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A Bayesian Approach to Estimate Skeletal Age-at-Death Utilizing Dental Wear

ABSTRACT: In the forensic context, teeth are often recovered in mass disasters, armed conflicts, and mass graves associated with human rights violations. Therefore, for victim identification, techniques utilizing the dentition to estimate the first parameters of identity (e.g., age) can be critical. This analysis was undertaken to apply a Bayesian statistical method, transition analysis, based on the Gompertz–Makeham (GM) hazard model, to estimate individual ages-at-death for Balkan populations utilizing dental wear. Dental wear phases were scored following Smith's eight-phase ordinal scoring method and chart. To estimate age, probability density functions for the posterior distributions of age for each tooth phase are calculated. Transition analysis was utilized to generate a mean age-of-transition from one dental wear phase to the next. The age estimates are based on the calculated age distribution from the GM hazard analysis and the ages-of-transition. To estimate the age-at-death for an individual, the highest posterior density region for each phase is calculated. By using a Bayesian statistical approach to estimate age, the population's age distribution is taken into account. Therefore, the age estimates are reliable for the Balkan populations, regardless of population or sex differences. The results showed that a vast amount of interpersonal variation in dental wear exists within the current sample and that this method may be most useful for classifying unknown individuals into broad age cohorts rather than small age ranges.

KEYWORDS: forensic science, forensic anthropology, Bayesian analysis, age estimation, tooth wear, Balkans

Due to their highly durable nature, teeth are not only recovered from typical forensic and archaeological settings, but also in cases of mass disasters, human rights violations, and armed conflicts, which often result in a high number of casualties and commingled remains. Therefore, techniques utilizing the dentition to estimate the age-at-death can be critical when trying to establish a person's identity.

Dental wear, or attrition, is the erosion of the occlusal or incisal surface of teeth or the contact points between teeth, caused by mastication, and has proved useful in age-at-death estimations (1–23). Dental wear has been employed as an estimator of age for prehistoric populations since the beginning of the 20th century (24–27), but its usefulness in forensic identifications was first analyzed by Gustafson (1). In his study, Gustafson (1) assessed age-related changes in six features of the human dentition: attrition, secondary dentin deposits, translucency of the root, periodontal recession, cementum annulation apposition thickness, and root resorption. Longitudinal sections were taken in order to assess the degree of dental change in each feature. Gustafson assigned an ordinal score (0, 1, 2, 3 points) to account for the amount of the dental change observed in each feature. In the point system, an increased score was equated with increased age. Although his results showed that translucency and secondary dentine deposits were the best indicators of age, dental attrition also showed promise due to the fact that this feature could be assessed without sectioning the tooth.

Most methods utilizing dental wear as an age indicator were developed on prehistoric archaeological samples. As the true age-at-death was unknown, the usefulness, reliability, and applicability of these dental wear methods were questioned. Researchers addressed this issue by calibrating dental wear with other age indicators throughout the skeleton. Calibrating molar eruption patterns to the amount of dental wear observed on the molars, a method first proposed by Miles (3), has proved very useful in estimating age-at-death (3–5,9,14,21,28–31). Because the first permanent molar (M_1) erupts at approximately 6 years of age, the second permanent molar (M_2) erupts at approximately age 12, and the third molar (M_3) erupts at approximately age 18, although the latter is highly variable, the rate of wear can be internally calibrated. From this eruption pattern, the difference in wear between M_1 and M_2, and M_2 and M_3 reflects approximately 6 years of wear. Therefore, subadult age can be estimated and then the adult ages-at-death can be extrapolated by using the internal calibration of molar wear (3,28,29,32). Several researchers tested Miles' (3,28) method against known-age samples (13,33) and concluded that Miles' method was reliable for estimating age-at-death.

Along similar lines, some researchers have been successful in calibrating the amount of dental wear through correlation to pubic symphyseal age (12,30,34). These researchers applied the internal calibration of molar wear, described above, and determined that dental wear was as reliable as pubic symphyseal aging.

One of the best known and widely utilized dental wear methods in North American bioarchaeology was developed by Murphy (2), who describes eight stages of wear for all tooth types based on Australian aboriginal populations. This method produced a very good correlation between age and dental wear, but when applied to other populations, did not fare as well.

