent variable), dental wear (independent variable) and alveolar bone status (independent variable), using a multiple linear regression (65).

Then, we subsampled only those teeth with a healthy alveolar bone (i.e. alveolar bone status scored as 1), to investigate whether the relationship between dental wear and root exposure holds true. On this selected dataset we ran a simple linear regression (only by tooth class because of the low numbers) with root exposure as the dependent variable and dental wear as the independent variable.
In all analyses, we used boxplots to graphically visualize the relationship between root exposure and dental wear/alveolar bone status.

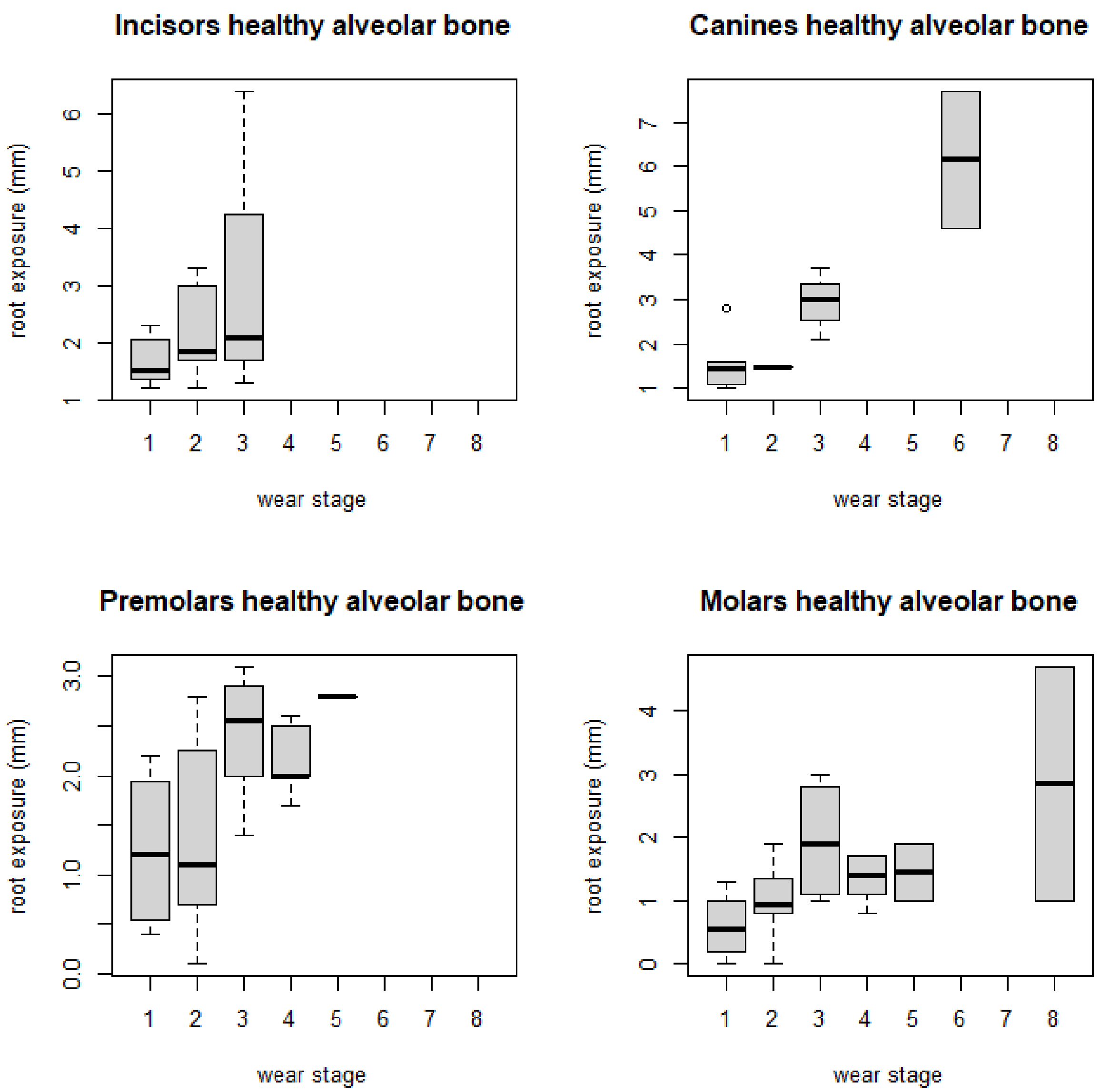

Figure 4 Dental wear stage vs root exposure in a subsample of only teeth with healthy alveolar bone. The boxplots show the variation of root exposure for the eight classes of dental wear stage (60). The black line is the median of the distribution; the box encloses the interquartile range (1st to 3rd quartile); whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box.