Boldsen (35) scored molar attrition following Murphy's method (2) to address the association between frailty (an individual's risk of dying) and dental wear. He concluded that dental wear could not be used to estimate age, but that dental attrition could, however, be used as a measure of overall health and well-being (35).

Smith (8) utilized Murphy's method in her research and produced a summary diagram of the eight stages of wear, where phase

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1 refers to little or no wear, and phase 8 refers to complete loss of the crown with the tooth taking the shape of the tooth root. This method (8) has been widely used in the estimation of age-at-death (19,36) and found to be more applicable than Murphy's (2) original method when applied to diverse populations. For this reason, Smith's (8) phases of dental wear were utilized for the current research.

The purpose of this research is to apply a Bayesian statistical method, transition analysis (37), based on the Gompertz–Makeham (GM) hazard model, to estimate individual ages-at-death for Balkan populations utilizing dental wear.

Materials and Methods

Sample

The sample consists of 420 single-rooted teeth of known age and sex from individuals identified from Kosovo. Identifications were considered presumptive or positive identifications based on forensic work conducted by the International Criminal Tribunal for the Former Yugoslavia (ICTY) (see Kimmerle et al., [38], for further discussion of the validity of these identifications). Permission for this research was given to the University of Tennessee, Knoxville, by the ICTY with the expressed goal of sharing data and results that would aid agencies working on human identification in the former Yugoslavia and other areas of the world. Only one tooth per individual was available for analysis, which consisted of a maxillary or mandibular incisor, canine, or premolar. The authors of this paper could not dictate which tooth type was utilized, as the teeth were obtained and provided by ICTY to the University of Tennessee.

The sample consists of 374 males, ranging in age-at-death from 15–90 years, with a mean age-at-death of 46.93 years and a standard deviation of 17.42 years, and 46 females, ranging in age-at-death from 19–88 years, with a mean age-at-death of 47.69 years and a standard deviation of 19.65 years. Due to the small size of the female sample, males and females were analyzed together. The entire sample has a mean age-at-death of 47.01 years and a standard deviation of 17.65 years.

Dental Wear Scoring

Dental wear phases were scored by the first author (DAP) following Smith's (8) eight-phase ordinal scoring method and chart (Table 1). All observations were made independent of any knowledge about the individual's actual age. None of the individuals in the sample were classified as phase 8; therefore, the analysis includes only phases 1–7. In addition, Smith (8) also lists phase 0, which corresponds to missing or unscorable data. This phase was not applicable with the current sample, and therefore not utilized.

Age Estimation

Transition analysis (37), the probability that an individual has attained a certain phase given age, was utilized to generate a mean age-of-transition from one dental wear phase to the next. Transition analysis can be employed with any age indicator that is unidirectional, and as such carries several assumptions: (i) phases do not overlap, (ii) an individual cannot skip a phase, and (iii) an individual cannot go back to a previous phase (37).

Because dental wear is scored with more than two phases, an unrestricted cumulative probit model was utilized to calculate the mean, standard deviation, log-likelihood, and standard errors of these parameters for each transition. Statistical models used to establish the ages-of-transition were run in the FORTRAN-based program Nphases developed by the third author (LWK) (http://konig.la.utk.edu/). In order to generate individual age estimations, the probability density function (PDF), or *f*(*a*), of the population must first be derived. Since *f*(*a*) for Balkan populations is unknown, it was estimated by maximizing the log-likelihood of the GM hazard model parameters given the known ages-at-death, which can be written as equation (1):

$$h(t) = \alpha_2 + \alpha_3 \exp(\beta_3 t)$$

$$S(t) = \exp\left(-\alpha_2 t + \frac{\alpha_3}{\beta_3}(1 - \exp(\beta_3 t))\right)$$

$$\log \mathrm{LK}(\theta | t - 15) = \sum_{i=1}^{747} \log(h(t_i - 15) S(t_i - 15) | \theta) \quad (1)$$

The GM hazard parameters, α_2, α_3, and β_3, denoted as theta in equation (1), were estimated from 747 identified Balkan males who were at least 15 years old at the time of death ($\alpha_2 = 0.0126$, $\alpha_3 = 0.0033$, $\beta_3 = 0.0594$, with 15 years subtracted from all ages). Individual ages-at-death are estimated from the calculated age distribution *f*(*a*), derived from equation (1) and the ages-of-transition (http://konig.la.utk.edu/) (37). To estimate the age-at-death for an individual, the highest posterior density region for each phase is generated. Bayes' Theorem was used to calculate the probability that an individual was an exact age at the time of death, which is written as equation (2):

$$f(\text{age}|\text{wear}) = \frac{\Pr(\text{wear}|\text{age}) \times f(\text{age})}{\int_{t=15}^{\omega} \Pr(\text{wear}|t) \times f(t)\mathrm{d}t} \quad (2)$$

Descriptive statistics and general data management were run in SPSS (39), while all other statistical procedures were run in the

TABLE 1—*Summary of Smith's dental wear phases 1–8 for incisors, canines, and premolars.*

Phase	Incisors and Canines	Premolars
1	No wear to wear with no dentine exposure	No wear to wear with no dentine exposure
2	Hairline or pinpoint dentine exposure	Mild cusp removal
3	Distinct line of dentine exposure	Moderate dentine exposure and/or full cusp removal
4	Moderate dentine exposure	Extensive dentine exposure on at least one cusp
5	Extensive dentine exposure but retention of enamel rim	Extensive dentine exposure involving both cusps
6	Extensive dentine exposure with enamel rim obliterated on one side	Extensive dentine exposure resulting in coalescence of cups but retention of enamel rim
7	Extensive dentine exposure with enamel rim present on at least one side	Extensive dentine exposure with enamel rim obliterated on at least one side
8	Complete loss of crown with tooth taking the shape of the root	Complete loss of crown with tooth taking the shape of the root

statistical program "R" (http://www.r-project.org/). For an in depth discussion of the statistical methods used, see Konigsberg et al. (40).

Results

The age-at-death distribution for the dental wear phases is depicted in Fig. 1 as stem and leaf plots. The numeral to the left of the "pipe" represents the decade, while the numerals to the right indicate the years (for example, the first 10 ages listed for phase I are: 17, 18, 18, 20, 20, 20, 20, 21, 21, and 24 years). This figure illuminates the interpersonal variation in dental wear for the Balkans, in that several individuals over the age of 50 were categorized as having very little wear or no wear and placed into phase 1, while several individuals under 20 showed heavy wear and were placed into phase 5. Despite these few cases, the overall trend reflects that tooth wear increases with age.

Table 2 lists the descriptive statistics for the transition analysis, which include the mean age of transition from one phase to the next and the standard deviations for each phase. Table 3 lists the most likely age-at-death for each phase estimated from the posterior distributions, along with the lower and upper bounds of each phase for the 50% and 90% highest posterior density regions.

Figures 2–8 depict the Bayesian estimates for the probability of age, at the 90% highest posterior density. Because this is an estimation of the most likely age-at-death, not a confidence interval of the mean age, the distributions are asymmetrical. Consequently,

FIG. 1—*Ages-at-death shown as "stem and leaf" plots within dental wear phases.*

TABLE 2—*Transition analysis parameters: mean age of transitions (years) and standard deviations with corresponding standard errors (SE).*

Transition	Mean	SE	Standard Deviation	SE
Phase 1 to 2	17.58	0.91	16.58	0.99
Phase 2 to 3	27.40	1.20	16.83	0.91
Phase 3 to 4	34.52	1.15	19.24	0.77
Phase 4 to 5	45.89	1.05	18.75	0.82
Phase 5 to 6	61.11	0.93	19.07	0.81
Phase 6 to 7	77.07	0.63	21.80	0.66

TABLE 3—*Highest posterior density (age in years) for each dental wear phase, 50% highest posterior density region (HPDR), and 90% HPDR.*

Dental Wear Phase	Highest Posterior Density	50% HPDR	90% HPDR
Phase 1	15.0	15.0–23.8	15.0–39.1
Phase 2	22.7	15.2–30.3	15.0–48.3
Phase 3	37.6	27.3–47.5	15.2–58.6
Phase 4	41.2	29.9–51.6	16.0–62.5
Phase 5	53.1	42.0–63.0	25.3–74.5
Phase 6	63.1	53.2–71.8	37.0–82.5
Phase 7	69.9	60.5–78.1	44.5–88.0