Results

For reasons of space, here we present only the boxplots of the sample merged by tooth class, since the patterns of the boxplots by tooth type are similar. All the boxplots show a clear relationship between root exposure and alveolar bone status (Figure 2) as well as between root exposure and tooth wear stage (Figure 3). In some cases, such as for the canines in figure 3, the pattern is less clear. This is probably due to the low numbers in some classes, but, in general, teeth with severe wear or with poor alveolar bone status have roots more exposed.

The multiple linear regression by tooth type confirms positive correlations (i.e. positive t-values) in all cases, although only for dental wear they are significant in most cases (6/8); on the other hand, correlations with alveolar bone status have a p-value < 0.05 only in the case of central incisors (Table 2).

The lack of diffuse significance might be partly due to the sample size. Indeed, if we merge teeth by class, stronger correlations with root exposure emerge also for alveolar bone status (Table 3).

Table 1. The sample analyzed, by tooth type and class.

Tooth type	Tooth class	N by tooth	N by class
I1	Incisors	38	80
I2		42	
C,	Canines	43	43
P3	Premolars	47	93
P4		46	
M1	Molars	37	106
M2		39	
M3		30	

If our hypothesis, that continuous and/or compensatory eruption can be responsible for root exposure in absence of periodontal disease, it is correct, then the correlation between root exposure and dental wear stage should be present in a sample with healthy alveolar bone. Thus, we selected only individuals for which alveolar bone status was scored as 1 and obtained a new sample, as presented in table 4. Since the numbers are relatively low, we analyzed only teeth merged by class. Although the sample is far from an ideal one, still roots are more exposed in teeth with higher wear stage (Figure 4). Also simple linear regression confirms the positive correlations, with p-values << 0.05 in all teeth except incisors (Table 5).

Table 2. Results of the multiple linear regression for each tooth. Significance codes: *<0.001; **<0.01; *<0.05.**

	t-value	p-value		t-value	p-value
I1			P4		
wear	0.169	0.8678	wear	7.904	4.1e-09 ***
alveolus	2.445	0.0273 *	alveolus	0.758	0.454
I2			M1		
wear	9.042	1.85e-07 ***	wear	4.874	5.72e-05 ***
alveolus	2.445	0.248	alveolus	0.924	0.365
C,			M2		
wear	5.048	9.92e-05 ***	wear	2.024	0.052284 .
alveolus	1.569	0.135	alveolus	3.735	0.000817 ***
P3			M3		
wear	3.911	0.00075 ***	wear	3.268	0.00326 **
alveolus	1.388	0.17897	alveolus	1.832	0.07939

Eventually, we estimated how many teeth with healthy alveolar bone have the root exposed for more than 2 mm. Many of the studies that consider root exposure as a marker of periodontal disease, place the threshold for the diagnosis of periodontal disease at 2 mm (24,32,44,55). The results presented in table 6, show that in many cases (from ~10% of the molars to the 50% of the canines) teeth with healthy alveolar bones can have roots exposed for more than 2 mm.

Discussion

Our results demonstrate that both alveolar bone status and tooth wear stage correlate with root exposure. Alveolar bone status is considered by many the most reliable marker of periodontal disease (46,51,52). Its correlation with root exposure is not unexpected, because alveolar bone resorption (leaving roots exposed) is the outcome of periodontal disease (40,41).