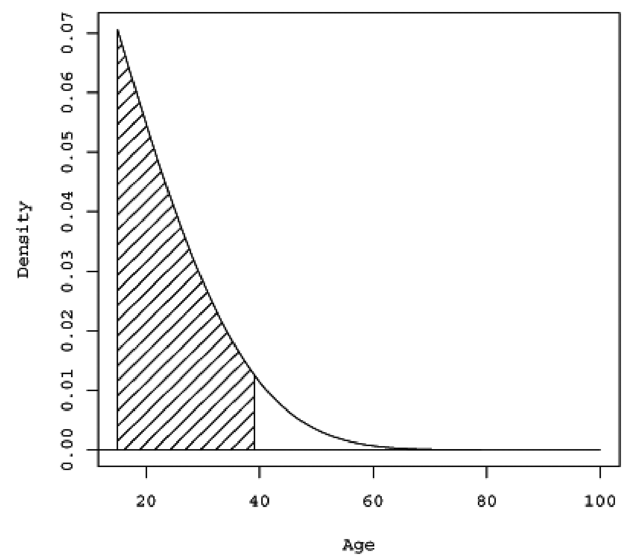

FIG. 2—*Phase 1 maximum density of age-at-death for Balkan population. Note the distribution is truncated because the lower age bound begins at 15 years.*

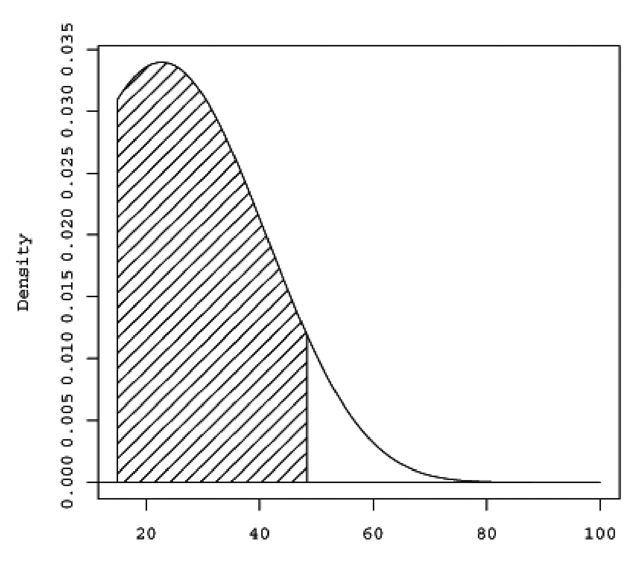

FIG. 3—*Phase 2 maximum density of age-at-death for Balkan population, 90% boundaries illustrated.*

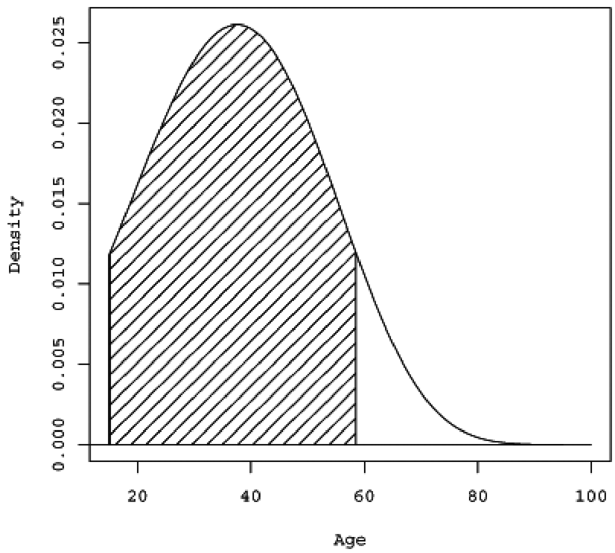

FIG. 4—*Phase 3 maximum density of age-at-death for Balkan population, 90% boundaries illustrated.*

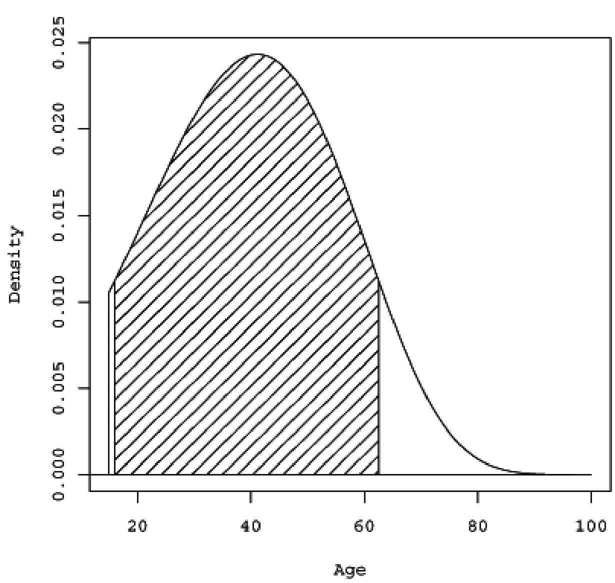

FIG. 5—*Phase 4 maximum density of age-at-death for Balkan population, 90% boundaries illustrated.*

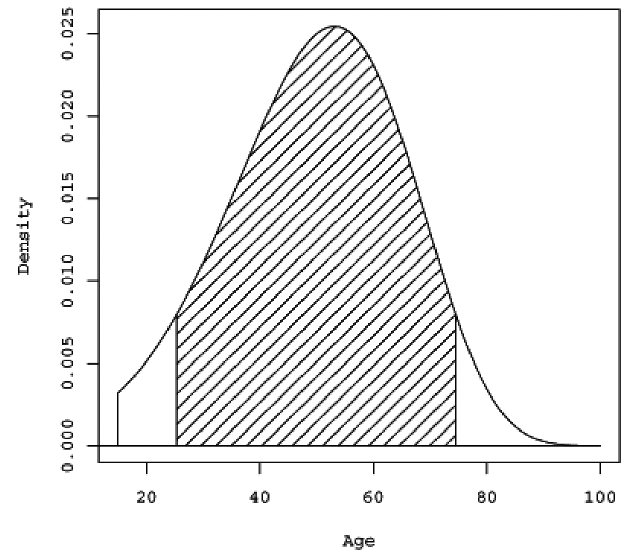

FIG. 6—*Phase 5 maximum density of age-at-death for Balkan population, 90% boundaries illustrated.*

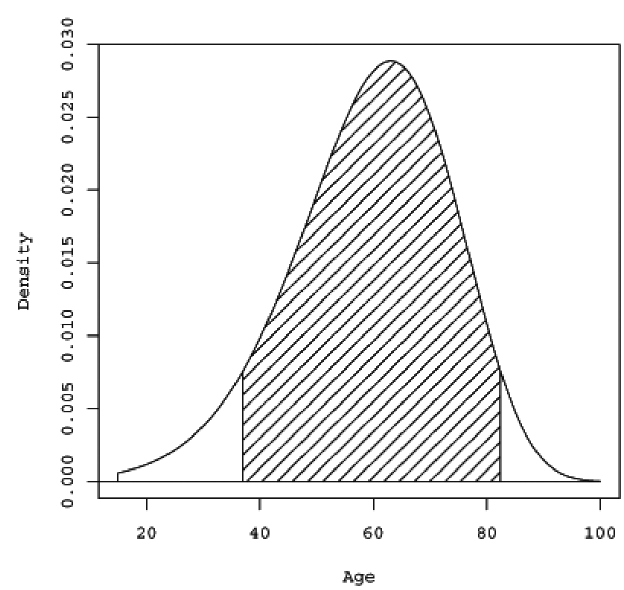

FIG. 7—*Phase 6 maximum density of age-at-death for Balkan population, 90% boundaries illustrated.*

younger individuals, those in phases 1–3, have truncated age intervals beginning at 15 (Figs. 2–4), whereas older individuals, those in phases 4–7, include upper and lower bounds (Figs. 5–8).

Discussion and Conclusion

It must be noted that with dental wear, the posterior density should be used cautiously because, even though it appears to reflect a method that would predict age well, the overall age intervals may be more useful for classifying unknown individuals into broad age cohorts (i.e., younger than 45 or greater than 50) rather than a small age range or point estimate (see Table 3). The intervals for each phase, as estimated from the posterior distributions, are wide, reflecting the range of variation in tooth wear throughout life.