On the other hand, the correlation with dental wear stage, points towards other physiological mechanism as co-responsible for root exposure, i.e. continuous and/or compensatory eruption (46,51,52). The effect of continuous /compensatory eruption is also confirmed in the sample including only healthy alveolar bone. This

is a problem when assessing periodontal disease by root exposure in human skeletal remains, since root exposure can be misleading for the diagnosis.
Usually, in studies considering root exposure as a marker of periodontal disease, the cutoff for the diagnosis is 2 mm (24,32,44,55). In our sample, from ~10% to 50% of the teeth with healthy alveolar bone have the root exposed more than 2 mm. Half of the healthy canines, in our results, show root exposure above 2 mm, thus the diagnosis of periodontal disease based on 2 mm root exposure threshold for this tooth can lead to a higher chance of a misdiagnosis. Molars, instead, show less root exposure in healthy cases but still it is possible to diagnose incorrectly 1 out of 10 cases. One may wonder if the diagnosis of periodontal disease through root exposure could still be valid in a sample with unworn teeth. Following this hypothesis, some works (e.g. 58) exclude from the analysis specimens with excessive wear. As we can see in figure 4, teeth with low wear stages are less likely to have the root exposed more than 2 mm than teeth with higher wear stage. Nonetheless, when we consider only specimens with healthy alveolar bone and wear stage 1 in our sample, the risk of misdiagnosis of periodontal disease remains high. In our sample, 21 teeth have healthy alveolar bone and wear stage 1; of these, 4/21 (19%) have roots exposed more than 2 mm. This, in turn, suggests that root exposure is linked to other factors excluding pathological origins and mechanical stress. Therefore, we recommend avoiding using this method in future paleopathological research even in samples with low dental wear.

Conclusion

Our study confirms that root exposure is linked to periodontal disease and to other physiological mechanisms (continuous and compensatory eruptions). Root exposure cannot be considered a good marker of periodontal disease and can lead to mis-diagnosis, even in absence of severe dental wear. We suggest that caution is needed when assessing periodontal disease from root exposure and we encourage the use of methods based on alveolar bone morphology, which allow discriminating periodontal disease independently of root exposure (52-54).

Table 3. Results of the multiple linear regression for teeth merged in classes. Significance codes: *<0.001; **<0.01; *<0.05.**

	t-value	p-value
Incisors		
wear	2.952	0.00578 **
alveolus	2.104	0.04311 *
Premolars		
wear	7.137	1.72e-09 ***
alveolus	1.863	0.0675
Molars		
wear	6.145	2.66e-08 ***
alveolus	4.295	4.72e-05 ***

Table 4. The selected sample, by tooth type and class, including only teeth with healthy alveolar bone.

Tooth type	Tooth class	N by tooth	N by class
I1	Incisors	9	16
I2		7	
C,	Canines	12	12
P3	Premolars	11	28
P4		17	
M1	Molars	10	29
M2		9	
M3		10	

Table 5. Results of the simple linear regression for only teeth with healthy periodontal bone. Significance codes: *<0.001; **<0.01; *<0.05.**

	t-value	p-value
Incisors		
wear	1.852	0.0852
Canines		
wear	5.841	0.000164 ***
Premolars		
wear	2.921	0.00712 **
Molars		
wear	3.269	0.00294 **

Table 6. Percentage of teeth with root exposure > 2 mm. The table refers to the sample with healthy alveolar bone.

Tooth class	N	root exposure > 2 mm	%
Incisors	16	6	37.5
Canines	12	6	50.0
Premolars	28	11	39.3
Molars	29	3	10.3

Declarations of interest: none

Author contributions

AR: design of the study, formal analysis, writing-original draft; writing-review and editing, supervision; CB and SS: data curation, formal analysis; SE: writing-original draft; SG: materials selection, data curation; JM-C; writing-original draft, writing-review and editing TM: writing-original draft, writing-review and editing; ID: writing-original draft, writing-review and editing.