A key assumption in utilizing dental wear to estimate age-at-death is that the tooth being scored had an opposing tooth while in the dental arcade (35). Tooth loss may be a contributing factor as to why some older individuals in the sample showed little dental wear. Boldsen (35), who was the first to apply transition analysis to dental wear scores found that "the relationship between time of use of a tooth (i.e., age) and level of attrition is confounded by several factors that make it impossible to use attrition scores for age estimation, even with a relatively homogenous population" (35:174).

The biological and cultural variation of different populations are important considerations when employing any aging method on skeletal or dental remains (4,5,8,9,14,30). When employing dental age estimation models, it must be recognized that there are many factors that can lead to attrition, other than tooth-on-tooth contact from mastication. Bruxism, the grinding or tapping of teeth, generates greater forces than mastication and leads to wear on the

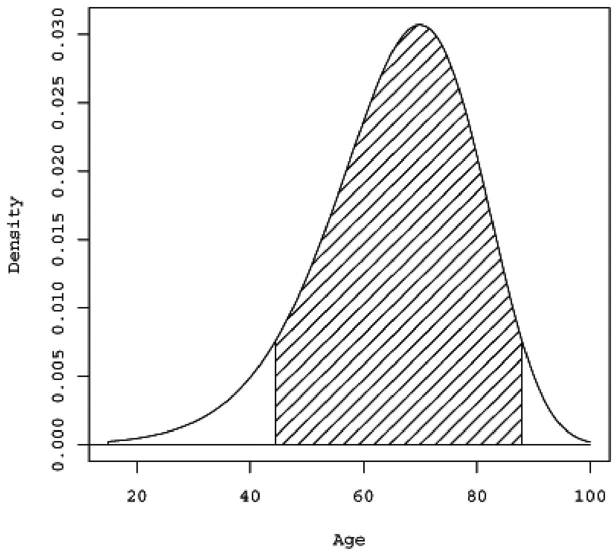

FIG. 8—*Phase 7 maximum density of age-at-death for Balkan population, 90% boundaries illustrated.*

occlusal and incisal tooth surfaces (36). The form of the temporomandibular joint (41,42) and the size and shape of the mandibular condyles (43) have also been linked to varying levels and higher amounts of attrition. In addition, Walker et al. (44) report that larger teeth wear slower than smaller teeth, which in turn leads to differential wear. Population differences due to diet have also been noted (5,22,35,45). Deliberate dental modification, such as amalgam and resin fillings, crowns, and inlays, and anomalous wear, such as wear from items such as tooth picks and pipes also contributes to increased attrition.

Differential wear between males and females could not be addressed in this research because of the small sample size of females in the study. However, previous research has yielded conflicting results about sexual dimorphism and dental attrition. Some researchers concluded that sex yielded a significant difference in the analysis of dental wear. In such studies, females showed precocious dental wear as compared with males (5,46–48), but other researchers found that sex did not have a significant effect (2,21,31,50–52). Studies that yielded a significant difference between the sexes were derived from archaeological samples, where a division of labor was responsible for the observed differences. Differences observed between males and females in dental wear can be attributed to differences in diet, where males ingested softer foods (46), and food preparation processes, where women would use their teeth as tools (53).

Ordinal scoring of dental attrition has several advantages in estimating age-at-death. Scoring the amount of wear observed can be done fairly quickly, and large collections can be scored in a relatively small amount of time. Teeth have a vast postmortem longevity; therefore, they are sometimes the only skeletal feature that can yield age-related information. Scoring dental wear is a nondestructive method, in which the teeth do not need to be removed from the alveolus to assess the amount of attrition.

This analysis was undertaken to apply a set of Bayesian statistical methods, based on the GM hazard model to estimate individual ages-at-death for Balkan populations using tooth wear. By using a Bayesian statistical approach to estimate age, the population's age distribution is taken into account. Therefore, the estimates presented here are reliable for the Balkan populations; these data and results, however, may not be appropriate for use with other populations.

Disclaimer

Permission to use and publish this data was granted by the United Nations, International Criminal Tribunal for the Former Yugoslavia, Office of the Prosecutor and Registry. This study does not represent in whole or in part the views of the United Nations or official DOD policy, but those of the authors.

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References

1. Gustafson G. Age determination on teeth. J Am Dent Assoc 1950;41:45–54.
2. Murphy T. Gradients of dental exposure in human molar tooth attrition. Am J Phys Anthropol 1959;17:179–86.
3. Miles AEW. Assessment of the ages of a population of Anglo-Saxons from their dentitions. Proc R Soc Med 1962;55:881–6.
4. Brothwell D. Digging up bones. London: British Museum of Natural History, 1963.
5. Molnar S. Human tooth wear, tooth function and cultural variability. Am J Phys Anthropol 1971;34:175–90.
6. Helm S, Prydsø U. Assessment of age-at-death from mandibular molar attrition in medieval Danes. Scand J Dent Res 1979;87(2):79–90.
7. Scott EC. Dental wear scoring technique. Am J Phys Anthropol 1979;51:213–18.
8. Smith BH. Patterns of molar wear in hunter-gatherers and agriculturalists. Am J Phys Anthropol 1984;63(1):39–56.
9. Smith BH. Rate of molar wear: implications for developmental timing and demography in human evolution. Am J Phys Anthropol 1984;63(1):220.
10. Cross JF, Kerr NW, Bruce MF. An evaluation of Scott's method for scoring dental wear. In: Cruwys E, Foley RA, editors. Teeth and anthropology. Oxford: British Archaeological Reports. BAR International Series No 291, 1986;291.
11. Dreier FG. Age-at-death estimates of the prehistoric Arikara using molar attrition rates: a new quantification method. Int J Osteoarchaeol 1994;4:137–48.
12. Lovejoy CO. Dental wear in the Libben population: its functional pattern and role in the determination of adult skeletal age at death. Am J Phys Anthropol 1985;68(1):47–56.
13. Lovejoy CO, Meindl RS, Mensforth RP, Barton JT. Multifactorial determination of skeletal age at death: a method and blind tests of its accuracy. Am J Phys Anthropol 1985;68(1):1–14.
14. Brothwell D. The relationship of tooth wear to aging. In: İşcan MY, editor. Age markers in the human skeleton. Springfield, IL: Charles C. Thomas, 1989;303–16.
15. Dahl BL, Oilo G, Anderson A, Bruaset O. The suitability of a new index for the evaluation of dental wear. Acta Odontol Scand 1989;47:205–10.