References

1. Bailey SE, Lynch JM. Diagnostic differences in mandibular P4 shape between Neandertals and anatomically modern humans. Am J Phys Anthropol. 2005;126(3):268-77.
2. Ortiz A, Bailey SE, Delgado M, Zanolli C, Demeter F, Bacon AM et al. A distinguishing feature of Pongo upper molars and its implications for the taxonomic identification of isolated hominid teeth from the Pleistocene of Asia. Am J Phys Anthropol. 2019;170(4):595-612.
3. Riga A, Boggioni M, Papini A, Buzi C, Profico A, Di Vincenzo F et al. In situ observations on the dentition and oral cavity of the Neanderthal skeleton from Altamura (Italy). PloS One. 2020;15(12):e0241713.
4. Lockwood CA, Kimbel WH, Johanson, DC. Temporal trends and metric variation in the mandibles and dentition of Australopithecus afarensis. J Hum Evol. 2000;39(1):23-55.
5. Veneziano A, Irish JD, Meloro C, Stringer C, De Groote I. The functional significance of dental and mandibular reduction in Homo: A catarrhine perspective. Am J Primatol. 2019;81(3):e22953.
6. Riga A, Oxilia G, Panetta D, Salvadori PA, Benazzi S, Wadley L, Moggi-Cecchi J. Human deciduous teeth from the middle Stone age layers of Sibudu cave (South Africa). J Anthropol Sci. 2018; 96:75-87.
7. Hanihara, T. Morphological variation of major human populations based on nonmetric dental traits. Am J Phys Anthropol. 2008;136(2):169-82.
8. Scott GR, Irish JD. Human tooth crown and root morphology. Cambridge University Press; 2017.
9. Rathmann H, Reyes-Centeno H. Testing the utility of dental morphological trait combinations for inferring human neutral genetic variation. Proc Nat Acad Sci. 2020;117(20):10769-77.
10. Riga A, Mori T, Pickering TR, Moggi-Cecchi J, Menter CG. Ages-at-death distribution of the early Pleistocene hominin fossil assemblage from Drimolen (South Africa). Am J Phys Anthropol. 2019;168(3):632-6.
11. Bermúdez de Castro JM, Martinón-Torres M, Lozano M, Sarmiento S, Muela A. Paleodemography of the Atapuerca: Sima De Los Huesos Hominin Sample: A Revision and New Approaches to the Paleodemography of the European Middle Pleistocene Population. J Anthropol Res. 2004;60(1):5-26.
12. Smith TM, Tafforeau P, Le Cabec A, Bonnin A, Houssaye A, Pouech J et al. Dental ontogeny in Pliocene and early Pleistocene hominins. PloS One. 2015;10(2):e0118118.
13. Nava A, Lugli F, Romandini M, Badino F, Evans D, Helbling AH et al. Early life of Neanderthals. Proc Nat Acad Sci. 2020;117(46):28719-26.
14. Dori I, Varalli A, Seghi F, Moggi-Cecchi J, Sparacello VS. Environmental correlates of growth patterns in Neolithic Liguria (northwestern Italy). Int J Paleopathol. 2020; 28:112-22.
15. Orellana-González E, Sparacello VS, Bocaege E, Varalli A, Moggi-Cecchi J, Dori I. Insights on patterns of developmental disturbances from the analysis of linear enamel hypoplasia in a Neolithic sample from Liguria (northwestern Italy). Int J Paleopathol. 2020; 28:123-36.
16. Ungar PS. Inference of diets of early hominins from primate molar form and microwear. J Dent Res. 2019;98(4):398-405.
17. Fiorenza L, Benazzi S, Tausch J, Kullmer O, Bromage TG, Schrenk, F. Molar macrowear reveals Neanderthal eco-geographic dietary variation. PLoS One. 2011;6(3):e14769.
18. Mant M, Roberts C. Diet and dental caries in post-medieval London. Int J Historical Archaeol. 2015;19(1):188-207.
19. Oxilia G, Fiorillo F, Boschin F, Boaretto E, Apicella SA, Matteucci C et al. The dawn of dentistry in the late upper Paleolithic: An early case of pathological intervention at Riparo Fredian. Am J Phys Anthropol. 2017;163(3):446-61.
20. Haddow SD, Tsoraki C, Vasić M, Dori I, Knüsel CJ, Milella M. (2019). An analysis of modified human teeth at Neolithic Çatalhöyük, Turkey. J Archaeol Sci Rep. 2019;28:102058.
21. Frayer D, Nava A, Tartaglia G, Vidale M, Coppa A, Bondioli L. Evidence for labret use in prehistory. Bull

Int Assoc Paleodont. 2020;14(1):1-23. Belcastro et al. 2018;
22. Belcastro MG, Mariotti V, Riga A, Bonfiglioli B, Frayer DW. Tooth fractures in the Krapina Neandertals. J Hum Evol. 2018;123:96-108.
23. Towle I, Irish JD, De Groote I. Behavioral inferences from the high levels of dental chipping in Homo naledi. Am J Phys Anthropol. 2017;164(1):184-192.
24. DeWitte SN, Bekvalac J. Oral health and frailty in the medieval English cemetery of St. Mary Graces. Am J Phys Anthropol. 2010;142:341-54.
25. Naito M, Yuasa H, Nomura Y, Nakayama T, Hamajima N, Hanada N. Oral health status and health-related quality of life: a systematic review. J Oral Sci. 2006;48(1):1-7.
26. Tubert-Jeannin S, Riordan PJ, Morel-Papernot A, Porcheray S, Saby-Collet S. Validation of an oral health quality of life index (GOHAI) in France. Comm Dent Oral Epidemiol. 2003;31(4):275-84.
27. Gift HC, Atchison KA. Oral health, health, and health-related quality of life. Med care. 1995:NS57-NS77.
28. Towle I, Riga A, Irish JD, Dori I, Menter C, Moggi-Cecchi J. Root caries on a Paranthropus robustus third molar from Drimolen. Am J Phys Anthropol. 2019;170(2):319-23.
29. Towle I, Irish JD, De Groote I, Fernée C. Dental caries in human evolution: frequency of carious lesions in South African fossil hominins. bioRxiv, 2019:597385.
30. Trombley TM, Agarwal SC, Beauchesne PD, Goodson C, Candilio F, Coppa A, Rubini M. Making sense of medieval mouths: Investigating sex differences of dental pathological lesions in a late medieval Italian community. Am J Phys Anthropol. 2019;169(2):253-69.
31. Chanamé-Marín, A, Reátegui-Navarro M, Arbildo-Vega H. Prevalence of dental paleopathology in a Peruvian pre-hispanic population. J Oral Res.2019;8(2):147-51.
32. DeWitte, SN. Sex differences in periodontal disease in catastrophic and attritional assemblages from medieval London. Am J Phys Anthropol. 2012; 149(3):405-16.
33. Keenleyside, A. (2008), Dental pathology and diet at Apollonia, a Greek colony on the Black Sea. Int. J. Osteoarchaeol., 18: 262-279. https://doi.org/10.1002/oa.934
34. Paine RR, Vargiu R, Coppa A, Morselli C, Schneider EE. A health assessment of high status Christian burials recovered from the Roman–Byzantine archeological site of Elaiussa Sebaste, Turkey. Homo. 2007;58(2):173-90.
35. Cucina A, Tiesler, V. Dental caries and antemortem tooth loss in the Northern Peten area, Mexico: a biocultural perspective on social status differences among the Classic Maya. Am J Phys Anthropol. 2003;122(1):1-10.
36. Lukacs JR. Sex differences in dental caries rates with the origin of agriculture in South Asia. Curr Anthropol. 1996;37(1):147-53.
37. Rose EK, Vieira AR. Caries and periodontal disease: insights from two US populations living a century apart. Oral Hlth Prev Dent. 2008;6(1):23-8.
38. Watson JT. Prehistoric dental disease and the dietary shift from cactus to cultigens in northwest Mexico. Int J Osteoarchaeol. 2008;18(2):202-12.
39. Temple DH, Larsen CS. Dental caries prevalence as evidence for agriculture and subsistence variation during the Yayoi period in prehistoric Japan: biocultural interpretations of an economy in transition. Am J Phys Anthropol. 2007;134(4):501-12.
40. Nelson GC. A Host of Other Dental Diseases and Disorders. In: Irish JD, Scott GR. A Companion to Dental Anthropology. John Wiley & Sons, Inc. 2016. p. 465-83.
41. Di Benedetto A, Gigante I, Colucci S, Grano M. Periodontal Disease: Linking the Primary Inflammation to Bone Loss. J Immunol Res. 2013:503754.
42. Kuo L-C, Polson AM, Kang T. Associations between Periodontal Diseases and Systemic Diseases: A Review of the Inter-Relationships and Interactions with Diabetes, Respiratory Diseases, Cardiovascular Diseases and Osteoporosis. Public Health. 2008;122:417-33.
43. DeStefano F, Anda RF, Kahn HS, Williamson DF, Russell CM. Dental disease and risk of coronary heart disease and mortality. BMJ. 1993;306:688–91.
44. Leigh RW. Dental Pathology of the Eskimo. Dental Cosmos. 1925;67:884-98.
45. Davies DM, Picton DCA, Alexander AG. An objective method of assessing the periodontal condition in human skulls. J periodont res. 1969;4(1):74-7.
46. Clarke NG, Hirsch RS. Physiological, pulpal and periodontal factors influencing alveolar bone. In: Kelley MA, Larsen CS, editors. Advances in Dental Anthropology. Wiley-Liss: New York, 1991. p. 241-66.
47. Costa RL. Periodontal disease in the prehistoric Ipiutak and Tigara skeletal remains from Point Hope, Alaska. Am J Phys Anthropol. 1982;59:97-110.
48. Clarke N, Carey S. The aetiology of chronic periodontal disease: an alternative perspective. J Am Dent Assoc. 1985;110:689-91.
49. Glass G. Continuous eruption and periodontal status in pre-industrial dentitions. Int J Osteoarchaeol. 1991;1:265-71.