16. Song HW, Jai JT. The estimation of tooth age from attrition of the occlusal surface. Med Sci Law 1989;1:69–73.
17. Ubelaker DH. Human skeletal remains, analysis, interpretation. Rev. Ed. Washington, DC: Taraxacum, 1989.
18. Johansson A, Haraldson T, Omar R, Kiliaridis S, Carlsson GE. A system for assessing the severity and progression of occlusal tooth wear. J Oral Rehabil 1993;20:125–31.
19. Buikstra JE, Ubelaker DH. Standards for the data collection from human skeletal remains. Research Series 44. Fayetteville, AR: Arkansas Archeological Survey, 1994.
20. Kim YK, Kho HS, Lee KH. Age estimation by occlusal tooth wear. J Forensic Sci 1999;45(2):303–9.
21. Li C, Ji G. Age estimation from the permanent molar in northeast China by the method of average stage of attrition. Forensic Sci Int 1995;3:189–96.
22. Ajmal M, Mody B, Kumar G. Age estimation using three established methods. A study on Indian population. Forensic Sci Int 2001;3:150–4.
23. Ball J. A critique of age estimation using attrition as the sole indicator. J Forensic Odontostomatol 2002;20(2):38–42.
24. Nicholls B. A contribution to the study of the teeth of the Australian and Tasmanian aboriginals. Transactions of the Sixth International Dental Congress. London: The Committee of Organization, 1914.
25. Bödecker CF. A consideration of some of the changes in the teeth from young to old age. Dent Cosmos 1925;67:543–9.
26. Campbell TD. Dentition and palate of the Australian Aboriginal. Publications under the Keith Sheridan Foundation, University of Adelaide. Adelaide, Australia: The Hassell Press, 1925.
27. Leigh RW. Dental pathology of Indian tribes of varied environmental and food conditions. Am J Phys Anthropol 1925;8:179–99.
28. Miles AEW. Dentition and the estimation of age. J Dental Res 1963;42:255–63.
29. Miles AEW. Teeth as an indicator of age in man. In: Butler PM, Joysey KA, editors. Development, function and the evolution of teeth. London: Academic Press, 1978;455–62.
30. Lavelle CL. Analysis of attrition in adult human molars. J Dent Res 1970;49:822–8.
31. Lunt DA. Analysis of attrition in adult human molars. In: Butler PB, Joysey KA, editors. Development, function, and evolution of teeth. London: Academic Press, 1978;465–82.
32. Zuhrt R. Stomatologische Üntersuchungen an Spätmittelalterlichen Funden von Reckkahn (12-14 Jh.): I. Die Zahnkaries und ihre Folgen. Dtsch Zahn Mund Kieferheilkd Zentralbl 1955;25:1–15.
33. Kieser JA, Preston CB, Evans WG. Skeletal age at death: an evaluation of the Miles method of aging. J Archaeol Sci 1983;10:9–12.
34. Nowell GW. An evaluation of the Miles method of ageing using the Tepe Hissar dental sample. Am J Phys Anthropol 1979;49:271–6.
35. Boldsen JL. Analysis of dental attrition and mortality in the medieval village of Tirup, Denmark. Am J Phys Anthropol 2005;126:169–76.
36. Hillson S. Dental anthropology. Cambridge, UK: Cambridge University Press, 1996.
37. Boldsen JL, Milner GR, Konigsberg LW, Wood JW. Transition analysis: a new method for estimating age from skeletons. In: Hoppa RD, Vaupel JW, editors. Paleodemography: age distributions from skeletal samples. Cambridge, UK: Cambridge University Press, 2002;73–106.
38. Kimmerle EH, Jantz RL, Konigsberg LW, Baraybar JP. Skeletal estimation and identification in American and East European populations. J Forensic Sci 2008;53:524–32.
39. SPSS Inc. SYSTAT 8.0 statistics users manual. Version 8.0. Chicago, IL: SPSS Inc., 1998.
40. Konigsberg LW, Herrmann NP, Wescott DJ, Kimmerle EH. Estimation and evidence in forensic anthropology: Age-at-death. J Forensic Sci 2008;53:541–57.
41. Johansson A, Fareed K, Omar R. Analysis of possible factors influencing the occurrence of occlusal tooth wear in a young Saudi population. Acta Odontol Scand 1991;49:139–45.
42. Johansson A. A cross-cultural study of occlusal tooth wear. Swed Dent J 1992;86:1–59.
43. Owen CP, Wilding RJ, Morris AG. Changes in mandibular condyle morphology related to tooth wear in a prehistoric human population. Arch Oral Biol 1991;36:799–804.
44. Walker PL, Dean G, Shapiro P. Estimating age from tooth wear in archaeological populations. In: Kelly MA, Larson CS, editors. Advances in dental anthropology. New York: Wiley-Liss, 1991;169–78.
45. Maples WR. An improved technique using dental histology for estimation of adult age. J Forensic Sci 1978;23:764–70.
46. Heithersay GS. Attritional values for Australian aborigines, Haast's Bluff. Aust Dent J 1960;5:84–8.
47. Molnar S, Mckee JK, Molnar I. Measurements of tooth wear among Australian aborigines: I. Serial loss of the enamel crown. Am J Phys Anthropol 1983;61(1):51–65.
48. Molnar S, McKee JK, Molnar IM, Przybeck TR. Tooth wear rates among contemporary Australian Aborigines. J Dent Res 1983;62:562–5.
49. McKee JK, Molnar S. Measurements among tooth wear in Australian aborigines: II. Intrapopulational variation in patterns of dental attrition. Am J Phys Anthropol 1988;76:125–36.
50. Hojo M. On the pattern of dental abrasion. Okajimas Folia Anat Jpn 1954;26:11–30.
51. Pal A. Gradients of dentine exposure in human molars. J Indian Anthropol Soc 1971;6:67–73.
52. Tomenchuk J, Mayhall JT. A correlation of tooth wear and age among modern Iglootik Eskimoes. Am J Phys Anthropol 1979;51:67–78.
53. Pedersen PO. Some dental aspects of anthropology. Dent Rec 1952;72:170–8.

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