50. Newman HN. Factors affecting the lifespan of the human dentition in Britain prior to the seventeenth century. Br Dent J. 1998;184:229.
51. Hillson S. Dental Pathology. In: Katzenberg M.A., Grauer A.L. Biological Anthropology of the Human Skeleton. John Wiley & Sons, 2008. p. 293-333.
52. Ogden, A. Advances in the palaeopathology of teeth and jaws. In: Pinhasi R, Mays S., editors. Advances in Human Palaeopathology. John Wiley & Sons, Lt; 2008. p. 283-307.
53. Kerr NW. Prevalence and natural history of periodontal disease in Scotland – The mediaeval period (900–1600 A. D.). J Periodont Res. 1991;26(4):346-54.
54. Kerr NW. A method of assessing periodontal status in archaeologically derived material. J Paleopathol. 1988;2:67-78.
55. Bertl K, Tangl S, Rybaczek T, Berger B, Traindl-Prohazka M, Schuller-Götzburg P, Grossschmidt K. Prevalence and severity of periodontal disease in a historical Austrian population. J Periodont Res. 2020;55:931-45.
56. Gonçalves PCG, Griffiths G, Rawlinson A. A study of the periodontal state of a late Medieval United Kingdom population. Archives of oral biology. 2015;60(12):1797-801.
57. Griffin, MC. Biocultural implications of oral pathology in an ancient Central California population. Am J Phys Anthropol. 2014;154:171–188.
58. Vodanović M, Peroš K, Zukanović A, Knežević M, Novak M, Šlaus M, Brkić H. Periodontal diseases at the transition from the late antique to the early mediaeval period in Croatia. Arch Oral Biol. 2012;57(10):1362-76.
59. Susini G. editor. Sestinum: Comunità antiche dell'Appennino tra Etruria e Adriatico. Sestino (Arezzo) 18 – 19 Settembre 1983; Ghigi editore: Rimini. 1989.
60. Gori S. Studio degli indicatori di stress scheletrici e dentari in una popolazione Medioevale di Sestino (Ar). Dissertation: University of Florence, 2002.
61. Sala S. Differenze nella mobilità delle popolazioni medievali: confronto tra siti cittadini e pedemontani della Toscana attraverso la biomeccanica del femore. Dissertation: University of Florence, 2019.
62. Buikstra JE, Ubelaker D. editors. Standards for data collection from human skeletal remains. Arkansas Research series no. 44: Fayetteville. 1994.
63. Smith BH. Patterns of molar wear in hunter–gatherers and agriculturalists. Am J Phys Anthropol. 1984;63(1):39-56.
64. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna Austria. 2020. URL https://www.R-project.org/
65. Olive DJ. Multiple linear regression. In: Olive DJ editor. Linear regression. Springer, Cham. 2017 (pp. 17-83)